

AGENT-BASED MODEL FOR SUSTAINABLE EQUIPMENT EXPANSION
WITH CO₂ REDUCTION OF A CONTAINER PORT

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To my God and my strength, may Your Name be glorified

"Be warned, my son, of anything in addition to them (wisdom). Of making many books there is no end, and much study wears the body. Now all has been heard;

here is the conclusion of the matter:

Fear God and keep his commandments, for this is the duty of mankind"

– Ecclesiastes 12:12-13

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May glory be to God, Amen.

ABSTRACT

Conserving port environment is gaining attention, seeing local port authorities beginning to establish green policies as a normative direction into container port expansion. However, there are conflicts among port authorities, port planners, port stakeholders in converting port equipment with carbon reducing technology. This attributes to the absence of electrification approach in port expansion process. This research aims to propose a sustainable equipment expansion approach by an agent-based model (ABM) to quantify carbon-reducing equipment profile that complies with an emission reduction standard (ERS). The approach simulates the port sustainability transition from port agent interaction that determines the expansion design approach. A combination of fundamental port expansion theories and an electrification logic are developed to simulate the carbon-reducing expansion profile. It is to meet the required CO₂ emission reduction standard while not forfeiting financial performance. An agent-based simulator (NETLOGO) is programmed to simulate port sustainability transition and the sustainable expansion profile. The results of PTP case study indicate that it is able to electrify all equipments by 2043. Results also indicate a viable green policy implemented at 4.5% yearly CO₂ reduction starting at 2024 while meeting the required port capacity and financial performance. Analysis infers the futility of imposing high emission reduction percentage and the execution of more conversions at higher throughput demand phase. In conclusion, ABM model can be a decision-making support system for the port community to execute appropriate emission reduction standard percentage and time to realise the green port concept.

ABSTRAK

Pemuliharaan alam sekitar di pelabuhan adalah semakin penting, menyebabkan lembaga pelabuhan tempatan mewujudkan dasar hala tuju mampan dan polisi hijau untuk pengembangan pelabuhan kontena. Namun begitu, wujud konflik antara lembaga pelabuhan, pengurus pelabuhan dan pihak berkepentingan pelabuhan untuk menukar penggunaan alat pengendalian pelabuhan kepada teknologi yang dapat mengurangkan karbon. Ini disebabkan ketiadaan dasar khas dalam pengelektrikan dalam proses simulasi pembangunan pelabuhan. Kajian ini dijalankan untuk mencadangkan satu kaedah pengembangan alat pengendalian pelabuhan yang mampan berasaskan model interaksi ejen dalam menentukan kuantiti alat pengendalian yang berkarbon rendah dengan berpandukan piawaian kadar pelepasan karbon. Kaedah ini dapat menjalankan simulasi bagi menentukan kesinambungan transisi pelabuhan melalui interaksi agen pelabuhan dalam reka bentuk pengembangan pelabuhan. Gabungan teori asas pembangunan pelabuhan dengan dasar pengelektrifikasian dapat dicadangkan menerusi simulasi profil alat pengendalian yang berkarbon rendah. Profil alat ini mematuhi syarat pelepasan karbon tanpa menjejaskan prestasi kewangan. Simulasi berdasar ejen bernama NETLOGO digunakan untuk memperolehi status transisi pelabuhan dan profil pembangunan alat pengendalian pelabuhan yang hijau. Keputusan akhir menunjukkan kajian kes ke atas PTP untuk mengelektrifikasi semua kren pada 2043 adalah sesuai. Keputusan juga menunjukkan kemungkinan pelaksanaan polisi hijau pada kadar pengurangan karbon pada kadar 4.5% setahun mulai 2024 masih dapat memenuhi keperluan kapasiti alat dan prestasi kewangan berdasarkan NPV. Kajian menunjukkan bahawa pelaksanaan piawaian pengurangan CO₂ adalah bermanfaat serta proses pengelektrikan perlu dilaksanakan untuk aktiviti pengendalian kontena. Secara kesimpulan, model ABM boleh digunakan sebagai panduan bagi komuniti pelabuhan untuk membuat keputusan dalam pengurangan karbon dan merealisasikan konsep pelabuhan hijau.

TABLE OF CONTENT

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENT	vii
	LIST OF TABLES	xiii
	LIST OF FIGURES	xvi
	LIST F ABBREVIATIONS	xix
	LIST OF SYMBOLS	xxi
	LIST OF APPENDICES	xxvi
1	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Research Background	4
	1.3 Problem Statement	8
	1.4 Research Objective	10
	1.5 Scope of Research	10
	1.6 Theoretical Framework	11
	1.7 Significance of Study	13
	1.8 Organisation of Thesis	14
2	LITERATURE REVIEW	
	2.1 Introduction	15
	2.2 Port Equipment Expansion Theory	16
	2.2.1 Cost-Effective Conceptual Framework	18
	2.2.2 Port Equipment Expansion	19

	2.2.2.1 Univariate Throughput Forecast	19
	2.2.2.2 Berth Expansion	21
	2.2.2.3 Equipment Expansion	23
	2.2.2.4 Project Financial Feasibility	24
2.3	Green Port Theory	25
	2.3.1 Zero-emission Equipment	26
	2.3.1.1 Quay Crane	27
	2.3.1.2 Electric Rubber-tired Gantry	28
	2.3.1.3 Electric Prime Mover	30
	2.3.2 Green Port Concept Paradigm Shift	32
	2.3.2.1 Emission Inventory	32
	2.3.2.2 Emission Reduction Demand	34
	2.3.3 Green Port Expansion Models	36
	2.3.4 Commercialization of Electrical Prime Mover	39
2.4	Agent-based Model (ABM)	40
	2.4.1 Benefit of Agent-based Model	41
	2.4.1.1 Port Simulation Models by DES	43
	2.4.2 ABM for Port Simulation	43
	2.4.2.1 Berth Allocation	45
	2.4.2.2 Crane Scheduling	46
	2.4.2.3 Truck Allocation	47
	2.4.2.5 Deduction and Criticism of ABM	47
	2.4.3 Port Agents Interaction and Behavior Under Green Port Concept	48
	2.4.3.1 Notteboom's Framework	50
	2.4.3.2 Lam's Framework	51
	2.4.3.3 Sustainability Transition	52
2.5	Research Gap	53
	2.5.1 Summary	55
3	METHODOLOGY	56
	3.1 Introduction	56
	3.2 Identification of Research Variables	57
	3.2.1 Development of ABM framework	58
	3.2.2 Listing of Generic Variables	59

3.2.3	Criteria of Selection	60
3.2.4	Sustainability Transition Variables	60
3.2.5	Sustainable Expansion Variables	61
3.2.6	Preliminary ABM with New Research Variables	62
3.3	Development of Agent-based Model	65
3.4	Development of Mathematic Algorithm for ABM	64
3.4.1	Port Sustainability Transition Algorithm	68
3.4.1.1	Port Institution Evolvement	70
3.4.1.2	Design Approach Evolvement	72
3.4.2	Sustainable Equipment Expansion Algorithm	75
3.4.2.1	ARIMA Throughput Forecast	75
3.4.2.2	Berth Expansion Algorithm	80
3.4.2.3	Preliminary Equipment Expansion	85
3.4.2.4	Carbon-Reducing Equipment Electrification Logic	86
3.4.2.5	Financial Constraint	92
3.5	Data Collection	97
3.5.1	Model Building Data	97
3.5.1.1	SME Consultation	98
3.5.1.2	Delphi Survey for ERS	98
3.5.2	Case Study Data	99
3.6	Development of Agent-based Model Source Code	103
3.7.1	Package of Agent Transition Module	103
3.7.2	Package of Preliminary Expansion	103
3.7.3	Package of Electrification Logic for Expansion	107
3.7	Verification of Agent-based Model	104
3.8.1	Verification of Agent-based Architecture	104
3.8.2	Verification of Equipment Expansion Algorithm	105
3.9	Validation Of Agent-based Model	106
3.9.1	Twofold Validation of ABM Architecture	106
3.9.2	Validation of Equipment Expansion Algorithm	107
3.10	Sensitivity Analysis	108

4	DATA ANALYSIS & ABM ARCHITECTURE	109
4.1	Introduction	109
4.2	Data Analysis	109
	4.2.1 ERS by Delphi Survey	110
	4.2.2.2 McNemar Test Result of ERS	110
	4.2.2 Stationary Analysis and Forecast of Time-series Data	112
	4.2.2.1 Throughput History	112
	4.2.2.2 Ship Call History	115
	4.2.3 Analysis of Queue-Congestion Factor	118
	4.2.4 Analysis of Estimated ship Service Rate	119
	4.2.5 Analysis of Average Equipment Travelled Distance	121
	4.2.5.1 RTG Travelling Distance	121
	4.2.5.2 PM Travelling Distance	122
	4.2.5.3 Emission Calculation Specification	124
	4.2.6 Analysis of Overhead Cost	124
4.3	ABM Architecture	126
	4.3.1 Overview	127
	4.3.2 Design	133
	4.3.3 Details	133
4.4	Summary	140
5	RESULTS	141
5.1	Introduction	141
5.2	Integrated ABM for Sustainable Equipment Expansion	141
5.3	Results Package of Sustainable Equipment Expansion	144
	5.3.1 Results of Port Institution & Design Approach Transition	144
	5.3.2 Results of Preliminary Equipment Expansion	147
	5.3.3 Results of Carbon-reducing Expansion	152
	5.3.3.1 Carbon-reducing Expansion Cost Breakdown	154
	5.3.3.2 Emission Profile	156
5.4	Database Package of Agent-based Model	159
5.5	NETLOGO Source Code Packages	160

