# AGENT-BASED MODEL FOR SUSTAINABLE EQUIPMENT EXPANSION WITH $CO_2$ 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 wearies 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 $CO_2$ 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 $CO_2$ 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 ajen 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 menjejas 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 $CO_2$ 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

# LIST OF TABLES

# LIST OF FIGURES

# 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 Autoregresion 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, Desciption 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 |
| $\emptyset_i$ | - | ARIMA Non-seasonal autoregression matrix at lag i |
| $\Theta_{k,j}$ | - | PACF Sample autocorrelation matrix coefficient |
| $\Phi_j$ | - | 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 |
| $\alpha$ | - | ADF intercept constant |
| $B^s$ | - | ARIMA Seasonal difference with seasonal lag of s |
| B | - | ARIMA Non-seasonal difference |
| $\beta$ | - | 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 |
| $\epsilon_t$ | - | 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 |
| $\lambda_{ship}$ | - | 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 |

| | | |
|---|---|---|
| $N_{hift}$ | - | Number of shifts |
| $P_{AKAM}$ | - | Akam's Transition Coefficient |
| ρ | - | Berth occupancy factor |
| $P(\mu)$ | - | Probability of ship arrival rate |
| P [ \| ] | - | 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 Stakehoder State-Variable |
| $ps'$ | - | Transition (t+1) of Port Stakehoder State-Variable |
| $PS_{S1}$ | - | State-variable Set of Port Stakehoder 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 |
| $\mu_{ship}$ | - | Service rate of ship per day |
| $\mu_{berth}$ | - | 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 |
| $\gamma$ | - | ADF Root coefficient |
| $y_t$ | - | Sample data at count t |

# LIST OF APPENDICES

# 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; Mohammead, 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.

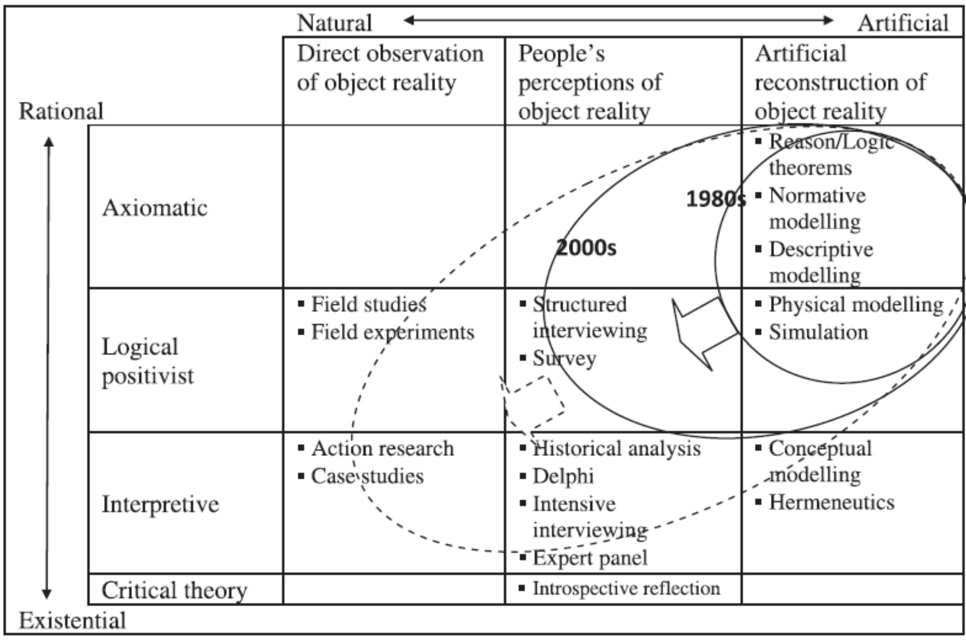


**Figure 1.1**: Frameworks for port research methods

(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 multidisciplinarity. 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.

