Journal of Sustainability Science and Management
Volume 10 *Number* 2, December 2015: 88-96

ISSN: 1823-8556

SUSTAINABLE EXPANSION MODEL FOR PRIME MOVER IN CONTAINER TERMINAL

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Abstract: The past and current studies are carried out to determine the effective and efficient of prime mover's performance. Most of the prime mover's research studies are focused on prime mover allocation or scheduling. Besides, conventional container terminal's expansion models do not emphasize on prime mover expansion needs based on future traffic demand. Therefore, this study intends to overcome the shortage and develops an alternative choice. It extends from current expansion's model and using algorithm to calculate the sustainable expansion requirement, to determine the incremental needs of prime mover for the existing container terminal. The purpose of using marginal approach is to determine the commercial viability of expansion. The port planner can determine the actual expansion time, size, cost, and investment recovery period for the expansion of prime mover. Thus, the terminal can minimum the opportunity cost and maximum the cash flow and profit.

Keywords: Prime mover, sustainable expansion, incremental needs, commercial viability; investment recovery.

Introduction

Container terminal plays an essential role in container interchanging and supply chain. It also acts as transhipment hub for the international and domestic cargo (Lu, 2011). Container terminal involves greater investments in cargo handling equipment which has capability to achieve higher handling rate and well executive its vital role. Bielli *et al.* (2006) added that the issue of low productive of infrastructure may decrease the handling volume of container terminal. Linda & Edward (1997) suggested a model to enhance equipment and facility service for medium term operations planning. Mattfeld & Kopfer (2003) developed an automated planning and scheduling system for vehicle allocation and scheduling in a container terminal. Yang & Shen (2013) studied the key operation performance and various container yard facilities in Port of Kaohsiung by using grey relational analysis and entropy concept. Branch (1986) stated that container handling equipment can be classified in many different ways, such as capacity, speed, height of lift, type of suspension, and etc. Those equipments used to serve the container operation systems. There are four types of key systems in a container terminal; namely ship, quay transfer, container yard and receipt/delivery operations. Some container terminals have the fifth system, there is container freight station operation (Thomas *et al.*, 1994). Sauri & Martin (2011) also highlighted that four operation systems in container terminal; namely ship to shore, transfer, storage, and delivery/receiving.

Reach stackers are mobile cranes that used to lift, handle, transport and stack the containers. They served quay transfer and container yard operations (Athanasios *et al.*, 2002). But, they could not stack very densely and need large area of space for movement. Therefore, prime mover sets are the most commonest equipment for quay transfer operation. An inbound container is brought in by vessel and loaded on prime mover by quay crane. An outbound container is loaded to prime mover set from container yard by rubber-tyred gantry crane (Zhang *et al.*, 2002). Prime mover set should be compatible to the ship operation and container yard operation to avoid interference among connection unit (Thomas *et al.*, 1994). To coordinate the interference among connection unit, Loke *et al.* (2004) studied the handling rate and move per hour of prime mover. It tries to concurrent the connection unit operation with ship and container yard operations.

Besides, a number of studies have been carried out and scientific methods have been proposed to solve the port development and expansion problems, namely UNCTAD (1985), Frankel (1987), Kendra (1997), Kader (1997), Thomas (1999), Niswari (2005), Mohd Zamani (2006), and Dekker *et al.* (2008). Most of the conventional models used the empirical approach to describe a container terminal development or expansion (UNCTAD, 1985 & Frankel, 1987). Thomas's model (1999) focused on a container handling system, Mohd Zamani's model (2006) modifies UNCTAD (1985), Frankel (1987) and Thomas's models (1999); while trying to overcome the lack of human approximation style by using linguistics' terms in conventional models. It considers the container port area, container freight station, berth-day requirement, ship cost at terminal, container handling system, and terminal other areas. Dekker model (2008) highlighted the lack of marginal cost in conventional models. His model is set to use marginal approach to control the optimal expansion between marginal investment costs and marginal benefits, but lack of control on individual expansion variables needs.

This study aims to modify from Dekker's model (2008) by using marginal approach to determine the significant of expansion of prime mover. Dekker's model (2008) related the expansion of total container terminal size in terms of TEU (Twenty Equivalent Unit) handling capability, but the details of the prime mover expansion is not considered. Therefore, this study tries to solve the shortcoming of previous study. The focus of the study is to create a generic marginal expansion model for prime mover in the existing container terminal.