5.6	Verification Results of Agent-based Model	161
	5.6.1 Verification of Agent-based Architecture	161
	5.6.2 Verification of Equipment Expansion Algorithm	162
	5.6.3 Verification of Emission Profile	167
5.7	Validation Results of Agent-based Model	170
	5.7.1 Empirical Validation of Agent-based Architecture	170
	5.7.2 Validation of Equipment Expansion Algorithm	172
	5.7.2.1 Preliminary Equipment Expansion	172
	5.7.2.2 Carbon-reducing Equipment Electrification Profile	174
	5.7.2.2 Validation of Emission Profile	175
5.8	Results of Sensitivity Analysis	178
	5.8.1 Sensitivity to ERS Period Change, ERS_t	178
	5.8.1.1 ERS_t Impact on Carbon-reducing Equipment Expansion	179
	5.8.1.2 ERS_t Impact on Emission Profile	179
	5.8.2 Sensitivity to ERS Percentage Change, $ERS_{\%}$	185
	5.8.2.1 $ERS_{\%}$ Impact on Carbon-reducing Equipment Expansion	185
	5.8.2.2 $ERS_{\%}$ Impact on Emission Profile	188
5.9	Summary	191
6	DISCUSSION	192
6.1	Discussion of Integrated ABM Novelty	192
	6.1.1 Strength and Weakness of ABM Architecture	195
6.2	Discussion of Sustainability Transition Results	197
6.3	Discussion of Carbon-reducing Equipment Expansion Results	199
	6.3.1 Strength and Weakness of ABM Algorithm	202
6.4	Discussion of Reference Database	205
6.5	Discussion of Agent-based Simulator in NETLOGO	206
6.6	Discussion of ABM Correctness	207
6.7	Discussion of ABM Validity	209
6.8	Discussion of ABM Robustness	213
	6.8.1 Sufficiency of Single Sensitivity Dimension	215

7	CONCLUSION	216
7.1	Objective Fulfillment	216
7.2	Concluding Remark	218
7.3	Future Research Recommendation	219
	REFERENCES	220
	Appendices A-H	235-249

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	MX-30 Full-Electric Prime Mover Specification	31
2.2	DES and ABS Model Comparison	42
2.3	Three Pillars of Port Institution	50
2.4	Summary of Literature Review Components	55
3.1	List of Previous Studies on Port Expansion	59
3.2	Sustainability Transition Variables and Degree-of-freedom	61
3.3	Sustainable Expansion Variables and Sub-variables	62
3.4	Determination of Electrification Logic	66
3.5	State-Variable Combination for Sub-model 1 (Port Institution)	68
3.6	State-Variable Combination for Sub-model 2 (Design Approach)	69
3.7	Standardised Port Operation Parameters	104
3.8	Time-Series Data Set	101
3.9	Port Operation and Expansion Data Set	101
3.10	Port Environment Data Set	102
3.11	Port Costing Data	102
3.12	Sensitivity Analysis	108
4.1	Two-Phase Delphi Survey Frequency	110
4.2	McNemar Test Frequencies for Delphi Survey	111
4.3	McNemar Test Statistics for Delphi Survey	111
4.4	Augmented Dickey-Fuller test statistic (Throughput)	113
4.5	Throughput Forecast Validation (2014-2015)	115
4.6	Augmented Dickey-Fuller test statistic (Ship Call)	115
4.7	Ship Call Forecast Validation (2014-2015)	118
4.8	Analysis Results of Average Travelling Distance	121
4.9	Summary of Emission Calculation Specification (PTP)	124
4.10	Definition of Port Agent Entities	127

4.11	State-Variable Combination for Sub-model 1 (Port Institution)	129
4.12	State-Variable Combination for Sub-model 2 (Design Approach)	130
4.13	Subject Matter Expert Consultation Record	138
4.14	Expert Panel List	138
4.15	Parameters for ABM Sensitivity Analysis	139
5.1	ABM Sustainability Transition Result	145
5.2	Berth , QC, RTG and PM Primary Expansion for 2014-2053 (8 phase expansion)	147
5.3	Summary Result on Preliminary Equipment Expansion	150
5.4	Carbon-reducing Equipment Expansion	152
5.5	Estimated Saving on Electrified Equipment (PTP)	154
5.6	NPV Performance Difference of Sustainable Project	155
5.7	Emission Profile from Projected Equipment Expansion	156
5.8	Verification of Berth Expansion	164
5.9	Verification of Quay Crane Expansion	165
5.10	Verification of RTG Expansion	165
5.11	Verification of Prime Mover Expansion	166
5.12	Verification of RTG & PM Emission Profile	167
5.13	Verification of Total Emission Profile	168
5.14	Validation of PTP-Johor Port Sustainability State	171
5.15	Validation of Berth Expansion	172
5.16	Validation of QC, RTG, PM Expansion	173
5.17	Validation of E-RTG Expansion	174
5.18	Validation of Zero-Emission E-PM Expansion	175
5.19	Validation of RTG & PM Monthly Emission (2014-2015)	176
5.20	Validation of Total Emission (2011-2015)	177
5.21	Frequency Distribution of ERS Implementation Period	179
5.22	ERS _t Period Impact on Carbon-reducing Equipment Expansion	180
5.23	Emission Performance at ERS of Phase 3 Commencement (Case 1)	182
5.24	Emission Performance at ERS of Phase 4 Commencement (Case 2)	183
5.25	Emission Performance at ERS of Phase 5 Commencement (Case 3)	183

5.26	ERS _% Percentage Impact on Zero-emission Equipment Expansion	185
5.27	Emission Performance at 4.5% ERS _% (Case 1)	188
5.28	Emission Performance at 6% ERS _% (Case 2)	189
5.29	Emission Performance at 7.5% ERS _% (Case 3)	189
6.1	Strength and Weakness of ABM Architecture	196
6.2	Strength and Weakness of ABM Algorithm	205

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Frameworks for port research methods	2
1.2	Sustainable Port and Main Indicators	3
1.3	Discrepancy of Port Model Combination	12
2.1	Parallel and Perpendicular Port Arrangement	17
2.2	Ship-to-Shore (STS) Quay Crane	27
2.3	Illustration of a E-RTG bus-bar system	30
2.4	MX-30 Electric Truck and Fast Charger Station	32
2.5	Institutional Framework based Port Planning Methodology	36
2.6	Minimum Marginal Costing for Emission Reduction Benchmark	37
2.7	Framework of Sustainable Port Development	38
2.8	Zero-emission Commercialization Phase-in Plan	40
2.9	Highlight of ABM Architecture in Port Simulation Building Process	44
2.10	Simplified View of Henesey's Agent-based Model Interaction	46
2.11	Sustainable Port Framework for Stakeholder Involvement	51
2.12	Research Gap Highlight	54
3.1	Research Methodology Flow Chart	57
3.2	Proposed Research Framework for Sustainable Agent-based Model	58
3.3	Fitting of Research Variables in Proposed ABM	62
3.4	Modular Flow of Agent-based Architecture (Model) and Algorithm	63
3.5	Model Linkage of ABM Architecture	64
3.6	Carbon-reducing Expansion Flow Chart	65
3.7	Markov Chain of Port Institution Transition (Submodule 1)	70
3.8	Markov Chain of Design Approach Transition (Submodule 2)	72
3.9	Electrification Logic by Emission Benchmark	87

3.10	Data Components for ABM	97
3.11	Structural & Empirical Validation of ABM Architecture	106
3.12	Illustration of Replicative and Predictive Validation of Results	108
4.1	ARIMA Monthly PTP Throughput Forecast (2014-2053)	113
4.2	Auto-Correlation Function (Throughput)	114
4.3	Partial Auto-Correlation Function (Throughput)	114
4.4	ARIMA Ship Call Forecast (2014-2053)	116
4.5	Auto-Correlation Function (Ship Call)	117
4.6	Partial Auto-Correlation Function (Ship Call)	117
4.7	Extrapolation of Congestion Factor of $E_2/E_2/n$	119
4.8	Berthing Time (Service Rate, ets) against Average Ship Throughput (Q_{sc})	120
4.9	Average RTG and E-RTG Route	122
4.10	PM Travel Point between Quay Crane and Loading Point	123
4.11	Scheduling of Submodules in Agent-based Architecture	132
4.12	Theoretical Principles of Proposed Model	133
4.13	Emergence of Emission Reduction Standard	134
4.14	Collectives for Model Simulation	135
5.1	Agent-based Model Data Flow	142
5.2	Finalized Algorithm Flow of ABM	142
5.3	Illustration of Sustainable Port Equipment Expansion Encompassing Cost-effectiveness	143
5.4	Graphical Illustration of Berth Expansion (2014-2053)	149
5.5	Graphical Illustration of Equipment (QC, RTG, PM) Primary Expansion (2014-2053)	150
5.6	Graphical Illustration of Preliminary Equipment Expansion	151
5.7	Graphical Illustration E-RTG Electrification	153
5.8	Graphical Illustration of E-PM Electrification	154
5.9	Graphical Illustration of Total Cost of Expansion	155
5.10	Graphical Illustration of Emission Profile	158
5.11	User Interface of NETLOGO Simulation for ABM	160
5.12	ABM Verification Process	162
5.13	PTP Expansion Plan Through 2045	163
5.14	Verification of Total Emission Profile	169
5.15	Case 1 Secondary Unit Expansion (ERS start Phase 3)	181