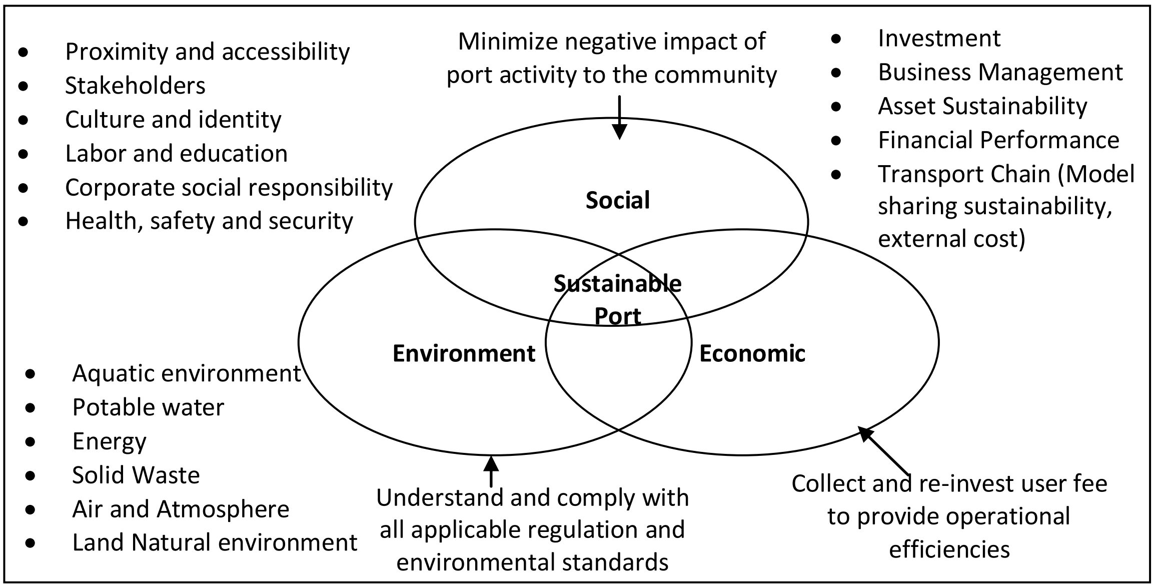


**Figure 1.2**: Sustainable Port and Main Indicators

(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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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. at, 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 $CO_2$ 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 $CO_2$ 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, $CO_2$ 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 evolvement. 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 $CO_2$ 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 evolvement 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 $CO_2$ 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 $CO_2$ 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 $CO_2$ 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 evolvement 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 $CO_2$ 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 $CO_2$ 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 NOx, SOx 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.

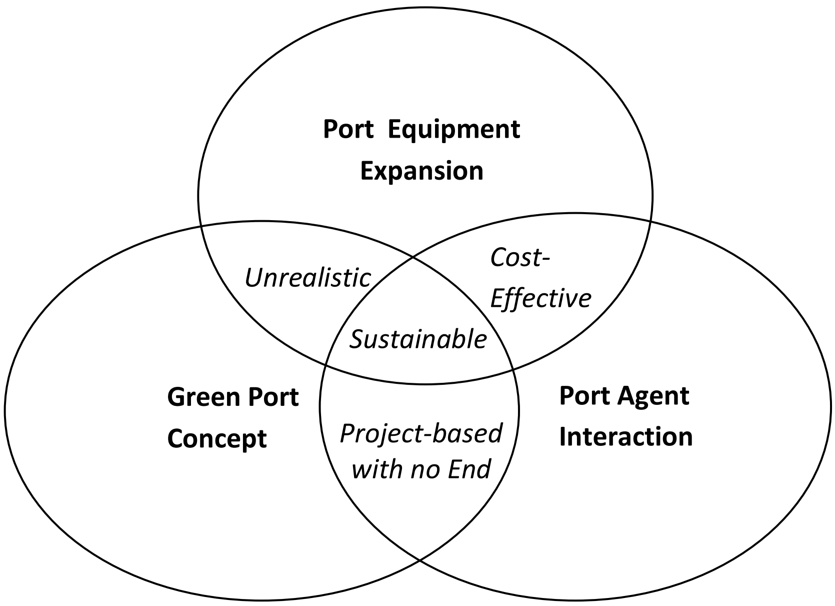


**Figure 1.3**: Discrepancy of Port Model Combination

Green port concept criteria is derived from Lam & Notteboom (2014) who highlights the emission reduction trend by setting up tangible $CO_2$ 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 $CO_2$ 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 $CO_2$ 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.

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