A STUDY ON MODERN CONTAINER TERMINAL EFFICIENCY

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CERTIFICATE OF ORIGINALTY

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Abstract

This thesis focuses on terminal efficiency in the modern container shipping industry, addressing three principal research questions: 1) How is a modern container terminal's efficiency, as commonly represented by the annual throughput volume, determined in principle during the different planning and operations stages in a terminal? 2) What are the hidden influences on terminal efficiency performance and how can they be accounted for in possible berth allocation solutions when vessel schedules fluctuate severely? 3) What is the effect on terminal efficiency and the best berth allocation arrangement when additional vessels are added to the original vessel set?

In Chapter 2, four key determinants are proposed after a detailed literature review on the topic. The effect of each determinant on terminals is elaborated. Together forming a comprehensive efficiency development space, the four key determinants are integrated container terminal design, terminal information system, customer service strategy, and operations planning and execution. A clear understanding of terminal efficiency in terms of costs, time, and quality is offered.

In Chapter 3, the first hidden influence on efficiency is introduced. The concept of vessel workload waiting time is defined and modeled for an effective solution, called "vessel reberth arrangement," in the berth allocation process for the best operational performance. Exceptionally long vessel berthing periods are reduced and terminal operational efficiency is effectively increased using the proposed solution.

In Chapter 4, the second hidden influence on efficiency is introduced. The concept of additional vessel workload demand is defined and modeled for another permanent solution, called “spare vessel window management,” in the berth allocation process for the best operational and business performance. Additional vessel workload demand is reviewed, and how it can be served at the lowest operational cost and causing the highest business profit without adversely affecting regularly operated vessels is determined.

This study contributes to the literature on container terminal efficiency in several ways. First, it identifies the four key determinants that form the efficiency development space for all types of container terminals. The impact of an improvement in one area on the overall strategy can be measured using these four key determinants. Second, the vessel workload waiting time problem is solved using the proposed reberth modeling strategy without the requirement of additional capital resources or staff. Terminal efficiency is not only improved at the quayside but also in the storage areas and along container movement routes. Third, the additional vessel service request problem is solved using the proposed spare window modeling, again without the requirement of additional capital resources or staff. Increased business profit is ensured when the optimal vessel berthing arrangement is employed. Terminal efficiency is improved with high flexibility and reliability. In practical terms, this study can help different players in the terminal and shipping industry to obtain a better understanding of modern terminal efficiency and how it can be improved without extra investment in capital or human resources, resulting in higher resource utilization and business profit.

Keywords: terminal layout and design; information system; customer service strategy; operations planning and execution; time and cost efficiency; vessel reberth; unplanned vessels;

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CHAPTER 1 INTRODUCTION

1.1 The Terminal's Role in the Changing Shipping Market

Maritime transport is the backbone of international trade and the global economy, with dominating percentages of global trade conducted using ocean-going container vessels in terms of cargo volume and economic value respectively (UNCTAD, Review of Maritime Transport 2016 and Statistics). High cargo transport efficiency is expected by shippers and freight forwarders regardless of a shipment's origin and destination. Once a shipment has been sent to the loading port, it is expected to arrive at the port of discharge and then its final destination as planned.

In the past, shippers normally used the shipping services offered by one or a few liners on a prolonged basis. Vessels were smaller and carrying capacities were lower. During peak seasons from the early 1980s to the mid-1990s, shipping demand was usually higher than capacity for many east-to-west liner services. Shippers located in Asia had substantial competition and paid surcharges for international shipping services. At the busiest times, they even needed to search for empty containers and unused vessel capacity among liners. Because of the limited capacity supply, freight rates increased dramatically. Shippers were able to pay these high freight charges because of their high profit margins, which were a result of their desirable international trading activities and business deals at that time.

The global economic situation has changed since the late 1990s, and this has affected many countries, ports, terminals, and liners. Even though the economic situation worsened in some developed countries including the United States, the United Kingdom, and many other countries in the North America and Europe, vessel size and carrying capacity kept increasing with no end in sight. This vessel growth still continues, with vessels of size up to 18k twenty-foot equivalent units (TEU) being used in 2016 and 20k TEU in early 2017 (UNCTAD, Review of Maritime Transport 2017 and Statistics) . This not only exacerbates existing overcapacity problems, but places further pressure on container terminals that have limited berth length and yard facilities. Mega vessels were designed to be deployed as transshipment consolidators that cross the globe horizontally and berth at hub ports. If their full capacity is to be utilized, however, increased shipment volume is necessary at localized ports and terminals, which is still uncertain and unavailable in most exporting countries. Therefore, the resulting freight rates paid to liners by shippers, container lifting charges paid to container terminals by liners, and even intermodal service charges have remained flat and slow-moving in the past decade. Numerous global liners are expected to recover only slowly in the coming 5 years.

Although the business environment is not promising, shippers are provided with much more real-time and comprehensive shipment information through internet platforms while shipments are in transit and can notice any signs of shipment delay much earlier than previously. Shippers can determine the status of a shipment instantly. They have thus become more sensitive and critical of liners' services in terms of whether arrival or departure occurs at the published schedule date and time, and they often make inquiries or even complaints whenever a shipment is late passing a checkpoint. Shippers are highly responsive to vessel scheduling because any vessel delay increases the risk to the shipment in terms of decreasing cargo value.

The worst case scenario for shippers is the cancelation of business deals by buyers or consignees because shipments do not arrive according to the contractually agreed schedule between shippers and consignees. The final result of this scenario is an undesirable profit margin that is lower than was planned upon according to the international trades or business deals conducted. Therefore, it is natural for shippers to react strongly whenever their chosen merchant vessel fails to arrive at the published schedule date and time; such complaints were perhaps less common in the past only because information could not be accessed instantly, as it can now. To minimize further risk and loss, subsequent shipments sent by shippers, traders, or producers are split by shippers or placed in alternative liners using Internet systems or even cell phone applications. Decision could be made and implemented quickly with the advanced information technology applied in the industry.

1.2 Competition among Liners and its Impact on Terminals

From the liners' perspective, to effectively maintain a stable customer base and avoid loss of business, a liner must be competent at providing competitive and reliable shipping services if they are to be profitable in an era of overcapacity and in a highly competitive business environment. Liners must develop a diversified shipping network and ensure high service quality without receiving reports of service failure from important clients, shippers, and freight forwarders, who have numerous choices for liner service. When the shipping service quality of global liners is similar, competition becomes focused on shipping cost and thus freight charges among similar port pairs. Discounted freight rates are a critical selection criterion for many sizeable shippers and traders, and global liners have no way to provide such rates unless they substantially increase the size of their container vessels and share the voyage cost with companies that can provide more containers to carry. This explains the launch of very large container carriers since the start of the twenty-first century, which are effective ways to decrease the average transportation cost per container per voyage. This lower average transportation cost, however, is only possible if there is adequate shipping demand, and this demand has still been in the recovery stage in recent decades in many countries. Extra carrying capacity results in excessive supply and further affects freight rates undesirably; nonetheless, further reductions in shipping costs and freight rates are expected by shippers who have many choices of shipping service provider. Currently, liners must give even higher incentives to shippers, traders, producers, and also their serving freight forwarders through significant time and cost savings. Such incentives are offered by numerous liners with global shipping service networks that are keen to maintain a steady and stable customer base and thus avoid excessive capacity and financial problems in the near future. None of these companies wish to follow in the footsteps of Hanjin Shipping, which was declared bankrupt in late 2016.