5.16	Case 2 Secondary Unit Expansion (ERS start Phase 4)	181
5.17	Case 3 Secondary Unit Expansion (ERS start Phase 5)	181
5.18	Total Emission vs ERS Implementation Period	184
5.19	Case 1 Zero-emission Unit Expansion (ERS at 4.5%)	187
5.20	Case 2 Zero-emission Unit Expansion (ERS at 6%)	187
5.21	Case 3 Zero-emission Unit Expansion (ERS at 7.5%)	187
5.22	Total Emission vs ERS Percentage	190
6.1	Comparison of Finalised Jonathan (2016) to model Hartman (2012) model	193

LIST OF ABBREVIATIONS

AAPA	-	America Association of Port Authorities
ABM	-	Agent-based Model
ABS	-	Agent-based Simulation
ACF	-	Autocorrelation Function
ADF	-	Augmented Dickey-Fuller Test
ARIMA	-	Integrated Autoregression Moving Average
CA	-	Conventional Approach
CC	-	Cultural Cognitive Institution
CO ₂	-	Carbon Dioxide
DA	-	Design Approach for Port Equipment
DES	-	Discrete-Event Simulation
EEDI	-	Energy-Efficiency Design Index
EMS	-	Environment Management System
E-PM	-	Electric Prime Mover
EPRI	-	Electric Power Research Institute
EPSO	-	European Seaport Organisation
ERS	-	Emission Reduction Standard
E-RTG	-	Electric Rubber-tired Gantry
GDP	-	Gross Domestic Product
GHG	-	Green House Gases
GIS	-	Geographical Information System
GPS	-	Global Positioning System
IMO	-	International Maritime Organisation
IRF	-	Impulse Response Function
IRR	-	Internal Rate of Return
JPA	-	Johor Port Authority
LA	-	Low Awareness
LE	-	Limited Engagement

MA	-	Moderate Approach
MAE	-	Mean Absolute Error
MAPE	-	Mean Absolute Percentage Error
MPE	-	Mean Percentage Error
NE	-	No Engagement
NI	-	Normative Institution
NPV	-	Net Present Value
ODD	-	Overview, Description and Details of ABM
PA	-	Port Authority
PACF	-	Partial Autocorrelation Function
PC	-	Progressive Communication
PI	-	Port Institution
PM	-	Prime Mover
PP	-	Port Planner
PS	-	Port Stakeholders
PTP	-	Port of Tanjung Pelepas
QC	-	Quay Crane
RI	-	Regulative Institution
RTG	-	Rubber-tired Gantry
SA	-	Sustainable Approach
SE	-	Significant Engagement
SHE	-	Safety, Health and Environment
SME	-	Subject Matter Expert
STS	-	Ship-to-shore
TC	-	Trained and Competant
UNCTAD	-	United Nation Conference on Trade and development
UNFCCC	-	United Nations Framework Convention on Climate Change
ZEE	-	Zero-emission Equipment Expansion

LIST OF SYMBOLS

$\$EQ_i$	-	Price of per unit equipment type i
$\$INF_i$	-	Price of per unit infrastructure for equipment type i
ϕ_i	-	ARIMA Non-seasonal autoregression matrix at lag i
$\Theta_{k,j}$	-	PACF Sample autocorrelation matrix coefficient
Φ_j	-	ARIMA Seasonal autoregression matrix at lag j
$A1$	-	State-variable Combination in Submodel 1 Scenario A1
$A2$	-	State-variable Combination in Submodel 1 Scenario A2
$A3$	-	State-variable Combination in Submodel 1 Scenario A3
$A4$	-	State-variable Combination in Submodel 1 Scenario A4
$A5$	-	State-variable Combination in Submodel 1 Scenario A5
$A6$	-	State-variable Combination in Submodel 1 Scenario A6
α	-	ADF intercept constant
B^s	-	ARIMA Seasonal difference with seasonal lag of s
B	-	ARIMA Non-seasonal difference
β	-	ADF Time trend coefficient
$B1$	-	State-variable Combination in Submodel 2 Scenario B1
$B2$	-	State-variable Combination in Submodel 2 Scenario B2
$B3$	-	State-variable Combination in Submodel 2 Scenario B3
$B4$	-	State-variable Combination in Submodel 2 Scenario B4
C_o	-	Initial investment cost
cef	-	Carbon Emission factor
CF_t	-	Cashflow of project at time, t
cf	-	Congestion Factor
CL_{PM}	-	Cost of labor for entire prime mover labor
CL_{QC}	-	Cost of labor for entire quay crane labor
CL_{RTG}	-	Cost of labor for entire rubber-tire gantry labor
$CO2_t$	-	Total emission from equipment at time t
$\Delta CO2$	-	Marginal amount of CO2 reduction
DA_t	-	State of Design Approach Set

da	-	Design Approach State
da'	-	Transition (t+1) of Design Approach
\overline{EC}_{ei}	-	Average electricity consumption per move
ϵ_t	-	ARIMA Error Correction coefficient at series count t
\overline{EC}	-	Total electricity consumption
$ers\%$	-	Percentage of emission reduction standard a year
E_t	-	Expenditure at time t
Et	-	Electricity tariff
ets	-	Estimated Ship Service Rate
f	-	TEU factor
fcc	-	Fuel consumption coefficient
$FCOh$	-	Fixed Cost of Overhead
fp	-	Fuel oil price
$GProfit_t$	-	Gross Profit at time t
$H.MCr$	-	Subsequent marine charges after 6 hours of docking
$hav(\theta)$	-	Haversine function
ir	-	Discount rate
k	-	ACF designated lag interval
λ_{ship}	-	Ship arrival Rate
l	-	ADF lag order
m	-	Order of Minkowsky Distance
MAE	-	Mean ABsolute Error
$MAPE$	-	Mean Absolute Percentage Error
MCr	-	Marine charges for the first 6 hours of docking
MPE	-	Mean Percentage Error
MPH_i	-	Move per hour of equipment type i
MSE	-	Mean Square Error
n_i'	-	Number of allowable conventional equipment type i
n_b	-	Number of berth
n_{ei}	-	Number of electrical equipment type ei
n_i	-	Number unit of equipment type i
NPV_{ce}	-	Net Present Value by Conventional Expansion
NPV_{ge}	-	Net Present Value by Green Expansion
NPV_t	-	Net present value of project at time, t

N_{nift}	-	Number of shifts
P_{AKAM}	-	Akam's Transition Coefficient
ρ	-	Berth occupancy factor
$P(\mu)$	-	Probability of ship arrival rate
$P [\quad \quad]$	-	Probability Transition from state-variable in a scenario to another state-variable of another scenario
pa	-	Port Authority State-Variable
pa'	-	Transition (t+1) of Port Authority State-Variable
PA_{S1}	-	State-variable Set of Port Authority in submodel 1
pi	-	Port Institution State
pi'	-	Transition (t+1) of Port Institution
PI_t	-	State of Port Institution Set
$PoC' \lambda_i$	-	Longitude of placement coordinate for equipment type i
$PoC' \varphi_i$	-	Latitude of placement coordinate for equipment type i
PoC'_i	-	Point of coordinate for container placement
PoC_i	-	Point of coordinate for container pick up
$PoC\lambda_i$	-	Longitude of pick up coordinate for equipment type i
$PoC\varphi_i$	-	Latitude of pick up coordinate for equipment type i
pp	-	Port Planner State-Variable
pp'	-	Transition (t+1) of Port Planner State-Variable
PP_{S1}	-	State-variable Set of Port Planner in submodel 1
PP_{S2}	-	State-variable Set Port Planner in submodel 2
pr	-	Power rating of equipments
ps	-	Port Stakeholder State-Variable
ps'	-	Transition (t+1) of Port Stakeholder State-Variable
PS_{S1}	-	State-variable Set of Port Stakeholder in submodel 1
PS_{S2}	-	State-variable Set of Port Stakeholder in submodel 2
P_{svc}	-	Probability Set of State-variable Transition
pth	-	Planning time horizon
\bar{Q}_{berth}	-	Average container handled per berth
\bar{Q}_{day}	-	Average throughput handled a day
\bar{Q}_{hip}	-	Average throughput handled per ship
Q_{year}	-	Annual container throughput
$r_{k,j}$	-	PACF Sample autocorrelation value

	-	Handling ratio coefficient
R_{earth}	-	Earth's radius
R_t	-	Revenue at time t
rd	-	Radian conversion
r_i	-	Handling ratio coefficient of equipment type i
r_k	-	ACF Sample autocorrelation value
$SCALL$	-	Total number of ship call
svc	-	State-variable Combination
svc	-	Transition (t+1) of State-variable Combination
SVC_{S1}	-	State-variable Combination Set of submodel 1
SVC_{S2}	-	State-variable Combination Set of submodel 2
tb	-	Total berth operation time
TCL_t	-	Total labor cost
$TCOh_t$	-	Total overhead cost
TCO_t	-	Total operating cost
$TEUCr$	-	Container charges
t_{op}	-	Time of operation
t_s	-	Time of operation service
μ_{ship}	-	Service rate of ship per day
μ_{berth}	-	Service rate of ship per berth
wt_{std}	-	Standardised Ship Waiting Time
wt	-	Ship Waiting Time
$\bar{X}_{i,j}$	-	Average distance for equipment type i, route j
\bar{x}	-	ACF average of sample data
x	-	ACF sample data at count i
\hat{y}_t	-	Average of sample data at count t
γ	-	ADF Root coefficient
y_t	-	Sample data at count t

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Subject Matter Expert Consultation and Data Collection Request	233
B	Verification of ABM Submodule 1	234
C	Verification of ABM Submodule 2	238
D	Subject Matter Expert Endorsement on Agent-based Model	241
E	Delphi Survey for Emission Reduction Standard	242
F	E2/E2/n Queue Chart	243
G	Port of Tanjung Pelepas GIS Map (Block 1 – 16)	244
H	Prime Mover Minkowsky Distance by GIS	246

CHAPTER 1

INTRODUCTION

1.1 Introduction

Port expansion theory primarily centers on expanding basic components such as container park area, container freight station, berth-day requirement and container handling system to meet port transportation demand. UNCTAD (1985) laid the ground work for port expansion with a general application of graphical extrapolation. However, it only accounts for port size of only within 400,000 TEU throughput a year, and considers limited equipment dynamics of only straddle carrier and prime mover combination. Yet, this well documented literature is still a document of referral for researchers as it expounds on the thorough process of port development management from market forecasting to project appraisal.