Material and Methods

The data required is focused on operating and financial data. The operating data is used for determination of physical infrastructure purpose and the financial data is used for determination of commercial viability purpose. A case study is selected from container terminal to test run the model, the purpose of case study is to validate the practicable of model in real world scenario. Face to face interview section is selected as data collection method. Two sets of data collection form are created; namely operating data collection form and financial data collection form. The data collected is used to test run the algorithm model and the results are displayed in table forms.

The objective of this study is to improve Dekker & Verhaeghe (2008) idea by translating twenty-foot equivalent unit (TEU) as an expansion variable into a practical variable. Therefore, the expansion requirement of prime mover would be studied and analyzed. Then, the expansion plan is investigated; like expansion size, expansion cost, sustenance period, expansion period, and significant of expansion. All the factors were exploited and an algorithm model was generated.

The intermediate outputs of this research produced first expansion time, interval time, expansion size, expansion time, sustenance time, and significance of expansion. At the end of this research, a mathematical model for prime mover expansion by marginal approach is produced. The model was displayed in table form, the series of expansion and magnitude over a long term planning horizon.

Results and Discussion

Development of Preliminary Container Terminal Marginal Expansion Algorithm

This expansion model is based on the changes in demand for the prediction of future traffic. Prime mover expansion plan will be more accurate if the quantity and periods of sustenance could be identified so that expansion of prime mover is on the right magnitude and at an exact time.

Figure 1 showed the mapping of preliminary modeling evaluation, the forthcoming throughput demand needs to be determined before any expansion plan takes action. Once the future demand is identified, the current capacity of prime mover needs to match with future throughput demand. If the current capacity is bigger than future demand, then prime mover does not need to be expanded. However, if the current capacity is smaller than the forthcoming demand, subsequently, prime mover needs to be expanded.

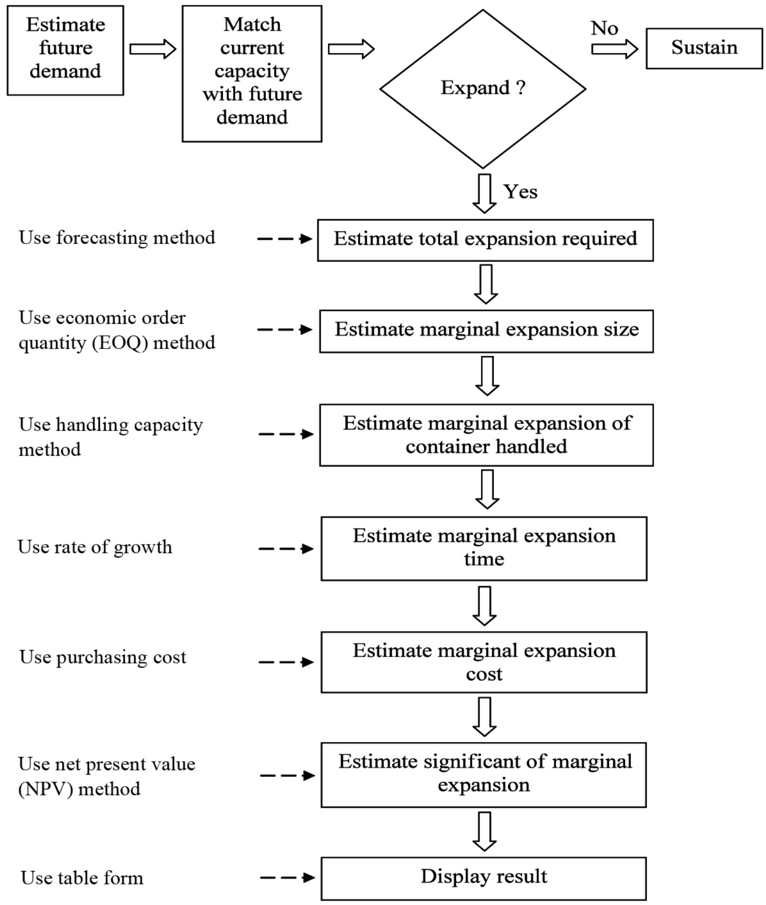

Figure 1: Preliminary modeling evaluation

The following paragraphs derive the algorithm for the calculation of Δpm, where Δpm is the sum of marginal expansion of equipments making up the quay transfer system that needs to be expanded.