Strong and long-term customer loyalty is currently a major objective for freight forwarder and liner businesses. To distinguish a company from its competitors, its incentives must be sufficiently attractive. Because merchant ship building already employs advanced engineering to enhance vessels, sailing time cannot be reduced substantially using current technology and fuel categories. Saving both time and money are difficult and prohibited by the large cost of fuel bunkers unless a significant reduction in cross-continental sailing speed can be achieved. Nevertheless, cost-saving initiatives, such as slow steaming, must be transparent to demanding shippers, who expect a low shipping cost with a fast transportation shipment cycle without a compromise in service quality. To achieve such transparency, liners must consider all possible time and cost-saving measures that can be made in each stage of the service process.

As passive and static service providers in the shipping industry, container terminals along shipping service loops are good targets for liners to reduce their costs because of such terminals' low bargaining power and large capital investment. Terminals are expected to contribute resources that increase the efficiency of vessel operations and support the slow steaming initiatives. They must search for all possible solutions if they are to support liners' increasing service requirements. Because port time represents only a small proportion of total voyage time, especially for intercontinental service loops, a small time saving at one terminal is not sufficient to affect costs, so the summation of savings at multiple terminals is required. Thus, all terminals are required to critically increase efficiency by liners. This explains why all terminals are eager to continuously improve efficiency to protect their businesses and vessels from losing to the neighboring competitor.

1.3 Terminal Efficiency Improvement: The Higher Expectations of Liners

Technically, in between ocean or trunk legs, container vessels exchange containers at container terminals for a short duration. Because there is little room for further cost reduction by decreasing sailing distances, liners look to lower costs by sailing at lower speeds. Therefore, vessels are expected to be served immediately once they arrive at a port, and vessel operations are expected to be completed quickly while the container volume that arrives late increases. Liners understand the difficulties faced by terminals, but they have no better way of achieving time and cost savings. Container terminals thus do not improve efficiency for marketing or promotional purposes; instead, they must maintain high efficiency and improve continuously if they are to survive the fierce competition because liners can switch to a different terminal or port by simply berthing their vessels elsewhere once their service agreements with the serving terminal are ended or expired. Liners could choose another terminal operator in the same port for a better performance on efficiency while terminal operator is relative passive in the contract negotiation and renewal processes.

Time efficiency is measured using the time at which a vessel arrives at port before it is actually berthed, and this is described through arrival latency. Liners put pressure on terminals to arrange the berthing of a vessel on its arrival, even if the vessel is significantly late or has arrived outside of its predefined schedule. Cost improvement plans focus on terminals as a means of lowering the overall voyage cost, despite terminal cost being a relatively small proportion of the total cost incurred. Time and cost savings at a particular terminal is not sufficient for satisfactory cost-saving performance for a particular service loop; all serving terminals must contribute concurrently. Error-free outcomes are expected as a basic quality standard without exception, with considerable cost and time improvements simultaneously expected. Any incident or accident results in decreased time and cost efficiency because complaints and claims are filed and processed by liners, which further incurs time and monetary costs during and after the vessel operation time period.

The accumulated time saved due to higher efficiency at terminals along a service loop is significant in the successful implementation of vessel slow steaming schemes, which are currently popular cost-saving methods in the liner community. Vessels sailing at lower speeds enable considerable bunker cost savings that are transparent to the liner’s end customers: shippers, freight forwarders, and consignees. Terminals are pushed progressively to achieve continuous time efficiency improvements while freight rates decrease and vessel sizes increase. Terminals must also offer even higher flexibility in their handling of ad hoc service requests with higher frequency; for example, many more containers arrive after predefined terminal cut-off times that would ensure good preparation of vessel operations, container dwell times are increasing considerably, and higher operational efficiency is expected for late vessels.

Although terminals are increasing their tolerance in many aspects, they do not necessarily have longer business contracts or service commitment periods with customers. Vessel carrying volume and calling frequency may change overnight because of the restructuring of vessel services. Terminals can experience a period of high vessel congestion and then find themselves in a serious deficit situation within only a few weeks. Their resource planning and utilization can become increasingly uncertain and challenging. To retain a stable customer base, the limit of a terminal's efficiency is constantly pushed up through short-term solutions, such as the employment of additional lifting equipment and transfer tractors, whereas long-term investment, such as implementing automation, is risky.

1.4 Effect of Liner Alliances on Terminal Efficiency Improvement

The critical restructuring of shipping alliances in the first quarter of 2017 indicated a clear change in port and terminal choice that also prohibits critical change. Liners may select terminals with lower costs at the same port or another port in the same region if connecting transportation routes are economic and reliable. Therefore, it has become highly uncertain whether long-term efficiency improvement projects in the terminal industry will break even within a given time period. This explains why short-term solutions are being used in many world-class terminals when higher efficiency is required without long-term and large-scale investment in landscape, infrastructure, and equipment. "What should be considered and implemented to improve efficiency?" is a common question for numerous terminal operators. To answer this question, a comprehensive understanding of modern container terminal efficiency is required. During this slow shipping demand recovery period, valuable insights into hidden problems and the formulation of effective efficiency upgrade solutions that do not require extra capital and human resource investment are also critical in the dynamic shipping market.

Traditionally, efficiency is known to be fast and smooth physical operations in container terminal frontline operations. For container terminal operations in particular, the speed of quay–deck operations—namely the lifting of containers to and from decks and vessels—is the most crucial factor in berthing the maximum number of ships in a certain period of time. The faster the quayside operation is, the shorter the stay of a particular container vessel and the more vessels can be berthed in a certain time period—1 week for example, which is a common cycle time for the weekly service of most container vessel schedules that are published worldwide. Quayside operations are supported by concurrent yard-side operations, which are further supported by advanced resource allocation and operations planning. Arranging the operation of more vessels is the business objective of all container terminals until they reach full capacity, after which further customer screening or expansion plans are triggered for long-term development.

1.5 New Concepts of Terminal Efficiency

The higher efficiency of terminals not only requires fast quay crane operation but also an overall process that delivers a better set of services at a lower unit cost and within a shorter vessel operation time. Time, cost, and quality performance are the three critical and traditional dimensions of efficiency, although a fourth dimension—environmental friendliness—has become popular in the past few years. A highly efficient container terminal attracts more business because of its favorable reputation for being reliable and operating on schedule. When a terminal is reliable, for example, a customer (liner) could promise its customer (a freight forwarder or big shipper) the target arrival time of one cargo batch upon the completion of on-time container vessel berthing and operations. Liners operate with a strategic partner or partners and form alliances for regular weekly service loops; containers from partners are loaded onto a particular liner vessel for a particular weekly service call. Therefore, the maintenance of a reliable service level is crucial to ensuring a container terminal's high reputation in the eyes of not just one liner but also that liner's strategic partner or partners. When service and operations are reliable, downstream supply chain operation is performed according to the logistical planning. The final customer or consignee receives the goods from a container as planned, which is always the ultimate objective of all container movement.

