Operations Research (OR) at ports: An update

S. Islam[a] **and T.L. Olsen**[a]

[a]*Department of ISOM, University of Auckland, New Zealand*
Email: m.islam@auckland.ac.nz

Abstract: Decision makers today face the problem of exploring ways to increase port capacity. The determination to increase port capacity is influenced by continuous growth in the number of containers entering or departing the port, the constant increase in ship size, as well as by many other, previously unforeseen, factors. Therefore, particularly in recent years, in a time of economic recession, practitioners, as well as academics, have become interested in capacity management. In order to make further contributions to this maritime logistics domain, this paper explores and addresses the drawbacks in the typical sub-system based literature that is available in regard to the subject of port capacity (i.e., literature focusing on specific components of a seaport): this paper also examines studies that could potentially address, diversify and broaden the research pertaining to port capacity expansion. Therefore, the paper presents an extensive review of the Operations Research (OR) literature, including a trend analysis. The trend examination is based on: the year of publication of the literature reviewed, the component or dimension (e.g., problems pertaining to crane allocation) examined, the coverage area (e.g., single or multiple sections) of the port system studied and the specific research approaches (e.g., simulation or analytical) adopted in those studies.

Keywords: *Simulation, Operations Research (OR), container terminal, capacity management, port*

1. INTRODUCTION

The increase in the number of Operations Research (OR) publications from international journals, conferences and books (or book chapters) with a higher scientific value, than was previously the case, contributing to the field of maritime logistics and operations is vital in ensuring that optimization plays a major role in every aspect of port planning and management (Steenken et al., 2004). One of the manifestations of the trends that can be seen from the increasing number of publications is, for example, that the same studies further confirm that much of the existing literature focuses on the optimization of separate parts of an entire port, where a port is a major player in the transport chain to ensure product delivery from warehouses to final customers. However, the optimization of the port as a whole is important, especially for capacity management, which is a major focus of interest for practitioners, as well as for academics. Keeping the previously mentioned issues under consideration, this study discusses and investigates the problems arising when addressing the subject of port operations management from a perspective that covers recent trends and information relating to the past few years from the year 2000 to 2010.

2. PORT CONTAINERIZATION

A container is a standard box that, in the field of maritime logistics, is one of the most significant inventions for the facilitation of freight transportation. The invention was pioneered by entrepreneur Malcom McLean in 1956 (Cudahy, 2006). Now, many years later, containerization is widely accepted in seaports because of the many advantages it offers, such as a fast cargo handling facility (Abrasheva et al., 2012). However, the introduction of containerization has provided both opportunities and challenges to maritime logistics; these are mainly applicable to container terminals (Bandeira et al., 2009). The challenges arise because the advent of containerization has changed the requirements for the improvement of existing terminal facilities and these involve changes to both infrastructure and technology. For example, new container terminals have to be designed and built to accommodate berths and cranes to handle both the existing and future increases in numbers of containers (Rashidi and Tsang, 2013). Berths and cranes have to be suited to the provision of adequate service to PostPanamax ships that are larger and heavier than the ships previously serviced. In order to move containers from and to such ships, gigantic PostPanamax container cranes, costing about $8 million each, are necessary (World Bank, 2003). Such a huge amount of money causes container terminals to be sensitive to capital investment. Suitable cranes and berths are not the only requirements for container terminals; in addition, container terminals are required to invest in the appropriate straddle carriers, terminal operators, and trucks to shift the containers from their berthing facilities to the yard and from the yard to the gate. Following the importance of investment in infrastructural facilities to accommodate containerized freight, it is also important to offer all the facilities and services that are necessary to ease the process of the temporary storage of containers to expedite the import and export process. These are just a few examples of the minimal level of facilities that are required to enable the transportation of containers from one port to another due to the, world-wide introduction and acceptance of containerization in the seaports of the world.