Δpm is calculated as

$$\Delta pm = N_{pm} \text{ x } RM_{pm} \qquad \text{----- (1)}$$

Where N_{pm} represents the number of pm capacity requested and RM_{pm} represents dollar requirement per unit of pm.

N_{pm} is calculated as follow.

$$N_{pm} = pm_{future} - pm_{now} \qquad \text{----- (2)}$$

Where pm_{future} represents number of pm capacity request in the future and pm_{now} represents current pm supply.

Hence,

$$pm_{future} = \frac{\delta Q_{ct}}{MPH_{pm} \text{ x } 24 \text{ x } 365 \text{ x } ut} \qquad \text{----- (3)}$$

Where δQ_{ct} represents container throughput forecasting in time t, MPH_{pm} represents Move Per Hour (MPH) of pm, and ut represents maximum utilisation rate of equipment, which is 90% (Dekker & Verhaeghe, 2008).

δQ_{ct} is calculated as follow.

$$\delta Q_{ct} = \gamma_{ct} (\delta T_n) + \delta Q_{c0} \quad if\ 1 \le T_n \le T_t \qquad \text{----- (4)}$$

$$\delta Q_{ct} = \gamma_{ct} (\delta T_t) + \delta Q_{c0} \qquad \text{----- (5)}$$

Where γ_{ct} represents container capacity growth given by the gradient of plot of demand growths, T_n represents the number of year within planning time horizon, δT_t represents maximum planning time horizon, and δQ_{c0} represents initial quantity demand of container throughput. This equation is used to determine the forecasting of container throughput to TEU.

δT_t is calculated as below (Dekker, 2005).

$$\delta T_t = \delta T_{pth} \quad \text{----- (6)}$$

$$\delta T_{pth} = \delta IRP_t \quad \text{----- (7)}$$

δIRP_t represents investment recovery period.

δIRP_t is calculated as follows.

$$\delta IRP_t = \frac{P}{I} \quad \text{----- (8)}$$

Where P represents estimation of total principal investment over the planning time horizon and I represents estimation of total net income per power, δT_t from the new investment. Equation is used to determine the maximum planning time horizon for the new investment (Dekker, 2005).

Insert equation (8) into equation (5)

$$\delta Q_{ct} = \gamma_{ct}\left(\frac{P}{I}\right) + \delta Q_{c0} \quad \text{----- (9)}$$

Equation (9) is used to determine the estimated of total container throughput over the planning time horizon.

Inserting equation (9) into equation (3).

$$pm_{future} = \frac{\gamma_{ct}\left(\frac{P}{I}\right) + \delta Q_{c0}}{MPH_{pm} \times 24 \times 365 \times ut} \quad \text{----- (10)}$$

Inserting equation (10) into equation (2).

$$N_{pm} = \frac{\gamma_{ct}\left(\frac{P}{I}\right) + \delta Q_{c0}}{MPH_{pm} \times 24 \times 365 \times ut} - pm_{now} \quad \text{----- (11)}$$

This equation is used to determine the total marginal future expansion size of prime mover.

Inserting equation (11) into equation (1).

$$\delta pm = \left[\frac{\gamma_{ct}\left(\frac{P}{I}\right) + \delta Q_{c0}}{MPH_{pm} \times 24 \times 365 \times ut} - pm_{now}\right] \times RM_{pm} \quad \text{----- (12)}$$

This equation is used to determine the total future investment cost of the prime mover.

The total marginal expansion calculated for future will be divided into several marginal increments by EOQ. After the N_{pm} is determined, EOQ will be used to determine every single incremental of expansion needed.

$$\delta Q_{pm_{EOQ}} = \sqrt{\frac{2\,(N_{pm})s}{RM_{pm} \times R}} \quad \text{for } m \leq \delta Q_{pmEOQ} \leq nm \quad \text{----- (13)}$$

The δQ_{pmEOQ} is bigger than m and smaller than n, where m is the minimum purchase unit of prime mover and n is the multiple unit of m. Where m is the minimum purchasing unit or minimum construction unit and n is the number unit/duplicate of m. This equation is used to determine the marginal expansion of prime mover, with the condition of minimum purchasing unit or minimum construction unit. RM_{pm} as cost per unit prime mover, S represents the cost per setup, and R represents carrying costs in percentage of holding cost, 25% (Fawcett *et al.*, 2007).