One classic example of high terminal efficiency is the Port of Singapore Authority, which is also known for its high reliability. Some growing ports, such as the Port of Shanghai, are supported by communal or government bodies in terms of land resources, infrastructure building, and even taxation; such ports are not regarded as efficient because they are still in the growth or development stage—their operational speed is not sufficiently high and reliable on a prolonged basis. A large number of manufacturers have established plants and factories in China in the past 30–40 years as a means of lowering production costs; Chinese ports, such as the Port of Shanghai, have thus nonetheless experienced tremendous and continuous growth. Such growth has been driven by the efficiency of supporting land resources rather than high terminal efficiency. Therefore, we can identify some critical questions: What is an efficient container terminal? How can a container terminal be made more efficient? What are the key factors governing or limiting a container terminal's potential to be efficient?

In this study on container terminal efficiency, critical determinants of container terminal efficiency were identified, and more importantly, the long-hidden factors influencing efficiency were investigated. Insightful solutions were provided. The critical four determinants are an integrated container terminal design, the container terminal’s information system, the container terminal’s customer service strategy, and the container terminal operations’ planning and execution. These four determinants have been sequentially or independently inspected in recent academic studies, and they reflect the fact that container terminal performance differs even when different terminals have a similar set of hardware resources, such as land and water depth. A parameter that can be used to classify the efficiency of container terminals is the quay crane performance index, named the gross crane rate (GCR). The higher the GCR, the faster the quayside operation is and the higher the efficiency of the container terminal. The hidden factors affecting efficiency are the vessel workload waiting time and the need to handle additional vessels on top of the fixed and expected number of vessels.

For a container terminal to become more efficient and make cost, time, and quality improvements, efforts must be made in the right operational area. In a complex terminal system, there are numerous parameters and some have a strong effect on efficiency, such as tractor and crane numbers. The more tractors, the longer are waiting times for crane service; more cranes are thus needed, or else efficiency is not improved but adversely affected. Due to the complex nature of a terminal system, obtaining a comprehensive picture of both business and operations is highly difficult. Numerous studies have investigated operations planning and execution only, such as yard and crane deployment, yard dimensions (length, height, and width), and how to optimize the use of a terminal’s internal tractors, which link the yard-side and quayside operations. These studies did not consider service agreements and strategies. An increasing amount of research has investigated integrated container terminal design, mostly triggered by the increasing size of vessels (e.g., mega vessels). The other two factors affecting terminal efficiency—information system quality and customer service strategy—are less popular research subjects as they are not easy to quantitatively review and analyze, other than using a case study or empirical analyses such as factor analysis, structural equation modeling, data envelopment analysis (DEA), or stochastic frontier analysis (SFA). However, they are of vital importance in the formation of a stable operating environment to achieve the target efficiency level and enable smooth vessel operation, as planned by the berth allocation team during the costing stage, well before the vessel's arrival. Without considering all four of the identified key determinants and some critical hidden factors affecting efficiency, a container terminal cannot be improved effectively. Terminal operation efficiency is always subject to some uncontrollable factors, such as adverse weather conditions or equipment breakdown, but the most influential factor is fluctuation in vessel schedule. We focus on problems related to this factor and propose a solution to the two hidden factors as a new strategy for tackling uncontrollable factors in the global industry.

CHAPTER 2 LITERATURE REVIEW

2.1 Terminal Performance Research

Given the fierce competition among terminal operators in the same port and also in the same regional area, numerous studies have been performed that have investigated container terminal efficiency. These studies have explored either the seaside, landside, or storage area of operations, and sometimes a mix of two of these (Carlo et al., 2015, Carlo et al., 2014). In the literature, terminals have been divided into different parts according to vessel operation by quay crane, yard operation by yard crane, and the use of connecting tractors throughout the terminal area (including both the quay and yard areas), and studies have made valuable contributions to readers' in-depth understanding of each area of interest. Nevertheless, a comprehensive literature review that has evaluated container terminal operations as a whole is currently missing, which is unsurprising given that the industry is complex by nature and continuous operation cost and service quality improvements are expected by senior terminal managers while the operation conditions of each cycle differ; this keeps experienced or senior-level managers from performing any comprehensive scholarly study. Through a critical review of the literature by the author of this thesis, who has more than 10 years of experience in the industry, most existing studies were discovered to investigate one of four problems. For example, the berth allocation problem is a critical problem and has been studied using different settings: discrete versus continuous berth lengths and the minimization of operation cost or maximization of profit. The problem has developed from considering only vessel arrival time to including additional considerations, such as quay crane quantity and nonspecific to specific quay crane assignment. These berth allocation studies are valuable that have high academic value in the area of interest, and they allow systematic research advancement in each area, whether for new or experienced researchers.

2.2 Assumption and Validity

Numerous assumptions are made in studies, either explicitly or non-explicitly, regarding various crucial business situations and operation conditions, and such assumptions are rarely realistic, such as those regarding terminal design specifications, customer service agreements, and information system design. Thus, the solutions proposed in these studies are optimal solutions only if the basic assumptions made are valid, which is generally not the case in real operations and planning processes. The overall situation comprises multiple dimensions instead of a single dimension such as cost minimization, which is achieved by the minimization of a weighted vessel's berthing time at the terminal. Cost is only minimized if the resource set is fully or nearly fully utilized; otherwise, it is always preferred by the berth allocation team to adjust the vessel berthing time period in order to cope with the available resource time period for a higher utilization rate of the terminal's input resources for vessel operation, such as the total number of work shifts for the equipment operators and transporter (internal tractor) drivers. Therefore, when the overall situation is not considered, the performance of the optimal solution proposed in a particular study in a particular area degrades unexpectedly when it is applied to a real situation in a real container terminal. Covering all possible business and operation situations or conditions in a study has always been difficult, however, especially when a model is formulated to present a problem. Assumption-making has been necessary, but the ultimate key efficiency determinants must be investigated as well. This explains the motivation for this literature review, which will be a crucial reference on container terminal efficiency, with the consideration of applicable individual studies.

2.3 Industrial Measures of Terminal Efficiency and Performance

Historically, efficiency has been perceived as fast lifting in container terminal quayside or seaside operations, which is represented by the productivity rate of the quay crane, namely the hourly gross crane rate (GCR). This GCR could vary from a lower boundary value about 20 to more than 30 in a modern container terminal. This means that a number of boxes is handled per hour, either discharge or load operations, or a mix of both types of movements. A quay crane may lift one, two, or even four containers at a time using current technology. However, critical to acquiring a stable GCR is the supporting facilities, equipment control, and equipment deployment rather than solely the crane functionality. The supporting infrastructure—such as the width of the quay deck on which transporters shuttle between the quay and yard zone areas, number of yard cranes supporting continuous vessel operation by the quay crane, and number of transport vehicles—is critical and must also be managed properly. Therefore, making advances in the use of one particular type of equipment, such as the quay crane, may not create the highest value or increase in productivity that is technically possible if the corresponding and supporting facilities and equipment are not properly set up and adjusted accordingly. The different equipment and facilities form an integrated system rather than standalone equipment operations. In particular, quay crane is the most important type of equipment in a container terminal as it serves the container vessel directly, and therefore, the two models considered in later chapters consider this type of equipment as key focus.