3. THE CAPACITY SHORTAGE ISSUE

Capacity shortage is evident in many of the container terminals of the leading seaports (Paul and Maloni, 2010). Some of the primary reasons for this are, the continuing increase in the number of containers worldwide (David and Sichman, 2009) and, the increase in vessel size both in production and use (Stopford, 2009). Other reasons are: the exporting of Chinese-manufactured goods across regions; the tendency to move production facilities to the low-cost countries (Pallis and de Langen, 2010); and the impact of rising GDP levels on worldwide trade volume (Chin et al., 2009). All of these factors, individually and in combination, contribute to the capacity shortage problem and this has many consequences. For example, capacity shortage accelerates congestion in seaports and increases costs and delays for shipping lines, terminal operators, trucking companies and shippers (Park and Noh, 1987, David and Sichman, 2009). Secondly, due to the capacity shortage problem, large container ships can visit only a limited number of ports (Henesey et al., 2009). Thirdly, the capacity shortage issue increases the transport costs of specific port routes and thus other, less congested, ports become more attractive to users (such as exporters and importers) (Dekker, 2005).

In order to respond to the capacity shortage problem, seaports are being forced to build new terminals and additional facilities to add to their infrastructure. For example, according to the United Nations, in order to accommodate the anticipated growth in the number of containers, more than 700 new container berths will be required in East Asian ports between the years of 2007 and 2015 (UN and Korea Maritime Institute, 2007). The maritime transport industry is growing at a more rapid rate than are the seaports; this in turn does not allow seaport operators to build sufficient facilities to smooth the flow of freight transportation (Pallis and de Langen, 2010); this is because it takes many years (ranging from two to over 10) from the point of the making of a decision to change, to the completion of the infrastructure improvements that are necessary to increase capacity (Henesey, 2006). As many terminals already exceed capacity limits, there is a need for seaports to address the problems discussed.

4. OBJECTIVE OF THE STUDY

To summarize, the surveyed peer-reviewed papers employ traditional Operations Research (OR) methods to optimize single, multiple (more than one), or all, sections of container terminal operations in order to increase port efficiencies or to advance operations planning to gain improvement in contemporary port performance. Therefore, the comprehensive literature review of seaport studies aims to organize, categorise and to hierarchically present the existing and evolving body of knowledge of the operation research methods of the port operations that are applied in the making, or formulation of, a seaport's crucial, strategic, operational and tactical decisions. Using the literature to accomplish the two major research objectives, firstly: (1) This study's systematic survey provides an approach for both academics and practitioners to grasp and deliver many valuable insights and details at a glance; these facts are useful in optimizing and amplifying the capacity of a typical container terminal using operations research methods, which is one of the prime objectives of this literature survey. Secondly: (2) along with this specific research objective, another objective to be explored in further depth is to pinpoint the focus on the findings of the current research study. For example, this paper explores a number of facts and expresses the need for further system-wide capacity expansion studies (upcoming) involving terminal operations. Hence the research recommends further research on an integrated view (i.e., including all sections and subsections) of container terminal operations.

To facilitate the achievement of the objectives of this study, the distribution of the publications studied includes the time period of the years 2000-2010. Conference proceedings are excluded; peer reviewed journal papers, only, are included in the analysis. With the intention of making the classification of papers transparent to readers, each paper that has been included, in accordance with the categorization of areas of optimization, will be sent to interested readers on request. The collection of literature in this study consists of 243 journal papers.

5. LITERATURE REVIEW

As far as the authors are able to identify, few studies have been published to date that review the literature on the application of operations research methods to seaport operations. Only two papers were found that attempted to review the literature comprehensively, such as those of Steenken et al. (2004) and Stahlbock and Voß (2008). Steenken et al. (2004) reviewed a collection of references up to the year 2004 and their classification is well-accepted in the literature. Stahlbock and Voß's (2008) work is an extension of Steenken et al.'s (2004) paper, and provides a survey of the state of the art operations at a container terminal and classifies their optimization methods. In addition, other studies review part of the literature briefly, such as Vis and de Koster (2003). This paper concisely extends the existing literature by updating and reviewing the present papers up to 2010. Therefore, the insights expressed in developing and updating this study reflect an adaptation, integration and extension of the basic ideas of earlier literature reviews on container terminal operations and planning, including, but not limited to, Steenken et al. (2004) and Stahlbock and Voß (2008).