After the δQ_{pmEOQ} is determined, the first total handling capacity for the marginal expansion of prime mover ($\delta Q_{pmi=1}$), the second total handling capacity of prime mover ($\delta Q_{pmi=2}$), and the thereafter expansion times ($\delta Q_{pmi=n}$) are calculated as below.

$$\delta Q_{pmi=1} = MPH_{pm} \times 24 \times 365 \times N_{pmi=1} \times ut \quad \text{---- (14)}$$

$$\delta Q_{pmi=2} = MPH_{pm} \times 24 \times 365 \times N_{pmi=2} \times ut \quad \text{---- (15)}$$

$$\delta Q_{pmi=n} = MPH_{pm} \times 24 \times 365 \times N_{pmi=n} \times ut \quad \text{---- (16)}$$

Where $\delta N_{pmi=n}$ is the total requested expansion of prime mover while $\delta Q_{pmi=n}$ is the marginal container throughput that handled by the current plus new expansion unit of pm.

After the $\delta Q_{pmi=n}$ is determined, the first expansion time for the marginal expansion of prime mover ($\delta T_{pmi=1}$), the second expansion time of prime mover ($\delta T_{pmi=2}$), and the thereafter expansion times ($\delta T_{pmi=n}$) are calculated as follow.

$$\delta T_{pmi=1} = \frac{\delta Q_{pmi=1} - \delta Q_{c0}}{\gamma_{ct}} \quad \text{----- (17)}$$

$$\delta T_{pmi=2} = \frac{\delta Q_{pmi=2} - \delta Q_{c0}}{\gamma_{ct}} \quad \text{----- (18)}$$

$$\delta T_{pmi=n} = \frac{\delta Q_{pmi=n} - \delta Q_{c0}}{\gamma_{ct}} \quad \text{----- (19)}$$

Formulas below are used to determine the marginal expansion cost, where $\delta\$pm_{i=n}$ is used to calculate the first, second and the next investment cost onward.

$$\delta\$pm_{i=n} = \delta\$_{pmi=n} \text{ x } RM_{pm} \quad \text{----- (20)}$$

After the $\delta\$pm_{i=n}$ is determined, the significant of expansion for each of the marginal expansion is calculated by NPV method. The formula of NPV is defined as below.

Hence,

$$\delta NPV_{pm} = -\delta Pi_{pm} + \frac{I_{pm}}{(1+r)^t} \quad \text{----- (21)}$$

Where NPV_{pm} represents NPV of pm, Pi_{pm} represents principle of investment for the particular expansion plan of pm, I_{pm} represents net income from that particular expansion of pm, r represents discount rate, and t represents number of year.

NPV decides on the concept of increment of extra output, where increase of input variables to support the extra output. e.g each expansion of expansion variable. Figure 2 showed the relationships between the input and output in time horizon.

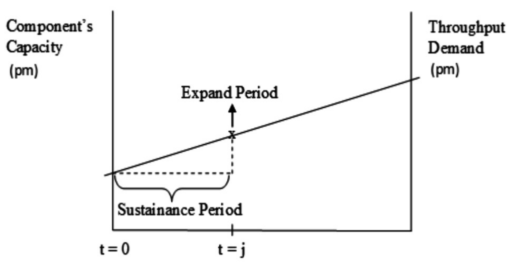

Figure 2: Relationships between input and output value of pm in the time horizon

The period of t = 0 to t = j is equal to period of sustenance, where the capacity of expansion variable is able to support the throughput demand.

In NPV concept, each unit of expansion input should produce economic cost of output. e.g. every dollar spent must be collected in term of port dues so that the investment is viable.

For δPi_{pmi} the value is the actual investment cost for the expansion carried out for the expansion variables for the particular expansion plan. For δI_{pmi}, the value is the actual investment return from the fact that the expansion variable is now enlarged.