Smooth and continuous quayside operation does not happen by its own functionality but must be strongly supported by reliable and efficient yard-side operations. Advanced resource allocation and operations planning minimize the risk of decreases in productivity. However, a high GCR does not increase profits if its cost is higher than is acceptable. One unacceptable situation is if the container picking-up distance is so long that numerous tractors are needed to maintain a high GCR. This implies that productivity does not increase linearly with the size of the supporting backyard and that high productivity does not guarantee a high profit for terminals. If the cost of a terminal's high GCR is higher than that for a competitor of equal productivity, the accumulated extra cost will harm the terminal in the long term. Additionally, if the communication or decision-making process at a terminal is not well supported by a high-quality information system, adding more tractors may increase costs associated with real-time order dispatching, communication, waiting, or even idling. For a container terminal, high efficiency is the execution of a vessel operation plan at the minimum operational cost but maximum productivity within the defined time period, as agreed and confirmed with each vessel's operating agent or customer during the service agreement formulation stage. Thus, in a slack period when no vessels are waiting to berth and it is possible for a vessel to be operated at a lower GCR but also lower cost, such a plan is always agreed with the customer to the customer's and terminal's mutual benefit. Customers benefit from a longer stay in port because it allows more transshipment of cargo to be arranged, especially on mega vessels, which require high utilization to keep the unit cost of oceanic transportation low.

Because different operation situations arise during an operation, even in the same terminal and same planning cycle, the highest efficiency level may vary with cost regardless of the constancy of the underlying and fundamental principles. This implies that for some shifts or vessels, maximum effort may be required to ensure the shortest vessel berthing period whereas for other shifts or vessels with lower priority or berthing periods that are not under pressure by other scheduled vessels, operating at maximum productivity may not be wise; cost efficiency should also be taken into high consideration. Container terminal efficiency is governed by various factors and result in different impact level, in particular, four key factors are concluded as the most crucial ones: container terminal design, information system design and technology, customer service strategy, and container terminal operations planning and execution. In particular, customer service strategy defines the highest efficiency level that the operations team should achieve instead of attempting to always and blindly maximize the productivity. The four components form a strong basis for a container terminal with high operational and cost efficiency. The principles of each component are summarized as follows:

- Container terminal design: suitable size, shape, yard–quay orientation, set of equipment, and buffer space;
- Information system design and technology: suitable level of automation, operation rule setting, matching of decision-making to system user seniority, level of wireless communication, and level of response or by-pass mechanism.
- Customer service strategy: suitable level of operation efficiency, mixture of customer demand patterns, priority setting, terminal penalties and customer surcharges, and sizes of client vessels with or without an overbooking strategy;
- Operations planning and execution: suitable input of resources over a definite planning period, prioritization of customer demands, feedback actions, and response or reaction in terms of the revised resource input in the execution process.

If a terminal's internal layout and traffic flow is not properly designed, prolonged traffic distances due to irregular shape or layout design or caused by too many traffic junctions shall cause efficiency problems regardless of if a larger area and larger buffer area are used in peak periods. These problems are not easily overcome after a terminal has been constructed, unless extra infrastructural or civil work can be performed. Efficiency is realistically limited to certain level that is lower than its optimal level. Little research has been performed that has simultaneously investigated the shape, size, and layout of terminals. For example, the design of a multiple-berths container terminal may not replicate a single-berth terminal design. The optimal size and shape of terminals with different numbers of berths is generally given little attention by researchers, and its effect on process efficiency has not been explored. The lack of research on the design of terminal expansions further indicates a strong need to conduct comprehensive research on these topics. Although the expansion or relocation of a port is expensive, short-term projects aiming to change the internal layout of terminals are also costly. Numerous famous and large ports took more than 20 to 30 years to build, and extra handling capacity and berthing for longer vessels have been crucial to terminals in their attempts to accommodate new vessel carrying volumes and length expansions.

A terminal handles a large volume of containers daily. Timely retrieval of accurate and error-free container information from the terminal's system database is a basic requirement of the terminal's operating system. Manual intervention must be minimal when interacting with system to minimize operational cost. This applies to both direct system user's time and the user's controlling tractor or lifting equipment in the outdoor terminal environment. Standard rules save time by mitigating repeated decision-making and allow operations to focus on monitoring of overall efficiency. Smooth operations require system support at all times. Tracking the status of huge numbers of containers—such as their real-time yard block, in-transit or quay deck location, shipping information, and movement status—requires reliable system functions that are designed to optimize operational efficiency. Most of the existing studies have been performed on particular data elements found in terminal information systems whereas the actual decision-making process has not been investigated. Other than studies on the data elements found in different terminal information systems and their impact on the perceived level of system efficiency by system users or customers, a tremendous number of studies have explored a particular aspect of the complex terminal operating system; berth allocation as a standalone problem, for example. The corresponding support processes, such as ship planning, yard planning, and the production operations required to adjust and improve—as reflected in terminal system design—are not addressed comprehensively. These processes are nonetheless an essential but missing part of the successful solution implementation for a terminal operation system.

Regarding customer service strategy, relative few studies have been conducted because of the complex and confidential nature of customer services. An over-simplified approach has usually been employed, such as the vessel first-come-first-serve (FCFS) approach that is regardless to the pre-agreed long term schedule or berthing priority defined by vessel size. In the latter case, a smaller vessel may be served with lower priority even it arrives earlier than a bigger one. This is not fair but terminal operator must consider more than the natural arrival sequence. Consideration includes the resources utilization rate and impact to other upcoming or operating vessels. For example, the bigger vessel may carry a larger amount of transshipment containers which are required to be transferred to other vessels with a tighter time windows for the larger volume. Therefore, the small vessel may be prioritized later for need to avoid other operational problems, include short-shipping. Productivity or efficiency has also been focused on in some studies, but such empirical studies have usually used surveys of only container terminal managers or leaders. The mixture and nature of individual customers in terminals has rarely been investigated, nor have studies on the competitive pro forma blueprint of all subsequent business operations and operation process efficiency. During a slack customer demand period, the operation policy of a responsive terminal may be substantially different than that during a period of excessive demand. For the large amount of studies that have used surveys for result collection and analysis, pinpointing and investigating terminal-specific characteristics and challenges were difficult, with only a comparison of general or common customer-service-related parameters possible. Therefore, the conclusions of such studies may be too general and affected by hidden assumptions taken by interviewees, not presenting a full picture for analysis and resulting in over conservative hypothesis testing results or biased conclusions.