6. RIGOUR OF THE RESEARCH PROCESS

Every research methodology has its own unique features along with its limitations. The approach adopted in this study is a content analysis to ensure the objectivity of the research process. However, to overcome its limitations, one of the tests adopted (e.g., content validity) confirms the rigorous research process followed in this paper in order to maximize objectivity. Content validity states the representativeness of the intended contents explored from journals and other sources (Patrick et al., 2011). However, the content validity method applied in this study is mainly of a qualitative nature and is dependent on the judgement of the researchers (for more information on the content validity method, see A.Wynd et al., 2003). Given the categories for analysis (e.g., berth and crane allocation issues), content validity is considered high in this study; the study's findings and recommendations have been taken from journal articles relevant to the specific dimensions of a port. Moreover, since every journal has its own cited references, the references cited were checked and used as a secondary source in this study to be certain that any relevant reference had not been omitted. However, the cited references were not added to the additional references initially found. In order to preserve the rigour of the research process in this review using content analysis, the procedure followed by the researchers was taken as a sign of content validity. A similar approach was adopted by Seuring and Müller (2008) to ensure rigour of the qualitative research process in their literature review.

7. CONNECTED COMPONENTS OF A CONTAINER TERMINAL

A container distribution process is fundamentally facilitated and further shaped by a series of functionally distinct, yet highly interdependent, capacity-influencing components, which are conceptually, and in practice, influenced by many stakeholders of the port, such as the port authority itself, railway operators, terminal operators, road carriers, and shipping lines. Since the components that are physically connected in a port are inter-linked and utilise the same space, delay in any one component can affect overall system-wide capacity (Huang et al., 2008). For example, a seaport is a subsystem of the entire transport system of the supply chain, and the seaport itself consists of other subsystems (individuals, groups, and departments that interact with one another with non-linear connections) that determine the performance of the entire seaport (Cetin and Cerit, 2010). A common problem with such an inter-connected distribution system is that individual component owners, groups, or parties, are interested only in their own monetary or non-monetary welfare and have no interest in, or view of, the overall efficiency of the whole distribution system (Dowd and Leschine, 1990). For instance, if container terminal capacity is increased to process a certain number of containers in a short time, the increased efficiency will also require a boost in the capacity of other parts of the terminal. Hence the key value of this increased efficiency in any one bottleneck resource depends on, for example, the ability of the dedicated straddle carriers and internal trucks to handle the newly added volume. Thus, the real value of an increase in terminal efficiency depends on whether, or not, that increase influences the efficiency of the entire system or creates bottlenecks in other parts (Dowd and Leschine, 1990). Thus, considering all these issues together, the management of the entire port is a complex process (Beškovnik and Twrdy, 2010).

7.1 Distribution across Years and Journals

As shown in Figure 1, the number of publications has grown at an increasingly steady rate. An enormous increase in the number of publications can be seen as having occurred during the period of 2006 to 2010. Most were published in the OR *Spectrum* (29 Papers), *European Journal of Operational Research* (25 papers), and *Transportation Research Part E* (20 papers). Thus, the *OR Spectrum* now plays a more significant leading role in terms of number of publications per year. Hence, these three journals altogether capture almost 30% of papers published concerned with optimization methods used in seaports.