Researchers built on UNCTAD framework to capture specific needs of different port. Instead of conventional UNCTAD approach, extended researches manipulate quantifiable port parameters to propose superior expansion profile. Tsinker (2004) studied future port expansion in relation to port connectivity with hinterland transportation while Gaur (2005) proposes a strategic port planning tool considering local institutional framework. Other researches on specifically enhancing the scheduling of crane-truck handling was done by Chen (2013), Gharehgozli (2014), Bierwirth (2010), among others. Decision to expand against strong

competition (Ferrari & Basta, 2009; Yap , 2011) from regional ports and acquiring additional equipments via marginal approach (Loke, 2012) or Black-Scholes option for an economic berth expansion (Novaes et al., 2012) are also researched upon. Above mentioned research are done in order to ensure port performance and ensure stakeholders interest to invest in port expansion. With information technology, computer simulation in expert fuzzy system (Zamani, 2006), operation and logistics optimization (Vacca, 2008; Yamada, 2003 , Measo et al., 2012) and complex port queuing modeling (Shabayek, 2007; Radmilovic, 1996; Mohammed, 2013) have served as tools to enhance informed decision-making. In short, research is pushing new ground in port planning and Woo (2011) has tabulated a concise record of all genres of port research in chronological order.

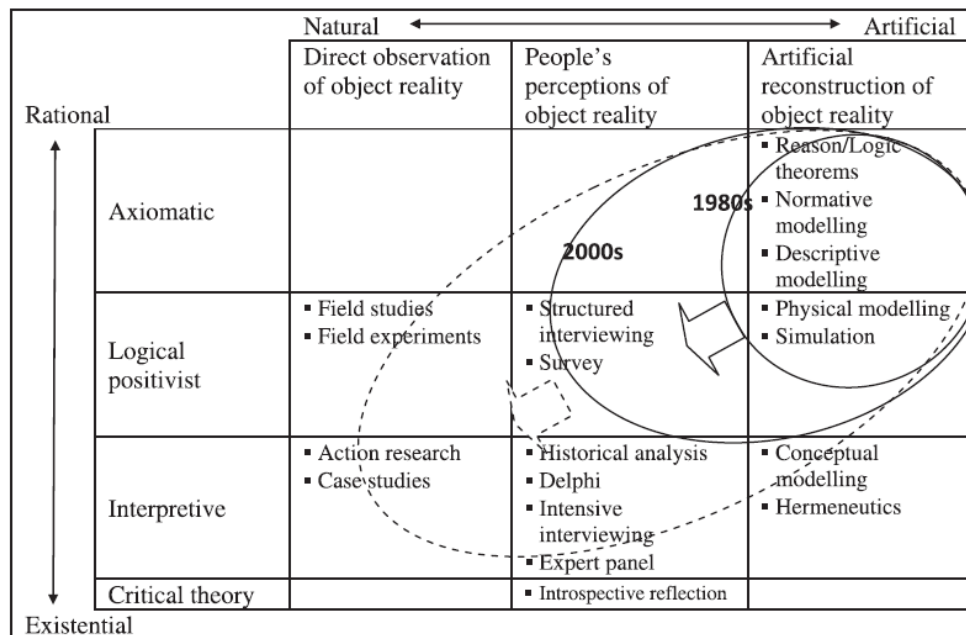


Figure 1.1: Frameworks for port research methods

(source: Woo (2011) & Meredith et al. (1989))

Also, Figure 1.1 shows the evolvement of port planning framework and research methods. Woo (2011) pointed out that interest are drawn in to researching port community behavior in areas of actor-oriented decision-making, choice of expansion and policy-making rather than on a port level analysis. On top of that,

environmental studies are increasing largely due to port reforms undertaken to address environmental concerns. Currently, knowledge creation in port research is in context of industrial practical, privatized terminals, and agent interaction over multidisciplinary. The context yields a more natural and existential model.

Research surge also can be seen in the area of port sustainability. This overarching framework demands comprehensive integration of three aspects of sustainability namely social, economical and environment indicator as described in Figure 1.2.

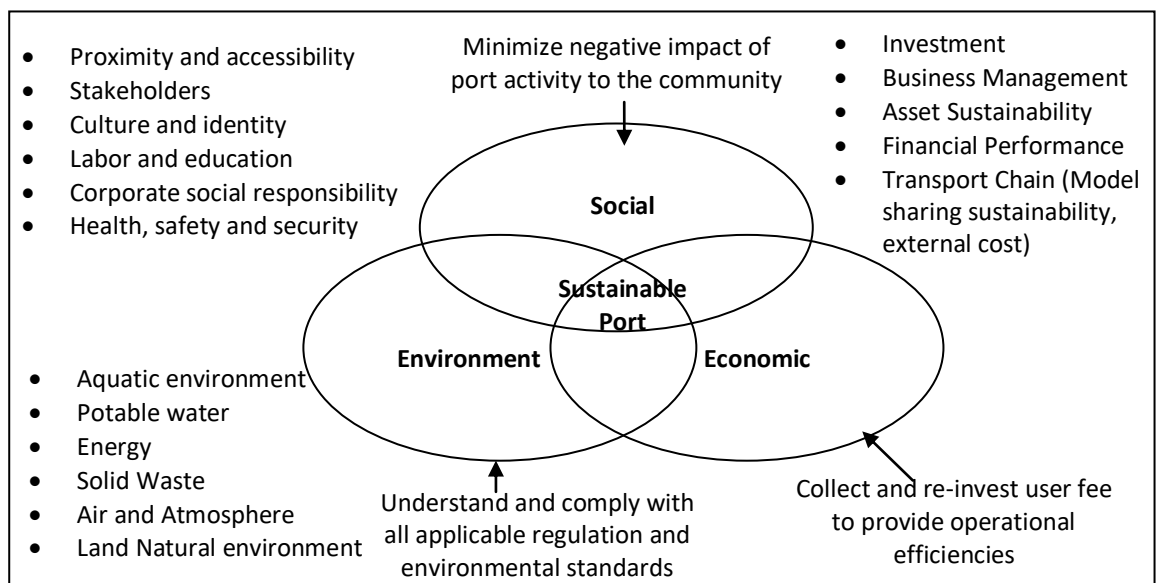


Figure 1.2: Sustainable Port and Main Indicators

(source: Denktas-Sakar, 2012)

With the paraphrasing quote of the Bruntland Commission, port sustainability is defined as "*business strategies and activities that meet the current and future needs of the port and its stakeholders, while protecting and sustaining human and natural resources (AAPA, 2007).*" The following sections will explore the topic of port expansion in context of port sustainability, then to establish the objectives of the research from research background, scope and flow of the research.

1.2 Research Background

Green port concept, has been widely studied by action research and case studies, involves multiple port actors interaction, mainly port authority, port operator and port stakeholders (internal and external), together they make-up port community actors. Many techno-socio researches on green port not only review and propose integrated green strategies but also report on technological breakthrough that radically mitigates environmental impact. Under the case study on the European Sea Port Organization (EPSO) and ECOPORT membership, Darbra, (2004 & 2009) identifies environmental aspects to setup effective environmental monitoring system for the European ports. So, ports adopting the established environmental management system (EMS) are awarded certificates of compliance and accepted as member of ECOPORT. Puig (2014) proposes an environmental indicator selection methodology to enhance the practice of green port development throughout the region. Other green port management literatures are available (Lun, 2011; Grigalunas et al., 2001; Lam, 2012; Chang, 2001), and some even suggest possible alternatives to achieve sustainability (Dekker, 2010; Joan, 2011)

Sustainable management tools have paved the foundation for quantitative mitigation of environmental impact. In emission inventory, Geerling (2011) and Yang (2013) have proposed methodologies to account for CO₂ emission and are able to model quantified emission mitigation by electrification of port equipment. Nevertheless, achieving the call of zero-emission port is still a far-fetch idea. Port of Rotterdam is at the forefront of combating climate change and has agreed on a multilateral collaboration to reduce 50% of CO₂ emission by 2025 compared to base emission year of 1990 (Lam, 2014). Port of Los Angeles also responded to California's Carbon Warming Solution Act in 2006 to cut its greenhouse gas (GHG) emissions to pre-1990 levels by 2020 and 80% below pre-1990 levels by the year 2050 (Kim et al., 2012). These commitments to lower CO₂ emission will integrate economical benefit, conserve climate change and spur global cooperation towards zero-emission port. These carbon-reducing initiatives will be implemented via 'green-fleet' program within the port and is proposed to be enforced via licensing inked in future port concession agreement. Even so, Denktas-Sakar (2012) implies

that such enforcement calls for the involvement of higher authority such as the Ministry of transport, state government environmental department and progressive communication with local port authorities.