A tremendous number of studies have investigated specific operations and planning tasks, but the given design specifications was always assumed to be negligible. Mathematical models have been proposed without addressing the terminal’s characteristics.. Input parameters were normally taken as self-explanatory and assumed to be constant. For example, the number of vessels in the berth allocation problem has been allowed to vary, whereas the different levels of effort behind ship planning and yard planning have usually been assumed to be constant and unimportant. Different choices of berthing arrangement, including berthing section and sequence, incur different downstream arrangement costs. To minimize overall operation cost instead of berth allocation penalty cost only, a larger scope of consideration must include the current container distribution in the terminal area. For example, the implementation of a given optimal berth allocation arrangement that minimizes berthing-specific operation cost may lead to the higher costs of other processes and result in an even higher total operation cost. The cost contribution of a particular problem to the overall terminal operation cost has not usually been addressed, and nor has the extra cost incurred by a proposed solution. Additionally, discussion on the most favorable operation conditions in a terminal has not been considered important.

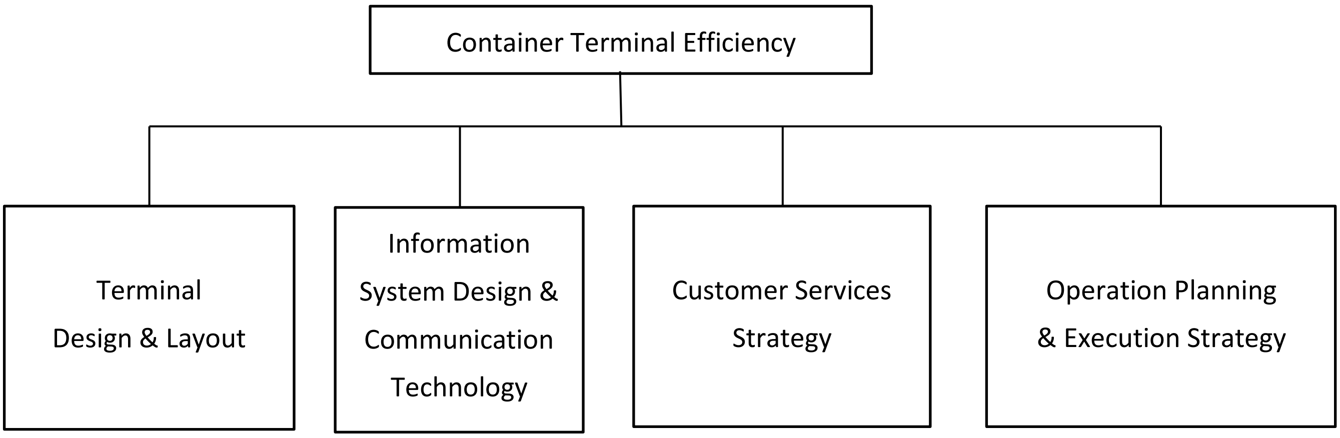


Figure 2.1 Key factors governing container terminal efficiency.

2.4 Practical Terminal Operations

Because operating duties are performed by different sub-teams—berth allocation, yard planning, ship stowage planning, crane deployment, and gang utilization sub-teams—the operations of a standard international container terminal for ocean-going marine vessels are briefly introduced herein for better understanding of the four key determinants of terminal efficiency and why they are representative and important.

Terminal design in terms of size and shape is critical to achieving the highest possible efficiency. It limits the routes via which internal equipment and tractors can move around the internal layout, which is dominated by the yard block and berth line. Once the master design of a terminal is confirmed, the actual storage capacity and required equipment can be determined according to the target annual throughput volume (expressed in TEU). Having a clear target, the terminal searches for customers or liners with the required service demand and volume. Different terminal layout designs are found worldwide that suit different operational needs, but they are mainly classified into only a few groups. A good design is critical to establishing a safe and stable operating environment and, most importantly, achieving the target operating rate and performance. Terminal daily performances should not fluctuate or else the terminal’s credibility is affected. Once the reliability of a container terminal is in doubt, the terminal may not be selected by customers (liners) when they review terminals’ service performance after a service loop, which links multiple terminals for regular services.

If a terminal always delays vessel operations and fails to fulfil the required operating rate, causing delay to a vessel on unberthing or departure, the vessel must navigate faster than planned by the customer to meet the schedule, which incurs a higher bunker cost. Bunker cost is expensive and its increase always avoided unless absolutely necessary. To meet the schedule, other terminals further along the same service loop may be required to operate faster and also offer an earlier time window once the vessel has arrived at the coast, which may not be easy or indeed possible for the terminals to arrange, given that they are most likely serving multiple customers whose time windows are already planned. Bad news can spread among liners in alliances and other partners are notified immediately because they may have containers on the delayed container vessel.

When these things occur, the poor performance of the terminal suggests that it is inefficient, not modern, and completely unreliable. The terminal may be removed from the service loop and replaced by another terminal the original terminal’s competitor) at the same port. Losing a liner is critical for all terminals because it is not only the loss of one particular customer or vessel, but rather the loss of a group of vessels operated by the same liner. If the liner is part of an alliance, the situation could worsen further if the other partners are also affected by the termination decision.

Before a liner makes such a serious decision, it sometimes starts to arrange more empty containers at the terminal in the hope of avoiding the delay of cargo-carrying boxes. The more empty boxes are in storage and operation, the more likely that the terminal is laden with slow-moving boxes instead of cargo-carrying boxes that are turned around quickly, regardless of whether they are purely inbound/outbound or transshipment containers. In turn, this increases the container terminal’s yard density beyond its normal level, which also affects the overall operating conditions for all other customer vessels. All container terminal staff thus know the importance of on-time vessel departure by all means necessary to keep operations flowing normally and business coming.

If a terminal is badly designed such that traffic flow is always congested during vessel operations, not only might the port stay of a vessel not be controlled and delays easily occur, the operating cost and even safety level of the terminal will be unfavorable. If an accident occurs, partial or even total terminal operations could be suspended for a few hours or even a few days for serious accidents, which causes sizeable business loss due to the serious and unexpected delay of berthed vessels and incoming vessels or even the loss of operating vessels due to a decision by the ship operating agent (SOA) to omit the port. Therefore, good terminal layout design is critical but also must be coupled with a well-designed operation strategy and traffic flow, which occasionally change in the transitions between peak and low seasons or because of an alteration of customer configuration. Because the shape of a terminal layout is fixed and not easily changed, ongoing review of the operation strategy is required to ensure constant favorable utilization of the berth line, yard shape, and terminal layout and an arrangement that suits the current and upcoming business operation needs.

The information system in a container terminal is usually regarded as the operating system that enables all operating teams to access one common and real-time database for all needed real-time operating processes and advance planning processes. For example, berth allocation and ship planning are planning processes that must be completed before a vessel’s arrival. A ship planner must plan the container loading procedure—how containers will be loaded from the container yard to the vessel—before the vessel arrives and before all containers are placed in the yard. They must also consider the discharging workload of the container vessel because the container discharging and loading processes always differ; namely, will discharge proceed bay by bay (partition or room from container to a location inside a container vessel) or not. For example, one quay crane may be discharging boxes from a particular vessel bay while another quay crane or cranes may have started loading boxes into other bays. Therefore, ship planners must ensure that the loading process offers sufficient flexibility to the control tower staff who direct the actual operation by coordinating the operators of the quay cranes, yard cranes, signal men, and labor on the operating vessel via a wireless communication channel, normally walkie-talkies with a particular channel frequency allocated to the operating vessel. For a small container terminal, multiple channel frequencies are sometimes unavailable.