Then, this part would estimate when t = j, the period that the expansion variable needs to be expanded.

Hence,

$$\delta I_{pmit=j} = \delta(D_{pmit=j} - C_{pmit=j}) \quad \text{---- (22)}$$

Where I represents net income for that particular expansion, D represents dues collected from that particular expansion, and C represents cost of the expanded part of the expansion variable (except the initial investment cost).

For the cost of the expansion, this part concerns more about the cost after initial principle investment.

$$\delta C_{pmi_{t=j}} = \sum_{t=j}^{T} (\delta OI_{pm} + \delta FP_{pm} + \delta OC_{pm} + \delta MC_{pm} + \delta MIT_{pm}) \quad \text{---- (23)}$$

Where OI represents operator's investment (e.g. training) spend in year t, FP represents fees (e.g. salary) paid by the operator in time t, OC represents operating costs in year t, MC represents maintenance costs in time t, and MIT represents mitigation (other costs) costs in time t.

δD_{pmt} is total dues (revenues, tariff, etc) collected after expansion of expansion variable.

Hence,

$$\delta D_{pmt} = \delta C_{ct} - M_{pm} \quad \text{---- (24)}$$

Insert (32) into (31),

$$\delta NPV_{pm} = -\delta Pi_{pm} + \sum \frac{\sum_{t=j}^{T}(\delta Q_{ct} \text{ x } M_{pm}) - \sum_{t=j}^{T}(\delta OI_{pm} + \delta FP_{pm} + \delta OC_{pm} + \delta MC_{pm} + \delta MIT_{pm})}{(1+r)^t} \quad \text{---- (25)}$$

Comparison with Dekker's Model

The comparison with Dekker's model aims to prove the marginal expansion plan produced by the current model is accurate in all-inclusive and per infrastructural component. Extensive comparison is done against outputs from Dekker's (2008) and current model, it is written highlighting again that both comparisons are in the investment recovery. Dekker (2008) model claims that investment recovery period of 11 years. Current model claims that investment recovery period of 14 years. Dekker's & Verhaeghe (2008) model is focued on the overall expansion of the entire terminal. However, current model is emphasized on the expansion needs of the particular infrastructure. The investment recovery period proposed by Dekker (2008) is lower than current model possibly because the other invest infrastructure that may create a quicker and higher rate of return and the current model is emphased on a particular infrastructure.

Model Robustness

Malaysian Port selected as a case study and data collected used to validate the algorithm model. Table 1 showed the input variables of the prime mover expansion model, and the output results displayed in Table 2 and 3. It derived the utilization rate at the plan horizon is 90% for the expansion variables. The maximum utilization rate is 90% (Dekker, 2008). This study used linear regression to determine forecasting demand. Thus, the incremental size for prime mover should be in a constant basis. However, due to the minimum purchase order quantity for prime mover based on unit size (minimum purchase order is 1 unit). Therefore, the expansion period for each expansion variable may plus minus 1 year in order to fulfill the minimum purchase order quantity. In order to check for the expansion sequent, it expands for 5 years from the current planning time horizon for the expansion.

Table 2 showed that the first expansion time for pm is in the year of 2025, which is the expansion year number 14. Thereafter, the expansion time for pm is on the year of 2027, 2029, and 2031, the expansion year number 16, 18, and 20. To prove for the interval time, the time planning extended 5 years thereafter (Table 3). It shows that the expansion time is in the year of 2032, 2034, and 2036, the expansion year number 21, 23, and 25. The interval period for the expansion is 1 to 2 years. This is because the expansion size is based on the unit of infrastructure purchase and is not based on TEU capacity. The expansion size of pm is 2 units for every purchasing time, and the interval size is 2 units of pm. The recovery period for expansion