On a more technical basis, Europe has developed a systematic action plan to phase-out regulation to dispose of old heavy emission trucks or prime-movers in series of EURO I, EURO 2, EURO 3, EURO 4, EURO 5 and EURO 6 (Dedinec et. al, 2013). These new replacement light-duty vehicle tiers will soon reduce GHG emission to levels of 0.005 g/km particle matter, 0.5g/km CO, 0.08 g/km NOX, while SOx level are regulated based on after-filtration system (Nylund, 2007). Morawska (2010) reports that Singapore, the world second largest port after Shanghai, will embrace EURO 6 standards for trucks entering port area by 2016 while Japan enacted their EURO 6 equivalent Post-Post New Long-Term (PPNLT) emission regulation to limit GHG emission from trucks.

Previous cost-effective approach to port expansion has now meet with a paradigm shift of green port concept. Moglia (2003) mentions the need for new concepts when new concepts arise. Yet, he reinstates that port expansion theory remains and can be categorized into project-based, short-term and long-term. Dooms (2003) affirms that new approaches should not remain as short-term project, ports master plan (long-term) should be incorporated such as green port concept and theory of stakeholder management in to ensure the realization of the intended cause.

It can be said that, long-term port expansion sets performance standards which quantifies the required expansion profile; long-term green port expansion at the discretion of port community will also set emission reduction performance and quantify the required carbon-reducing equipment profile.

To-date, with technological breakthrough in battery technology, it is technically feasible to achieve zero-emission green port. State-of-the-art battery thrives in battery life and short charging intervals that would not disturb normal

operation or require huge redundancy in case of breakdown. Furthermore, as lithium-ion batteries commercialise with economics-of-scale, the application of batteries will be extensive (CALSTART, 2013). EPRI (2008) piloted the project to explore electrification option in port handling equipment and found a solution in electrifying RTG by setting up latch-on bus bar and battery set for driving across lanes. With success, APM terminal announced the program to retrofit and electrify worldwide RTG fleet and predicted to reduced CO₂ significantly by 60% (APM, 2011). Pelabuhan Tanjung Pelepas, a member of APM global terminals, recorded 40% reduction in diesel consumption after retrofitting 90 conventional RTG units. Another major contribution of CO₂ emission is the prime-mover fleet. In 2007, the Baqon electric truck initiative from the Port of Long Beach and Port of Los Angeles, under the commitment to San Pedro Bay Ports Clean Air Action Plan (CAAP), has piloted a project on electrical prime-mover - model MX30. With minimal additional infrastructure of charging stations which can replace existing diesel refilling stations, CO₂ emission can be mitigated within the governance of port community (EPRI, 2011).

The emergence of technical feasibility of installing green equipment has not compel most ports community to participate in deploying 'green fleet' program . Neither has the most port authorities implemented quantified emission reduction standard (ERS) as had Port of Rotterdam and Port of Los Angeles agreed to its local governments initiative. Besides financial constraints and lacking technical support made available, Notteboom (2012) argues that a maturity corresponding to the collective port community interaction is key to the successful implementation of emission reduction standard. Notteboom states that port community interaction in sustainability context can be divided into (1) cultural cognitive institution, (2) normative institution and (3) regulative institution, of which the last is the peak of institution maturity enabling port authority to execute coercive rule such as emission reduction standard. This regulative mechanism will be legally sanctioned instead of morally governed; with environmental indicators to abide by law instead of social obligation. In effect, it will grant continuation of licence to complying port operators instead of awarding certificate of recognition for environmental compliance.

However, pre-mature implementation of any regulation on environment may not only fail to yield desired outcome as intended but also create a step-back in institution evolution. Tews (2003) who studies environmental policies list countries such as USA Norway, Taiwan, South Korea, India, South Africa, New Zealand, Switzerland and Japan to have implemented carbon tax as means to radically mitigate CO₂ emission and channel the collected due tax to reinvest in cleaner energies and green technologies. Australia and state of Maryland (USA) also saw Carbon Tax implementation of A\$23 and USD\$5 per ton carbon dioxide in 2012 and 2010 respectively. However, Australia was the first to repeal the legislation and Maryland in 2011 citing that the tax was a punitive fee rather than a tax (Taylor, 2014). Lam & Van (2012) elaborate that for sustainable growth of green port strategy, the key framework is in structured stakeholder involvement, green market development and cost-effective green policy as well as sustainable port operations (Figure 2.11). Without the evolution in stakeholder involvement in strategic green development, pre-mature policies will cripple the system. Norsworthy (2013) reports also that voluntary clean truck programs has lower achievement of 1-4% of emission reduction compared to the potential reduction 12-15% reduction for particulate matter and 31-34% for nitrogen oxides by compulsion.

In respect to the three stages of port community interaction, individual port community are path depended in the maturity time-frame to implement 'green-fleet' program. So time to evolve into a regulative institution over time is a factor to the reduction of CO₂ emission. Nevertheless, as all elements to evolve institutionally happens, port community will be able to adopt sustainable approach to devise port expansion. Institutional change do not necessarily diverge port expansion from its fundamental approach but rather adds value (Peter, 2007). In green port context, it adds environmental conservation to port expansion theory.

In brief, the reform of port expansion facing the green port paradigm shift has called for the framework of port expansion with emission reduction standard. The decision to implement emission reduction standard is subjected to the port sustainability transition in reaching regulative institution. With emission reduction

standard to guide long-term port expansion, a quantified cargo handling equipment in long term expansion will yield objective performance in reducing CO₂ emission.

1.3 Problem Statement

Research background points towards future environmental requirement of enforcing port emission reduction. Current green port practice to reduce emission via voluntary basis may not be able to effectively reduce emission to desired level (Norsworthy, 2013). Even strict light-duty vehicle phase-out regulation will still leave clean diesel engine emitting GHG emission. Though such environmental management efforts serves to strengthen and realize green port concept, implementing emission reduction is the key to effectively reduce GHG emission. However, it requires the evolvement of port institution to enforce emission reduction standard so that it will steer ports to adjust long-term planning approach (Moglia, F. et al., 2003) to operate within a inventoried sustainable emission level.

As long-term port equipment expansion is to provide quantified amount of equipment to increase operation performance (Novaes et al., 2012); long-term sustainable equipment expansion is also to provide quantified amount of green equipment to meet designated emission standard performance. There has not been quantified environmental reduction that requires planning of carbon-reducing equipments by long-term until emergence of pledges by ports such as the Port of Rotterdam and Port of Los Angeles, though on a city level. Hence, a method to estimate quantified carbon-reducing equipment in order to reduce CO₂ emission to a desired level is needed.

On the other hand, Lam (2012) argues that planning for green expansion with the assumption that all port community approves of carbon-reducing equipment would prove unrealistic and premature. Sustainable port expansion approach can only conform to port community interaction framework of Notteboom (2012) as it

evolves over time from cultural cognitive institution to normative institution; from normative institution to regulative institution. When necessary elements of green incentive, tariff adjustment, available technical support and competency in green management is in practice, port institution can be regulative-ready. Only then, by port concession, port institution of regulative institution can execute carbon-reducing equipment planning upon agreement by the consensus of port agents. Therefore, an agent-based model is needed to simulate port institution evolution that determines adopted design approach for equipment expansion.

In short, the research gap requires an agent-based model to simulate long-term carbon-reducing equipment not only to reduce emission to designated levels but also in an expansion approach that conforms to the institution state of port agents interaction.

1.4 Research Objective

To build on the port expansion theory, this research will address the above mentioned problem by combining green port concept into the long-term planning of port expansion to yield quantified equipment expansion approach that meets the emission reduction standard. This research problem can be solved by accomplishing the following objectives:

- i. To propose an expansion approach to quantify carbon-reducing container handling equipment complying to emission reduction standard
- ii. To simulate equipment expansion with CO₂ reduction according to the port institution and design approach.
- iii. To validate the agent-based model for carbon-reducing equipment expansion

1.5 Scope of Research

As port research is dynamic and complex, this research set the study boundaries as follows:

- i. Equipment expansion considers only container port type with parallel layout that utilizes equipment types of quay crane, rubber-tire gantry and prime-mover. This terminal type accounts for 90% of Asian ports. (Brinkmann, 2011)
- ii. Only direct CO₂ emission will be modeled. Indirect emission from electricity usage generated in power stations are beyond the boundaries and governance of port community. Other air pollutant such as NO_x, SO_x and PM are not studied.
- iii. Agents in the port community will consist of three main actors namely, port authority (land-owner), port operator and port stakeholders. Port Stakeholders are seen as one, regardless of external stakeholders (Port Authority, Freight Forwarders, Industrial support) or internal stakeholders (Executive Planners, Port Investors,)
- iv. Tactical and strategical method of planning port equipment expansion is used, rather than on a operational time-frame
- v. Future container throughput are forecasted by univariate method with no economic assumption and market-driven competition.
- vi. Emission from lesser equipments such as forklifts and tugboat, though under the ownership of port operator will not be considered due to insufficient data and the negligible percentage it accounts for the overall emission.
- vii. Due to insufficient and confidentiality of data from port operator, any available data given at the discretion from port authority will be extrapolated for modeling use.
- viii. Cost optimization is not exercised except constraints of NPV and IRR are set as project criterion parameters to the carbon-reducing equipment expansion

1.6 Theoretical Framework

The development of green agent-based expansion model is combination of three components of port expansion, green port concept and port community interaction. Without each component, the end-goal realization of quantifiable carbon-reducing port cannot be attained as depicted in Figure 1.3

Port expansion theory have been extended by many researchers. This research will follow the model developed by Novaes et al. (2012) and Sharif (2011) to expand berth length and equipment profile complying to operation standard and minimum net present value. Loke (2012) and Chu and Huang (2005) provided detail expansion methods to expand smaller equipments in port such as RTG and PM which accounts more than 90% of port total emission.