During the berth allocation process, the terminal team must receive the most up-to-date cargo information for an incoming vessel via electronic data interchange, the customer’s (liner’s) information system, or sometimes directly from the last departure port. Performing cross checks is crucial until the vessel has departed from the last port on the route before it will reach the terminal, at which point the containers loaded are confirmed and no more changes are possible. After receiving the final confirmed container information and the actual number of containers that will be discharged and loaded, the estimated port stay is calculated using all the available resources reviewed including the possible quay time window, equipment and labor availability, yard density and remaining capacity, and possible connections for onward travel, including hot connections of discharged or reloaded (transshipment) containers to/from other berthed vessels at the same or nearby terminals.

Minor amendments may be sent from the liner to terminals but normally these are not critical and do not affect the already-defined port stay, unless they involve special cargo such as a yacht that requires loading or discharging; in such a situation, berth allocation may be adjusted to minimize the risk of unexpected damage and subsequent compensation claims through minimizing the length of stay of the expensive cargo.

Next, the ship planning team facilitates the required hot connections by arranging the proper location into which containers should be loaded in a timely manner to avoid a last-minute rush. In the case of too-early arrival of boxes requiring reloading, the boxes are normally placed back in the container yard or temporarily stowed on the quay deck, if and only if the quay deck is not busy and extra space is available without affecting the traffic flow to and from the container yard stack area (where the yard crane runs and serves the terminal's internal tractors) and to the quay deck (where the quay cranes runs and serves the terminal's internal tractors and berthed vessels). The information system is critical in tracing all boxes' real-time locations during operation hours, and it allows the yard planning team and control tower (vessel operating team) to plan and execute the actual physical movements of boxes to and from the yard stack storage area and vessel stowage location or those that are being released to other terminal locations or pickup customers.

Without an efficient information system, a terminal could not operate even one vessel and would face substantial difficulty in tracing the location and status of a large number of containers. Most of the research that discusses information systems in container terminals has focused on improving the logic of berth allocation; the optimization or improvement of ship planning sequence and arrangement, yard storage strategy and improvement, and actual vessel operation program setup and improvement have been less investigated. Additionally, few studies have reviewed the ergonomic aspect of the user interface design used by operations office staff or the handheld terminals used by ground staff despite the operating system being used intensively by control tower staff every minute. Communication between yard planning or control tower staff (who use computers) and ground staff is normally by walkie-talkie as previously mentioned and wireless handheld terminals (used by ground staff to update container location status as loaded or discharged to or from the berthed vessel); little research has been conducted in this area, despite the possibility of establishing unique identification IDs for containers to avoid the manual input of container status, which occasionally results in human error. The internal tractors are normally equipped with a computer that is also linked to the information system wirelessly; such computers are named “Wi-Fi pagers” and allow drivers to receive work order information include location, pick or drop action at the target location, and unique container numbers. The information is normally also displayed on the tractor window for the information of staff coordinating tractor arrival and container loading sequence.

Again, relatively little research has been performed in this area regarding how to improve operation efficiency, for example, on the possibility of linking up work order information with layout routing to guide the driver to select the optimal route within the terminal yard area, which can be large and congested during peak hours. Currently, in terminals with non-automated guided vehicles, it is up to drivers to select the best route, which is not possible without a bird’s eye view. Control tower staff, who have an overall view via the real-time update system and work order display (normally named the “queue” for particular containers to be discharged and put inside the yard or retrieved from the yard stack and loaded onto a vessel), must therefore assist the driver to avoid the traffic, which may comprise external tractors during peak hours, and they thus are paying less attention to the vessel operations quay deck area, which is unfavorable.

Customer service strategy is omitted in most studies because of its complex and confidential nature; otherwise, it is included in an oversimplified manner, such as in consideration of vessel on-time berthing strategy or berth allocation priorities in terms of high utilization of the berth line and berthing resources only. Conversely, numerous studies have been performed on operations planning based on either the quayside or yard-side or both; however, they normally make various impractical assumptions, for example, that vessel arrival sequences or port stays are predetermined, without any possibility of delay, or that there is no connection between berthing vessels within a predetermined period of time.

Therefore, the final outcome—namely the production efficiency—is not normally calculated based on these sequential factors, but rather using numerical approaches such as surveys and applies various statistical tools (such as DEA and SFA) to draw conclusions based on the survey results. We strongly believe that this is not a rounded approach that will yield favorable decision models that can be used to establish a good customer configuration and customer pro forma (long-term berth window) arrangement. Instead, we wish to construct a tactical optimization model that can be employed in further systematic research in the future.

2.5 Terminal Efficiency Research: Specific Focuses versus General Reviews

A terminal’s design, information system, customer service strategy, operations planning, and production efficiency collectively and simultaneously perform operations by considering efficiency opportunities and the cost of inefficiency. Efficiency optimization problems are focused either on the container terminal design level only as a strategic level when a new terminal design is required or an existing facility is being upgraded and the customer capability and characteristics are well defined, or they are heavily elaborated in terms of operations planning optimization problems. Such optimization problems mainly have an objective function defined by the quay crane or yard crane operation rate or both, with internal tractors or yard trailers used to link the two different equipment serving points. Customer service strategy is not commonly investigated in studies because of its high specificity and confidential nature. Different strategies may result in different revenue configurations and future roadmaps.

More than 132 operational terminal efficiency–focused references from the previous 20 years were reviewed, followed by a review of wider scope that searched for relevant port and maritime references in the journal *Maritime Policy and Management*. This journal has published international shipping and port research since 1972. By searching through the 40 articles with the most citations, in addition to the latest set of 12 relevant references (up to 2016) in the same journal, a much broader perspective on terminal efficiency was obtained, analyzed, and summarized. A comprehensive overview of terminal efficiency in the past, present, and future is provided herein. It is hoped that a clear overview is presented to readers that includes 88 key papers.

2.6 Terminal Design & Layout

Natural Landscapes and Artificial Islands

Studies on the shape of a container terminal that optimizes terminal efficiency and performance were not found, despite terminal shape being the fundamental element in terminal design. The surrounding landscape constrains the size, berths, and vehicular flow of a terminal. Previously, undeveloped construction skills limited the building of artificial islands and thus coastal building was common, which resulted in short continuous berth lengths. Artificial islands have enabled the extension of terminals from the coast and have resulted in longer berth lengths, deeper water drafts, and higher flexibility in the different sizes of vessel that can be accommodated, but also potentially longer traveling distances for transfer tractors. A terminal with four continuous berth sections, which is common in numerous modern terminals, is displayed in Figure 2.2(a).