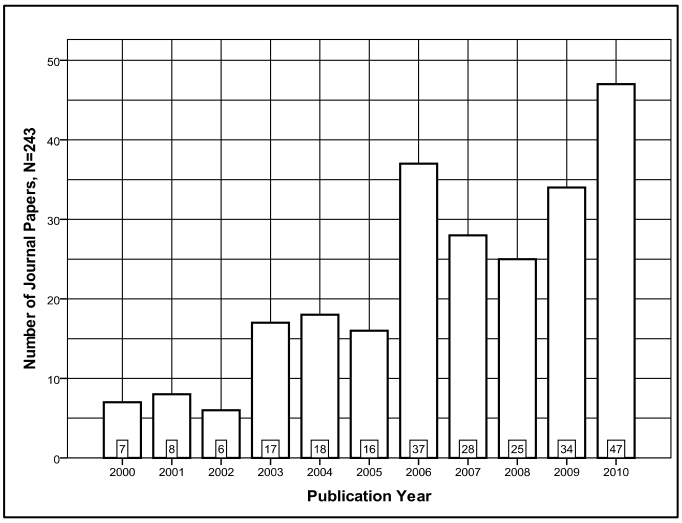

Figure 1. Distribution of Publications across Years

The rest of the papers published are widely spread among the following journal outlets: *Transportation Research Part B* (10 papers), *Engineering Optimization* (9 papers), *Computers and Industrial Engineering* (8 papers), *Computers and Operations Research* (8 papers), *Journal of Intelligent Manufacturing* (8 papers), *Maritime Economics and Logistics* (7 papers), *Naval Research Logistics* (7 papers), *System Engineering Theory and Practice* (6 papers), *Transportation Research Record* (6 papers), *Transportation Science* (6 papers), *International Journal of Production Economics* (5 papers) and *Transportation Research Part C* (3 papers). Publications are also distributed among other journals in smaller and varying proportions.

7.2 Applied Research Methodologies

During the evaluation of the identified studies, it becomes clear that the existing literature can be further subdivided into analytical, simulation, and combined approaches. The combined approach represents both the analytical and simulation approaches that are shown in Figure 2. The majority of the papers (212 out of 243, or 87%) adopted analytical approaches that exclusively apply optimization algorithms to optimize container terminal operations. However, in order to optimize the entire container terminal operations (Huang et al., 2008), the use of this approach to simultaneously deal with different types of problems, is difficult, although not impossible (especially in regard to stand-alone components). This is a major limitation of the widely used analytical approaches in traditional literature. On the other hand, in order to examine and investigate system-wide performance effects (Hamzawi, 1992), approaches using simulation that reproduce and capture the interactions between the connected subsystems of a seaport system, are also found in the literature in a number of papers (15 out of 243, or almost 6%). In this study, combined approaches represent the models that have been developed in order to study optimization problems in planning and in the management of seaport operations for an existing, or new, terminal layout with a fixed set of instruments within an artificially simulated setting; this is in order to test the performance of the optimization algorithms. Combined approaches also account for a small number of papers (almost 7%).