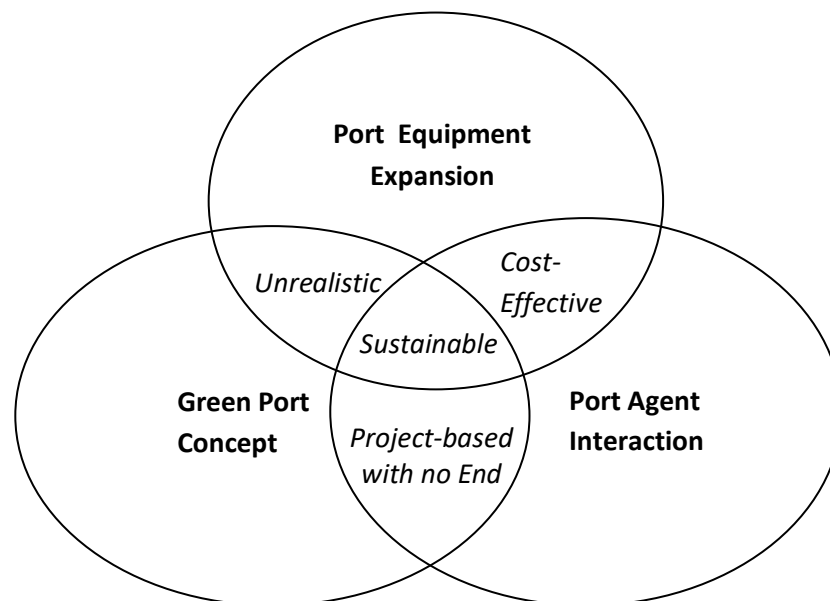


Figure 1.3: Discrepancy of Port Model Combination

Green port concept criteria is derived from Lam & Notteboom (2014) who highlights the emission reduction trend by setting up tangible CO₂ reduction percentage. The work of Geerling & Duin (2011) and Yang & Chang (2013) contributed the methodology to model quantifiable emission mitigation and Hartman

& Clott (2012) established method to replace clean engine truck to reduce CO₂ emission level.

Finally, port agent interaction framework was developed extensively by Henesey (2006) to enhance container terminal performance. Though his work did not include agents interaction on green port concept, Lam & Van (2012) defined the behavior and rule-based interaction of port in reaching sustainability in port management. While, Notteboom (2012) developed a framework to theorize three port institution as a result from the evolvement from port agent interaction. Those three pillars are "cultural cognitive institution", "normative institution" and "regulative institution". Together these three component will be combine to develop the agent-based model for sustainable equipment expansion of a container port.

1.7 Significance of study

Upon accomplished the research objectives, the model quantifying long-term carbon-reducing equipment expansion according to agent interaction will serve as a reference tool for future decision-making to reduce CO₂ emission. The model will allow for manipulation of variables to aide decision-making process or negotiation session with other port agents, specially for tariff adjustment during port concession.

The model will project the effects of port community interaction to emission performance based on port institution path. This foresight will aide port environmental management adjust with urgency along the depended path to facilitate sustainable expansion by carbon-reducing equipment at required expansion phase.

On top of that, the yield quantified green equipment expansion projected over the long planning-time-horizon will give opportunity for port planners to explore alternatives to maximize port performance financially or operation wise. Whether to

purchase carbon-reducing equipment by acquisition option or facilitate the additional spatial requirement, the foresight of long-term carbon-reducing equipment will be essential.

Planning is bringing the future into the present so that something can be done about it.

1.8 Organisation of Thesis

The remaining of this thesis will present the research details in the following structure: **Chapter 2** includes extensive literature review covering aspects of port planning philosophies in the context of container terminal. It further elaborates on green port concepts in altering container port expansion approach but yet maintains the fundamental philosophies. Port Agent interaction impact on port expansion and individual agent behavior rule is delineated. Mathematical algorithms on forecasting throughput, expanding equipment profile, calculating equipment emission and financial analysis are also reviewed.

Chapter 3 presents the integrated methodology for the proposal of an agent-based model (ABM) to simulate long-term carbon-reducing equipment. Procedure for the development of ABM architecture and the key component of emission reduction standard (ERS) by Delphi Survey are explained. Then, it shows the development of the agent-based model sustainability transition and the port expansion mathematical algorithm incorporated into the ABM. The mathematical algorithm encompasses throughput forecasting, equipment profiling, emission calculation and financial analysis. Method of data collection is also stated and analysis of data collected is also performed. Finally, the chapter ends with the verification and validation of agent-based model.

Chapter 4 presents the 7 packages of results of agent-based model. The packages are the integrated ABM, sustainable equipment expansion profile, database reference, the NETLOGO source code, the verification and validation results and the sensitivity analysis results. The final results will be discussed in great detail with remarks and inferences drawn from the results observation.

Chapter 5 presents conclusion of the whole thesis, highlighting the fulfillment of research objectives and remarks for future research recommendation.

REFERENCES

- AAPA (2007) Embracing the concept of sustainability as a standard practice for ports and the association (American Association of Port Authorities) (http://aapa.files.cmsplus.com/PDFs/sustainability_resolutions.pdf)
- Abdul-Mageed, Loay (2012), An Agent-based Approach for Improving the Performance of Distributed Business Processes in Maritime Port Community. Research Theses, Faculty of Science and Technology, University of Plymouth. <https://pearl.plymouth.ac.uk/handle/10026.1/1239>
- Akam T, Costa R, Dayan P (2015) Simple Plans or Sophisticated Habits? State, Transition and Learning Interactions in the Two-Step Task. *PLoS Comput Biol* 11(12): e1004648. DOI:10.1371/journal.pcbi.1004648
- Akam, T., Costa, R., & Dayan, P. (2015). Simple Plans or Sophisticated Habits? State, Transition and Learning Interactions in the Two-Step Task. *PLoS Comput Biol*, 11(12), e1004648.
- AMHAD, M. Z. B. (2006). The Application of Fuzzy Expert System to Preliminary Development Planning of Medium Size Container Terminal (Doctoral dissertation, Universiti Teknologi Malaysia).
- APM (2011), APM Terminals to Retrofit and Electrify RTG Fleet Worldwide Press Release: March 4, 2011 (www.apmterminals.com)
- Ayub, Y., & Faruki, U. (2009). Container Terminal Operations Modeling through Multi agent based Simulation.
- Bailey, D., & Solomon, G. (2004). Pollution prevention at ports: clearing the air. *Environmental Impact Assessment Review*, 24(7), 749-774.1

- Barnes D.J., D. Chu, Introduction to Modeling for Biosciences, DOI 10.1007/978-1-84996-326-8_2, © Springer-Verlag London Limited 2010
- Berger, R. (2014), Conceptual Port Master Plan for Johor. Roland Berger Strategy Consultant, Final Report.
- Bierwirth, C., & Meisel, F. (2010). A survey of berth allocation and quay crane scheduling problems in container terminals. *European Journal of Operational Research*, 202(3), 615-627.
- Bonabeau E (2002). Agent-based modeling: Methods and techniques for simulating human systems. In: *Proceedings of the National Academy of Science of the USA*. 99:7280-7287.
- Bradshaw J (1997). *Software agents*, MIT Press, Cambridge, MA. (cited in Odell J (2002). Objects and agents compared, *Journal of Object Technology*, 1(1):41-53)
- Brinkmann, B. (2011). Operations systems of container terminals: A compendious overview. In *Handbook of terminal planning* (pp. 25-39). Springer New York.
- CALSTART (2013), I-710 Project Zero-Emission Truck Commercialization Study Final Report, prepared for Gateway Cities Council of Governments, Los Angeles County Metropolitan Transportation Authority
- Chang, C.-C. and C.-M. Wang (2012). Evaluating the effects of green port policy: Case study of Kaohsiung harbor in Taiwan. *Transportation Research Part D: Transport and Environment* 17(3): 185-189.
- Chang, Y. T. (2013). Environmental efficiency of ports: a data envelopment analysis approach. *Maritime Policy & Management*, 40(5), 467-478.
- Chen, L., Langevin, A., & Lu, Z. (2013). Integrated scheduling of crane handling and truck transportation in a maritime container terminal. *European Journal of Operational Research*, 225(1), 142-152.
- Chen, L., Langevin, A., & Lu, Z. (2013). Integrated scheduling of crane handling and truck transportation in a maritime container terminal. *European Journal of Operational Research*, 225(1), 142-152.