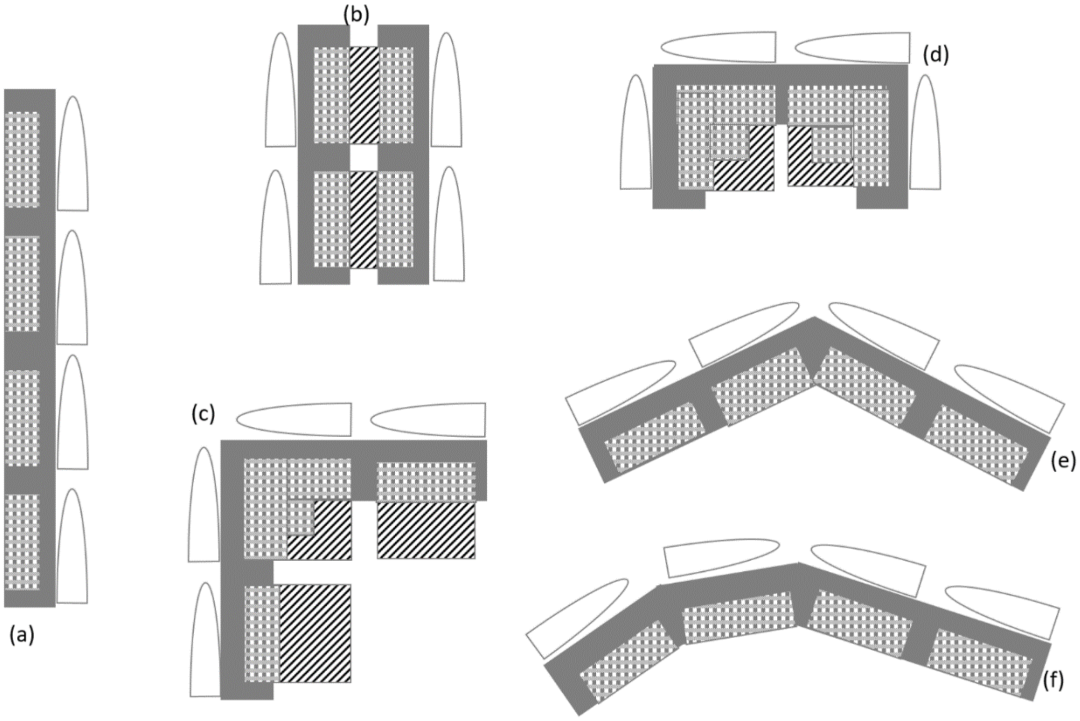


Figure 2.2 Different designs and layouts for a four-berth terminal.

Different Backyard Design

Other possible terminal designs are presented in Figure 2.2(b)–(f) that have different backyard designs, which affect vehicular flow and efficiency. Backyard design critically limits the level of equipment automation. Tractor flow and traffic junctions between yard and quay areas are the primary consideration when yard block orientation was considered by Taner et al. (2014). The authors explain that terminals with different shapes perform differently. Feeder terminals of different shapes perform differently with different combinations of transporter dispatch rules (transporter means an internal tractor, which transports containers between quay and yard cranes), and selecting the optimal shape can result in significant efficiency gain and cost saving in terms of the required number of active automated guided vehicles (AGVs). Despite artificial islands mainly being built for feeder operations (which connect to ocean-going marine vessels), they clearly show that terminal design is an influential factor affecting terminal operation efficiency. Customized dispatch rules for tractors are required to achieve the best performance in each case. Simulation models are developed in this paper that enable container terminals to examine the effect of transporter dispatch rules and resource allocation strategies on efficiency in terms of the total annual handling cost. The results obtained using the model show that the efficiency of a given layout is strongly related to the actual transporting vehicle dispatch rules and container box allocation strategies. The essential yard block layouts—P, L, p, or W formats—are clearly explained and also applicable to ocean terminals. Operations efficiency improvement is also discussed for each type of yard block orientation: parallel or perpendicular or a combination of both.

Indented and Channel Berth Lines

A substantial area is required for yard storage and operations for ocean-going vessels. The layout of the hinterland behind main berths is studied. Terminals are becoming much larger to accommodate vessels of increasing length and capacity (Imai et al., 2007, 2013); therefore, a substantial area is also required for yard storage as the hinterland behind main berths. Regarding berth line design, indented and channel shapes are investigated and compared with the conventional terminal design and which is best for handling mega vessels (more than 10,000 TEU) is determined. In the conventional berth design, a vessel is served on its port or starboard side only, but not both. New designs offer crane services on both sides of mega vessels to significantly increase or double crane productivity (Imai et al., 2013). The corresponding orientation of container yard blocks are denoted as P- or L-shaped, a new design for the optimal operational performance. However, no further study is carried out on the required yard planning strategy that optimize the terminal performance.

Although much higher lifting volumes are assumed to be needed by mega vessels, no consideration is given to the choice of crane working side and number during slack seasons. In reality, it can be assumed that mega vessels will not be used when lifting volume is not sufficiently high and justified for deploying a mega vessel, which has a higher bunker cost than smaller vessels. Mega vessels occasionally may be phased out and replaced with smaller vessels by liners. When smaller vessels are swapped in, neither the indented nor channel design may be appropriate to serve these vessels from both sides, due to the smaller vessel being narrower. Crane operation will take place at one side of the vessel only, leaving the crane at the other side undesirably idle. To operate cranes at both sides concurrently, the cranes might be applied to the much smaller connecting feeders only, which can berth concurrently at each side of the channel. This results in a low crane and resource utilization problem. This may be the key reason why these proposed new designs have not been implemented.

According to the perspective of terminal management, handling both mega- and mid-size vessels is important, and the ratio may vary greatly during the global shipping demand and international trade life cycle. Therefore, terminals are not willing to take the risk and invest heavily in a specific design for improved efficiency when the roadmap to cost recovery is uncertain and operational hindrances are expected. In the literature, studies have assumed stable and long-term service demand with increased vessel size and lifting volume, and have focused on quay area and berth line but not the whole terminal design nor the required yard storage and stacking strategy. Without elaboration on the corresponding yard block design, operational rules, and supporting resources in the peak and low seasons, the resulting predictions of improved crane and terminal efficiency are subject to high variation in practice.

Yard Block Design

Other than the studies on quay zone working area and berth line, various studies on block length were identified by Petering and Murty (2009) that did not consider the optimal block width. To fill this gap, Petering (2009) investigated the optimal block width and concluded that the optimal width ranged from 6 to 12, depending on terminal size, shape, and throughput target. The study was performed using a fully integrated and discrete event simulation model. Experiments were conducted with dozens of yard configurations and four container terminal settings. The result shows that the relationship between quay crane rate and block width is concave when yard storage capacity and number of pieces of yard equipment is constant. A few assumptions were made in the study of Petering (2009). First, the terminal transshipment ratio was not considered despite its high impact on block usage and thus the subsequent simulation results. Second, the study assumed a constant stacking height of all the yard blocks. In reality, terminals with a low transshipment ratio may store pure import and export containers for longer on average than they do transshipment containers. Terminals may purchase a different set of cranes that result in different time results for different stacking heights, affecting storage capacity in practice. For wide yard blocks—those with widths 10 or higher—a rail-mounted gantry crane (RMGC) is usually deployed by remote control instead of the rubber-tire gantry crane (RTGC) that is usually operated by equipment operators. The productivity is assumed to be equal for all types of yard cranes in these studies. The bigger the block, the higher the amount of container shuffling during peak seasons, which may cause terminal efficiency to decrease unexpectedly. When the boxes stored in the lower levels of a large yard block are needed for vessel loading or external tractor pick-up, the number of re-handling tractors may increase substantially. Conversely, crane utilization may drop substantially during the slack season without there being any possibility of decreasing the block size due to the predefined block width and equipment size. Therefore, determination of yard block size and width should be considered using different business cases that reflect the peak, normal and low seasons.