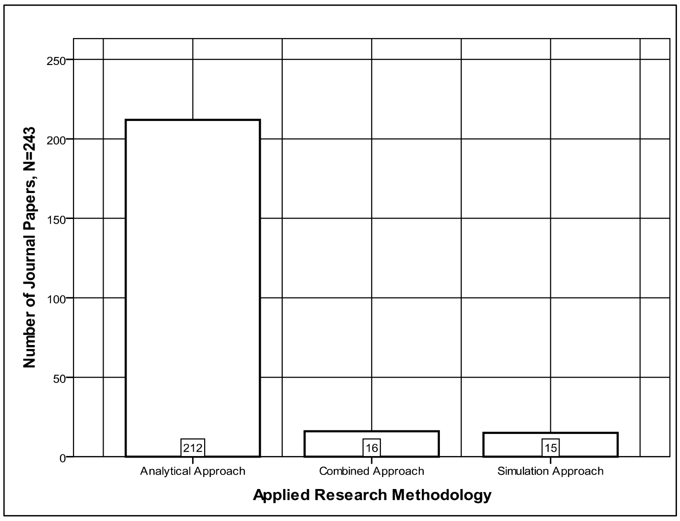

Figure 2. Applied Research Methodologies

7.3 Optimization Areas of a Container Terminal

As previously stated, the idea of the literature review is the objective of extracting additional capacity (capacity improvement possibilities) from the container terminal using operations research methods (i.e., simulation and optimization). Seven optimization areas have been identified and differentiated, these include issues relating to: (1) transport optimization; (2) berth allocation; (3) crane allocation; (4) storage space allocation; (5) empty container movement or repositioning; (6) integrated approach (simulation); (7) integrated approach (analytical). Figure 3 shows the assignment of papers to the areas of optimization

One of the main objectives of the solution for the issues relating to *berth allocation* is to minimize the total amount of ship to yard distance for all containers during the loading and unloading process (Karafa et al., 2013). The proposed solution for the issues relating to c*rane allocation* focuses on the distribution of cranes for the bays of a ship and the operating schedule of the bays (Liang et al., 2009); whereas, issues relating to *storage space allocation,* dictate which block and slot is to be selected for a container to be stored in the yard, thus minimizing reshuffling (Bazzazi et al., 2009). Transport optimization involves both quayside and landside optimization. *Quayside transport optimization* means the reduction of transportation time and the harmonization of the crane loading and unloading sequence of the quay with that of transportation (Rashidi and Tsang, 2013). *Landside transport optimization* pays attention to the selection and distribution, as well as pooling, of vehicles to each part of the operation in accordance with the anticipated workloads; it deals mainly with train and truck operations. The e*mpty container repositioning problem* is one of the most complex issues relating to global freight distribution, and requires the minimization of the inefficiencies in container operations, and, in particular, the repositioning of empty equipment to meet cargo demand (Song and Carter, 2009). Each of the acknowledged and described optimization issues relates to only one of the dimensions of container terminal operations and are the focus of the majority of the published papers (222 out of 243 papers or more than 91%) in the existing literature. A very small number of papers (21 out of 243, or almost 8%) that are concerned with the integrated optimization of container terminal logistics have been published to date. Those papers are based on the rationale that it is impossible to improve container terminal performance in isolation, requiring the integration of many components that are functionally interconnected with each other; and at least, pair-wise, functionally interconnected. These studies can be further classified into the approaches of integrated-simulation (mainly, computer modelling and simulation) and integrated-analytical (largely, mathematical modelling and optimization algorithms).