- Chen, S. H., & Chen, J. N. (2010). Forecasting container throughputs at ports using genetic programming. *Expert Systems with Applications*, 37(3), 2054-2058.
- Cheryl, R. K. (2009), Treatment technology for the control and management of ballast water: Available options. *Impak*, 4/2009, 14-15.
- Chu, C. Y. and W. C. Huang (2004). Determining container terminal capacity on the basis of an adopted yard handling system. *Transport Reviews* 25(2): 181-199.
- Coto-Millán, P., Pesquera, M. A., & Castanedo, J. (Eds.). (2010). *Essays on port economics*. Springer Science & Business Media.
- Darbra R.M., Pittam N., Royston K.A., Darbra J.P., Journee H. (2009), Survey on environmental monitoring requirements of European ports, *Journal of Environmental Management*, Volume 90, Issue 3, March 2009, Pages 1396-1403, ISSN 0301-4797, 10.1016/j.jenvman.2008.08.010.
- Darbra, R. M., et al. (2004). "The Self Diagnosis Method: A new methodology to assess environmental management in sea ports." *Marine Pollution Bulletin* 48(5–6): 420-428.
- Darvishi, M., & Ahmadi, G. (2014). Validation techniques of agent based modelling for geospatial simulations. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 40(2), 91.
- De Monie, G., (2004), Mission and role of port authorities after privatisation. *Proceedings ITMMA PPP Seminar (Antwerp: ITMMA)*.
- Dedinec, A., et al. (2013). "Assessment of climate change mitigation potential of the Macedonian transport sector." *Energy* **57**: 177-187.
- Dekker S. (2010), "Sustainable Port Development In The Netherlands – Framework For A Comprehensive Approach Applied To Amsterdam Port" , 12th Wctr Lisbon, Portugal. (Strategic Consultant Transport & Economics, Grontmij Nederland Bv)
- Dekker, S. (2005). *Port investment: towards an integrated planning of port capacity*. TU Delft, Delft University of Technology.

- Denktas-Sakar, G. and C. Karatas-Cetin (2012). Port Sustainability and Stakeholder Management in Supply Chains: A Framework on Resource Dependence Theory. *The Asian Journal of Shipping and Logistics* **28**(3): 301-319.
- Di Francesco, M., Lai, M., & Zuddas, P. (2013). Maritime repositioning of empty containers under uncertain port disruptions. *Computers & Industrial Engineering*, *64*(3), 827-837.
- Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American statistical association*, *74*(366a), 427-431.
- Dooms, M., & Macharis, C. (2013). A framework for sustainable port planning in inland ports: a multistakeholder approach. In *The 43th European Congress of the Regional Science Association (ERSA)*.
- Ee, J. Y. C., Kader, A. S. A., Ahmad, Z., & Beng, L. K. (2014). Univariate throughput forecasting models on container terminal equipment planning. *Jurnal Teknologi*, *69*(7).
- EPRI (2008), *Equipment Electrification Resource Guide for Port of Los Angeles Tenants*. EPRI, Palo Alto, CA and LADWP, Los Angeles, CA: 2008: 1018220.
- EPRI (2011), *Transportation Electrification: A Technology Overview*, EPRI, Palo Alto, CA: 2011. 1021334
- Ferrari, C. and Basta, M. (2009). Port concession fees based on the price-cap regulation : A DEA approach, *Maritime Economics and Logistics*, *11*(1), 121-135
- Frankel, E. G. (1989). Strategic planning applied to shipping and ports. *Maritime Policy and Management*, *16*(2), 123-132.
- Franziska Klugl (2008), *A Validation Methodology for Agent Based Simulations*, (Unknown Publisher) Department for Artificial Intelligence, University of Würzburg Am Hubland, 97074 Würzburg Copyright 2008 ACM 9781595937537/08/0003

- Fried, R., & George, A. C. (2011). Exponential and holt-winters smoothing. In *International Encyclopedia of Statistical Science* (pp. 488-490). Springer Berlin Heidelberg.
- Gaur, P. (2005). Port planning as a strategic tool: a typology (Doctoral dissertation, Antwerp University).
- Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental innovation and societal transitions*, 1(1), 24-40.
- Geerlings, H. and R. van Duin (2011). A new method for assessing CO₂-emissions from container terminals: a promising approach applied in Rotterdam. *Journal of Cleaner Production* 19(6-7): 657-666.
- Gharehgozli, A. H., Yu, Y., de Koster, R., & Udding, J. T. (2014). An exact method for scheduling a yard crane. *European Journal of Operational Research*, 235(2), 431-447.
- Ghashat, H. M., & Cullinane, K. P. (2013). The future governance structure of Libya's container ports: A survey of stakeholder attitudes. *Research in Transportation Business & Management*, 8, 7-16.
- Gilman, S. (2003). Sustainability and national policy in UK port development. *Maritime Policy & Management*, 30(4), 275-291.
- Giuliano, G. and T. O'Brien (2007). "Reducing port-related truck emissions: The terminal gate appointment system at the Ports of Los Angeles and Long Beach." *Transportation Research Part D: Transport and Environment* 12(7): 460-473.
- Gosasang, V., Chandraprakaikul, W., & Kiattisin, S. (2011). A comparison of traditional and neural networks forecasting techniques for container throughput at Bangkok port. *The Asian Journal of Shipping and Logistics*, 27(3), 463-482.
- Grigalunas, T. A., Luo, M., & Chang, Y. T. (2001). Comprehensive framework for sustainable container port development for the United States east coast. University of Rhode Island Transportation Center.

- Grimm, V. et. al. (2006). A standard protocol for describing individual-based and agent-based models. *Ecological modelling*, 198(1), 115-126.
- Hartman, B. C. and C. B. Clott (2012). An economic model for sustainable harbor trucking. *Transportation Research Part D: Transport and Environment* **17**(5): 354-360.
- Henesey L. E. (2006) *Multi-Agent Systems for Container Terminal Management*, Blekinge Institute of Technology Doctoral Dissertation Series No 2006:08, SWEDEN, ISBN 978-91-7295-099-3
- Hsu, C. C., & Sandford, B. A. (2007). The Delphi technique: making sense of consensus. *Practical assessment, research & evaluation*, 12(10), 1-8.
- IMO (2009). *Second IMO Greenhouse Gas study 2009*. Retrieved 1 June, 2010 from IMO website at : <http://www.imo.org/>
- Iqbal, M. (2015). *A Multi-agent Based Model for Inter Terminal Transportation*.
- Jenkins, G. M., & Reinsel, G. C. (1976). *Time series analysis: forecasting and control*.
- Joan C. R. and Armin W. (2011), *Sustainable Container Terminals: A Design Approach*, *Handbook of Terminal Planning, Operations Research/Computer Science Interfaces Series Volume 49*, 2011, pp 61-82
- JPA (2014). *Johor Port Authority Green Port Policy 2014-2020* (source: www.lpj.gov.my/images/accordian/green-port.pdf)
- Kader, A.S.A. (1997) *Cost Modelling for Inland Waterway Transport Systems*. Liverpool John Moores University, Liverpool, 276.
- Kasmin, S.(2010) *Enforcing ship-based marine pollution for cleaner seas in the Strait of Malacca*. *EnvironmentAsia* 3 (special issue), 61-65.
- Kim, J., Rahimi, M., & Newell, J. (2012). Life-cycle emissions from port electrification: A case study of cargo handling tractors at the port of Los Angeles. *International Journal of Sustainable Transportation*, 6(6), 321-337.
- Kreis, D., McCormack, S., Van Dyke, C., & Gibson, B. (2014). *Audit Template for Inland Port Sustainability*.

- Kreis, D., McCormack, S., Van Dyke, C., & Gibson, B. (2014). Audit Template for Inland Port Sustainability.
- Lam, J. S. L., & Notteboom, T. (2014). The greening of ports: A comparison of port management tools used by leading ports in Asia and Europe. *Transport Reviews*, 34(2), 169-189.
- Lam, J. S. L., & Van de Voorde, E. (2012). Green port strategy for sustainable growth and development. In *Transport Logistics for Sustainable Growth at a New Level, International Forum on Shipping, Ports and Airports (IFSPA)* (pp. 27-30).
- Laubenbacher, R., Jarrah, A. S., Mortveit, H. S., & Ravi, S. S. (2009). Agent based modeling, mathematical formalism for. *Encyclopedia of complexity and systems science*, 160-176.
- Li, X. & Xu, S. (2011). A Study on Port Container Throughput Prediction Based on Optimal Combined Forecasting Model in Shanghai Port. *ICCTP 2011*. 3894–3905.
- Lirn, T. C., Jim Wu, Y. C., & Chen, Y. J. (2013). Green performance criteria for sustainable ports in Asia. *International Journal of Physical Distribution & Logistics Management*, 43(5/6), 427-451.
- Liu, F. C. (2011). Validation and Agent-Based Modeling: A Practice of Contrasting Simulation Results with Empirical Data. *New Mathematics and Natural Computation*, 7(03), 515-542.
- Lloyd (2009) “ Future of shipping : Why CO2 is changing the world and shipping with it” 4. (December 2009)
- Loke, K. B., Kader, A. S. A., & Zamani, M. (2012, October). Optimising Expansion Control On Quay Crane Development In Container Terminal. In *International Conference on Marine Technology Kuala Terengganu, Malaysia*(pp. 20-22).
- Longo, F., Bruzzone, A., Nicoletti, L., Massei, M., & Spadafora, F. (2014) An advanced and flexible simulation tool for environmental impact evaluation and sustainability enhancement in marine ports. *International Journal of Engineering, Science and Technology*, 6(3), 70-84.