Table 1: Input variables of the prime mover expansion model

Variable Input	Meaning of Variable	Used Value	Unit
γ_{ct}	Gradient from the plot of demand growths for container throughput	42,957.57	TEU/Year
FP_{pm}	Fees (e.g. salary) paid to operator in time t	4000	RM/Month
I	Estimation of total net income from the new investment	25,000,000	RM
M_{pm}	Tariff per service of container throughput	55	RM/TEU
MC_{pm}	Maintenance costs in time t	9	RM/TEU
MIT_{pm}	Mitigation (other costs) costs in time t (set to zero, Chan *et al.*, 2000)	0	RM
MPH_{pm}	Move Per Hour for prime mover	5	MPH
OC_{pm}	Operating costs in time t (included in FP; Chan *et al.*, 2000)	0	RM
OI_{pm}	Operator's invesment (e.g. training) spend in time t	30,000	RM/Person
P	Estimation of total principal investment cost over the palnning time horizon	500,000,000	RM
Pi_{pm}	Principal investment cost for that particular expension time	583,721	RM
pm_{now}	Current supply of prime mover	35	Unit
Q_{c0}	Initial quantity demand of container throughput	830,700	TEU
r	Discount rate	8	%
R	Holding costs as a percentage	25	%
RM_{pm}	Dollar requirement per unit of prime mover	583,721	RM
S	Cost per setup	50,000	RM
ut	Maximum utilisation rate of equipment (Dekker *et al.,* 2008)	90	%

Table 2: Illustrative example for the model application (pm)

i^{th} Expansion	Year	Expansion Size Unit	Utility Rate (%)	Investment Cost (MR$)	NPV (Year)
1	2012	-	90	-	-
2	2013	-	90	-	-
3	2014	-	90	-	-
4	2015	-	90	-	-
5	2016	-	90	-	-
6	2017	-	90	-	-
7	2018	-	90	-	-
8	2019	-	90	-	-
9	2020	-	90	-	-
10	2021	-	90	-	-
11	2022	-	90	-	-
12	2023	-	90	-	-
13	2024	-	90	-	-
14	2025	2	90	1,167,442	14
15	2026	-	90	-	-
16	2027	2	90	1,167,442	14
17	2028	-	90	-	-
18	2029	2	90	1,167,442	14
19	2030	-	90	-	-
20	2031	2	90	1,167,442	14
Total		8		4,669,768	56

Table 3: Illustrative example of the output validation (pm)

i^{th} Expansion	Year	Expansion Size Unit	Utility Rate (%)	Investment Cost (MR$)	NPV (Year)
21	2032	2	90	1,167,442	14
22	2033	-	90	-	-
23	2034	2	90	1,167,442	14
24	2035	-	90	-	-
25	2036	2	90	1,167,442	14
Total		6		3,502,326	42

is 14 years, and the expansion is significant for this particular expansion. The purchase of equipment is based on the unit, like prime mover. Therefore, the interval expansion time is plus minus 1 year basic. The interval expansion time for pm is every 2 years or 1 year.

The accurate of the output results advise the port planner for the actual expansion time and size, to be better control on the financial investment. The current model can overcome the shortage of the previous models which focused on the entire expansion, e.g. expanded the overall infrastructure of the terminal at the same time. It did not undertake the individual expansion needs.

Conclusion

The main objective of this research is to develop a prime mover expansion model based on marginal approach. The model is aimed at assisting container terminal planner in deciding the minimum economic expansion required for quay transfer system. The required salient features of the model's output are time for first expansion, interval time, subsequent expansion time, sustainable time, expansion size, and significant of expansion. The model needs to be accurate and practical for application in the real-world scenario. Therefore, the research has successfully developed an accurate and valid generic mathematical model to calculate the marginal expansion requirement for prime mover at the existing container terminal. It is useful for port planner to determine the future expansion needs without paying consultation fees to port consultant company. Furthermore, the expansion size, time and cost of prime mover can be predicted with more accurate and precise.

Container terminal has four key operation systems (Thomas *et al.,* 1994, Sauri & Martin 2011); namely ship operation, quay transfer operation, container yard operation, and receipt and delivery operation. The delay or shortage of any operation will affect the other operations and consequently delays the overall operations. Prime mover is a key equipment to serve for the quay transfer operation. Therefore, the sustainable expansion and sufficient supply of the prime mover is one of the important parts for supporting the container terminal operation.

Acknowledgements

With extend our sincere appreciation and indebtedness to Universiti Teknologi Malaysia (UTM) and their funder (vote No. 77205) for the guidance, support and encouragement. This study is part of PhD thesis. We would like to thank the reviewers of this paper for they helpful suggestion.

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