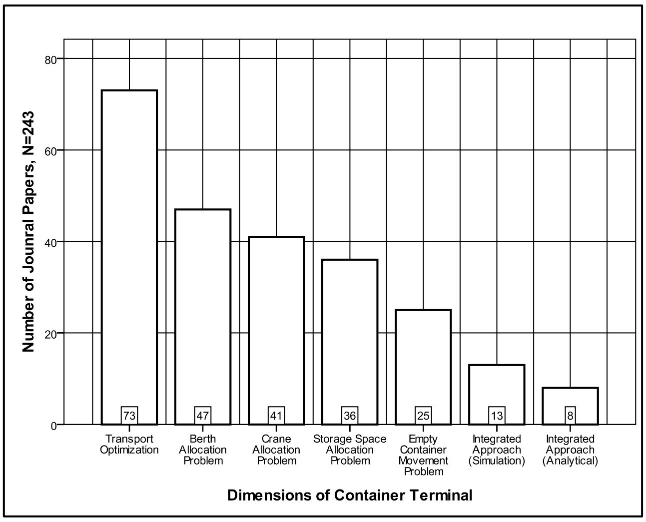

Figure 3. Optimization Areas of Container Terminal

The conventional way of solving such optimization problems is to divide the problem into smaller, but similar, sub-problems, using a, previously described, specified set of parameters; in which each decomposition stands for one specific and completely disconnected portion; this confirms the fact that integrated approaches (as shown in Figure 2) receive less consideration in seaport performance optimization and simulation (Stahlbock and Voß, 2008). However, depending on the implementation quality of the components in the process, a condition of the appropriate performance of a seaport is that each of its many subsystems should fit with the others since they are all functionally unified with the enhancement of performance management; the capacity shortage in one section will affect the service quality in other parts of the system. These "system-wide performance effects" can be properly investigated through simulation (Hamzawi, 1992). Hence, the next appropriate step should be the use of computer-based simulation modelling. Nonetheless, simulation modelling is given lower priority and less focus in the literature (as indicated in Figure 2); however, simulation modelling does need to be investigated in future research.

8. CONCLUSION

Within this rapidly changing maritime domain, operations research methods are used in the optimization processes that are put in place to improve the capacity of the various sections of a typical container terminal, in order to enable them to adapt sufficiently rapidly to keep pace with environmental change. This paper provides an overview of the problems that arise in the management of a container terminal and presents a comprehensive coverage and review of recent papers in the OR literature; the trend analysis being based on year of publication (e.g., from 2000 to 2010), coverage area (e.g., one dimensional versus the integration of dimensions), and approach (e.g., analytical versus simulated). The paper also identifies some critical issues that are consistent with the findings of earlier literature (for an example, see Stahlbock and Voß, 2008), concerning the urgent need for further research on the integrated approach using simulation procedures. The reason for this need is that (as shown in Figure 2) the majority of studies have adopted analytical methods for improving the capacity of a specific component of a container terminal; this leaves room for further research on the overall integration of the parts of a seaport. With respect to the consequences of capacity shortage issues, it is sufficient to draw the conclusion that simulation should be a frequently and widely used method in experiments designed to study the many types of capacity-related issues discussed above. The application of simulations to maritime logistics and transportation could involve any port component, or lead to almost any aspect of port planning, operation or management; this could, in turn, to a certain extent, effectively improve existing terminal capacity. Without the active assistance of simulation, the stochastic components that trigger the random process variations in port container operations cause system behaviours that are difficult to imitate, test and experiment with. The use of simulated models avoids risk or disturbance to real-life port processes; this is particularly the case in the high-volume container terminals of leading ports.

REFERENCES

A.Wynd, C., Schmidt, B. & Schaefer, M. A. 2003. Two quantitative approaches for estimating content validity. *Western Journal of Nursing Research,* 25**,** 508-518.

Abrasheva, G., Senk, D. & Häußling, R. 2012. Shipping containers for a sustainable habitat perspective. *Revue de Metallurgie. Cahiers D'Informations Techniques,* 109**,** 381-389.

Bandeira, D. L., Becker, J. L. & Borenstein, D. 2009. A DSS for integrated distribution of empty and full containers. *Decision Support Systems,* 47**,** 383-397.

Bazzazi, M., Safaei, N. & Javadian, N. 2009. A genetic algorithm to solve the storage space allocation problem in a container terminal. *Computers & Industrial Engineering,* 56**,** 44-52.

Beškovnik, B. & Twrdy, E. 2010. Planning organization and productivity simulation tool for maritime container terminals. *Transport,* 25**,** 293-299.

Cetin, K. C. & Cerit, A. G. 2010. Organizational effectiveness at seaports: A systems approach. *Maritime Policy and Management,* 37**,** 195-219.

Chin, H., Curlow, J., Löwik, L. & XU, S. Y. 2009. Global ports: trends and opportunities. Available: http://www.rreef.com/content/_media/Research_GlobalPorts-TrendsandOpportunities4-09_LR.pdf [Accessed 12 August, 2011].

Cudahy, B. J. 2006. The containership revolution: Malcom McLean's 1956 innovation goes global. *TR News***,** 5-9.

David, N. & Sichman, J. S. 2009. *Multi-agent-based simulation,* Berlin, Springer.