- Lucas, A., Silva, C. A., & Neto, R. C. (2012). Life cycle analysis of energy supply infrastructure for conventional and electric vehicles. *Energy Policy*, 41, 537-547.
- Ludwig, B. (1997). Predicting the future: Have you considered using the Delphi methodology? *Journal of Extension*, 35 (5), 1-4.
- Lun, Y. H. V. (2011). Green management practices and firm performance: A case of container terminal operations." *Resources, Conservation and Recycling* 55(6): 559-566.
- Maeso, E., Ballesteros, M., & Caballero, J. (2012). Logistic Management Optimization for a Container Port Terminal. In *Industrial Engineering: Innovative Networks* (pp. 283-290). Springer London.
- Makridakis, S., et. al. (1993). The M2-competition: A real-time judgmentally based forecasting study. *International Journal of Forecasting*, 9(1), 5-22.
- Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, 41(6), 955-967.
- Memos, C. D. (2004). Port planning. *Port engineering: planning, construction, maintenance, and security*, edited by Gregory P Tsinker, 7-64.
- Moglia, F., Sanguineri M., 2003. Port planning: the need for a new approach? *Maritime Economics and Logistics*, 5 (4), pp. 413-425.
- Mohammad, O. A.(2013). Application of Agent-Based Approaches to Enhance Container Terminal Operations. (Doctoral dissertation). Retrieved from <http://scholarcommons.sc.edu/etd/2429>
- Morawska, L., Jayaratne, E. R., Knibbs, L. D., & Megatmokhtar, M. (2010). Regulations and policy measures related to the reduction of ambient particulate matter. In *Urban Airborne Particulate Matter* (pp. 599-622). Springer Berlin Heidelberg.
- Moss, S., Downing, T., & Rouchier, J. (2000). Demonstrating the role of stakeholder participation: An agent based social simulation model of water demand policy

- and response. CPM Report No. 00-76, Centre for Policy Modelling, The Business School, Manchester Metropolitan University, Manchester, UK, 29, 39.
- Mousazadeh, H., et al. (2010). "Evaluation of alternative battery technologies for a solar assist plug-in hybrid electric tractor." *Transportation Research Part D: Transport and Environment* 15(8): 507-512.
- Mukherjee, A., & Muga, H. (2010). An integrative framework for studying sustainable practices and its adoption in the AEC industry: A case study. *Journal of Engineering and Technology Management*, 27(3), 197-214.
- Mustafee, N., & Bischoff, E. E. (2011, December). A multi-methodology agent-based approach for container loading. In *Proceedings of the Winter Simulation Conference* (pp. 234-245). Winter Simulation Conference.
- Musso, E., Ferrari, C., & Benacchio, M. (2006). Port investment: profitability, economic impact and financing. *Research in Transportation Economics*, 16, 171-218.
- Nam, K. C., Kwak, K. S., & Yu, M. S. (2002). Simulation study of container terminal performance. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 128(3), 126-132.
- Nazery K., Tang J. Rajamanickam S. (2012) *Greening the Maritime Sector: Preparing for a Low Carbon Future*, Centre for Maritime Economics and Industries Maritime Institute of Malaysia
- Ng, A. K. Y., & Song, S. (2010). The environmental impacts of pollutants generated by routine shipping operations on ports. *Ocean & Coastal Management*, 53, 301–311.
- Norsworthy, M., & Craft, E. (2013). Emissions reduction analysis of voluntary clean truck programs at US ports. *Transportation Research Part D: Transport and Environment*, 22, 23-27.
- Notteboom, T., et al. (2012) Institutional plasticity and path dependence in seaports: interactions between institutions, port governance reforms and port authority routines. *J. Transp. Geogr.*

- Novaes, A. G., Scholz-Reiter, B., Silva, V. M. D., & Rosa, H. (2012). Long-term planning of a container terminal under demand uncertainty and economies of scale. *Pesquisa Operacional*, 32(1), 55-86.
- Olivier, D., Slack, B., (2006). Rethinking the port. *Environmental Planning A* 38 (8), 1409–1427.
- Othman, J. (2014) Reducing CO2 Emissions in Malaysia: Do Carbon Taxes Work?.
- Panayides, P.M., (2006). Maritime logistics and global supply chains: towards a research agenda. *Maritime Economics and Logistics* 8 (1), 3–18.
- Park, N. K., & Lim, C. K. (2013). Financial Approach for Solving Stakeholders' Conflicts of Interests in Port Redevelopment: Incheon Inner Port. *The Asian Journal of Shipping and Logistics*, 29(3), 315-334.
- Pentland, A., & Liu, A. (1999). Modeling and prediction of human behavior. *Neural computation*, 11(1), 229-242.
- Peris-Mora, E., Orejas, J. D., Subirats, A., Ibáñez, S., & Alvarez, P. (2005). Development of a system of indicators for sustainable port management. *Marine Pollution Bulletin*, 50(12), 1649-1660.
- Peter V. Hall (2007) Seaports, Urban Sustainability, and Paradigm Shift, *Journal of Urban Technology*, 14:2, 87-101, DOI: 10.1080/10630730701531757
- Pirhonen, J. (2011). Automated shuttle carrier® concept. In *Handbook of terminal planning* (pp. 41-59). Springer New York.
- POLA (2007), Electric Truck Demonstration Project Fact Sheet, The Port of Los Angeles report. Source: <https://www.portoflosangeles.org>
- POLA (2011), The Port Of Los Angeles Inventory Of Air Emissions For Calendar Year 2011, Starcrest Consulting Group, Long Beach, California.
- Puig, M., et al. (2014). "Identification and selection of Environmental Performance Indicators for sustainable port development." *Marine Pollution Bulletin* **81**(1): 124-130.

- Radmilovic, Z., Colic, V., & Hrle, Z. (1996). Some aspects of storage and bulk queueing systems in transport operations. *Transportation planning and technology*, 20(1), 67-81.
- Rebollo, M., Julian, V., Carrascosa, C., & Botti, V. (2001). A MAS approach for port container terminal management. In 3rd Iberoamerican workshop on DAI-MAS (pp. 83-94).
- Rijsenbrij, J. C., & Wieschemann, A. (2011). Sustainable container terminals: a design approach. In *Handbook of terminal planning* (pp. 61-82). Springer New York.
- Rowe, G. 2007. A Guide to Delphi. *Foresight: The International Journal of Applied Forecasting*. 8: 11–16.
- Scott, W. R. (2001). *Institutions and organizations*. Sage.
- Shabayek, A. A., & Yeung, W. W. (2000). A queuing model analysis of the performance of the Hong Kong container terminals. *Transportation Planning and Technology*, 23(4), 323-351.
- Sharif Mohseni, N. (2011). *Developing a Tool for Designing a Container Terminal Yard* (Doctoral dissertation, TU Delft, Delft University of Technology).
- Siebers PO, Macal CM, Garnett J, Buxton D and Pidd M (2010) 'Discrete-Event Simulation is Dead, Long Live Agent-Based Simulation!'. *Journal of Simulation*, 4(3) pp. 204-210.
- Sinha, D. (2011). *Container Yard Capacity Planning: A Casual Approach* (No. LD-11-04).
- Smith, A., Voß, J. P., & Grin, J. (2010). Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. *Research policy*, 39(4), 435-448.
- Stahlbock, R., & Voß, S. (2008). Operations research at container terminals: a literature update. *OR spectrum*, 30(1), 1-52.

- Syafi'i, K. K., & Takebayashi, M. (2005). Forecasting the Demand of Container Throughput in Indonesia. *Memoirs of construction engineering research institute*, 47.
- Taylor, R., & Hoyle, R. (2014). Australia becomes first developed nation to repeal carbon tax. *The Wall Street Journal*, 17.
- Tews, K., BUSCH, P. O., & Jörgens, H. (2003). The diffusion of new environmental policy instruments1. *European journal of political research*, 42(4), 569-600.
- Tsinker, G. P. (2004). *Port Engineering: Planning, Construction, Maintenance, and Security*, Wiley. ISBN: 9780471412748
- UNCTAD, 1985. *Port Development – A Handbook for Planners in Developing Countries*. UNITED NATIONS, New York. 227 pages.
- Vacca, I., Bierlaire, M., & Salani, M. (2008). Optimization at container terminals: Status, trends and perspectives (revised version) (No. TRANSP-OR-REPORT-2008-012).
- Van Rooij, B. (2006). Implementation of Chinese environmental law: Regular enforcement and political campaigns. *Development and Change*, 37(1), 57–74.
- Verhoeven, P. (2010). A review of port authority functions: towards a renaissance?. *Maritime Policy & Management*, 37(3), 247-270.
- Wang, P., & Liu, P. C. (2009). Light type rail tired gantry crane. *Hoisting and Convening Machinery*, 6, 72–74 (In Chinese).
- Wiese, J., Suhl, L., & Kliewer, N. (2011). Planning container terminal layouts considering equipment types and storage block design. In *Handbook of terminal planning* (pp. 219-245). Springer New York.
- Woo, S.-H., et al. (2011). Seaport research: A structured literature review on methodological issues since the 1980s. *Transportation Research Part A: Policy and Practice* 45(7): 667-685.

- Xie, G., Wang, S., Zhao, Y., & Lai, K. K. (2013). Hybrid approaches based on LSSVR model for container throughput forecasting: a comparative study. *Applied Soft Computing*, 13(5), 2232-2241.
- Yamada, T., Yoshizawa, G., Frazila, R., & Mori, K. (2003). Optimizing the handling capacity in a container terminal for investigating efficient handling systems. *Journal of the Eastern Asia Society for Transportation Studies*, 5(1), 597-608.
- Yang, Y. N. (2003). Testing the Stability of Experts' Opinions between Successive Rounds of Delphi Studies.
- Yang, Y.-C. and W.-M. Chang (2013) Impacts of electric rubber-tired gantries on green port performance." *Research in Transportation Business & Management*(0).
- Yap, W.Y., Lam, J.S.L. and Cullinane, K. (2011). A theoretical framework for the evaluation of competition between container terminal operators, *Singapore Economic Review*. 56(4), 535–559
- Zamani, A. Z. B. (2006). The Application of Fuzzy Expert System to Preliminary Development Planning of Medium Size Container Terminal (Doctoral dissertation, Universiti Teknologi Malaysia).