Dekker, S. 2005. *Port investment: towards an integrated planning of port capacity.* PhD Thesis, Netherlands TRAIL Research School.

Dowd, T. J. & Leschine, T. M. 1990. Container terminal productivity: a perspective. *Maritime Policy & Management,* 17**,** 107-112.

Hamzawi, S. G. 1992. Lack of airport capacity: exploration of alternative solutions. *Transportation Research Part A: Policy and Practice,* 26**,** 47-58.

Henesey, L., Davidsson, P. & Persson, J. A. 2009. Evaluation of automated guided vehicle systems for container terminals using multi agent based simulation. *In:* NUNO, D., JAIME, S. & O, S. (eds.) *Multi-Agent-Based Simulation IX.* Springer-Verlag.

Henesey, L. E. 2006. *Multi-agent systems for container terminal management.* PhD Doctoral Dissertation, Blekinge Institute of Technology.

Huang, S. Y., Hsu, J., Chen, C., Ye, R. & Nautiyal, S. 2008. Capacity analysis of container terminals using simulation techniques. *Int. J. Comput. Appl. Technol.,* 32**,** 246-253.

Karafa, J., Golias, M., Ivey, S., Saharidis, G. D. & Leonardos, N. 2013. The berth allocation problem with stochastic vessel handling times. *The International Journal of Advanced Manufacturing Technology,* 65**,** 473-484.

Liang, C., Huang, Y. & Yang, Y. 2009. A quay crane dynamic scheduling problem by hybrid evolutionary algorithm for berth allocation planning. *Computers and Industrial Engineering,* 56**,** 1021-1028.

Pallis, A. A. & de Langen, P. W. 2010. Seaports and the structural implications of the economic crisis. *Research in Transportation Economics,* 27**,** 10-18.

Park, C. S. & Noh, Y. D. 1987. An interactive port capacity expansion simulation model. *Engineering Costs and Production Economics,* 11**,** 109-124.

Patrick, D. L., Burke, L. B., Gwaltney, C. J., Leidy, N. K., Martin, M. L., Molsen, E. & Ring, L. 2011. Content Validity—Establishing and Reporting the Evidence in Newly Developed Patient-Reported Outcomes (PRO) Instruments for Medical Product Evaluation: ISPOR PRO Good Research Practices Task Force Report: Part 2—Assessing Respondent Understanding. *Value in Health,* 14**,** 978-988.

Paul, J. A. & Maloni, M. J. 2010. Modeling the effects of port disasters. *Maritime Economics and Logistics,* 12**,** 127-146.

Rashidi, H. & Tsang, E. P. K. 2013. Novel constraints satisfaction models for optimization problems in container terminals. *Applied Mathematical Modelling,* 37**,** 3601-3634.

Seuring, S. & Müller, M. 2008. From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production,* 16**,** 1699-1710.

Song, D.-P. & Carter, J. 2009. Empty container repositioning in liner shipping. *Maritime Policy & Management,* 36**,** 291-307.

Stahlbock, R. & Voß, S. 2008. Operations research at container terminals: A literature update. *OR Spectrum,* 30**,** 1-52.

Steenken, D., Voß, S. & Stahlbock, R. 2004. Container terminal operation and operations research - a classification and literature review. *OR Spectrum,* 26**,** 3-49.

Stopford, M. 2009. *Maritime economics,* Oxon, Routledge.

UN & Korea Maritime Institute. 2007. *Regional shipping and port development* [Online]. New York. Available: http://www.unescap.org/ttdw/Publications/TIS_pubs/pub_2484/pub_2484_fulltext.pdf [Accessed 02 February 2011].

Vis, I. F. A. & de Koster, R. 2003. Transshipment of containers at a container terminal: an overview. *European Journal of Operational Research,* 147**,** 1–16.

World Bank 2003. *The evolution of ports in a competitive world,* Washington, DC, World Bank.