Automatic Yard Design and Application

Liu et al. (2004) investigated two terminal layout designs: horizontal and vertical blocks against the berth line. Similar to those on block length and width, that study was also conducted without accounting for terminal size or shape. No matching of block design to terminal size or shape was performed. In particular, two different container layout designs for optimizing the movement of AGVs during daily container operations were studied. Traffic flow within the container stacking block by yard cranes are similar in the two different layout design. However, the traffic flow for tractors were entirely different. The consideration on working lane, pass by lane and junction area was not addressed.

Liu et al. (2004) concludes that AGV systems are beneficial only when a terminal has a suitable layout. A multiattribute decision-making method was employed to review the performance of two terminals and determine the optimal number of deployed AGVs in each terminal. Switching from a traditional labor-intensive terminal to an AGV-enabled terminal requires a deep consideration of a terminal's existing design and layout, even if capital investment and staffing are well prepared for long-term change. If a terminal plans to increase efficiency through an automation feasibility review, terminal layout and design should be the starting point.

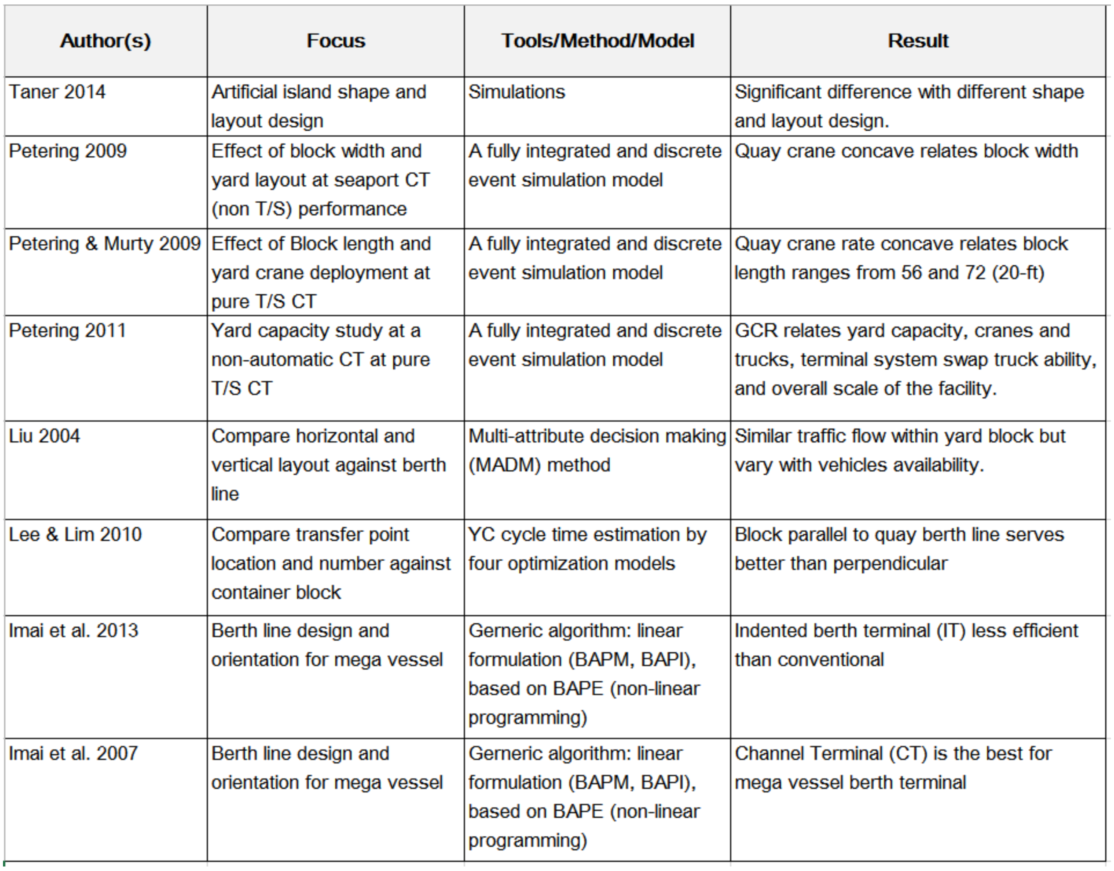
Yard Block Orientation: Parallel or Perpendicular to the Berth Line

A design with a block parallel to the berth line is superior to one in which they are perpendicular according to Lee and Kim (2010), who assumed that only one type of yard crane was available and the equipment and tractor productivity both quayside and yard-side were constant, regardless of fluctuation in demand. In reality, the yard block orientation in a terminal may not be clearly classified as either parallel or perpendicular but can use a combination of the two for highest area utilization. Other than the main block served by yard cranes (such as RTGCs or RMGCs), the front-loader serves in empty container stacking that is worth consideration because empty container handling is also a key type of container movement. Yard block orientation should be extended to include empty container block orientation for a complete picture. External tractor demand was also assumed in Lee and Kim (2010) to have minimal or no impact on vessel operation. The block orientation design did not consider the need to provide a queuing or staging area to external tractors. For a terminal with inbound containers, liners arrange external tractor pickup before the end of the free storage time period to prevent detention charges, and additionally, they return empty boxes after devanning to prevent demurrage charges. Therefore, external demand was not considered in that study for the potential high impact in the yard area in case of excessive external tractors that arrive in peak hours.

Vessels are assumed to be independent and non-sequenced for transshipment container transfer from one vessel to another, with or without temporary storage available in the yard area. Simulation models have been applied for scenario testing among different combinations of equipment and workload parameters and block layout settings; conclusions have been drawn from numerical results without further consideration of fluctuation in demand. Yard crane–side (such as transporter waiting time) performance or quay crane–side (such as vessel operating rate by taking one vessel as a whole) performance are taken as key indicators, instead of the overall terminal productivity in terms of average cost per container lift in different business scenarios.

Summary: Terminal Design as Limiting Cost and Time Efficiency

In summary, a limited number of operations research studies have investigated design and layout, despite the specific settings of terminals' internal infrastructure and facilities—such as yard cranes, yard block sizes, and orientation—being readily available. Terminal design and layout detail are regarded as data inputs rather than study targets. Although there are numerous possible designs and layouts, no specific design or layout is considered to be the best. That no study has investigated or compared terminal efficiency for terminals with similar throughput volume but different terminal designs is interesting. The key papers reviewed in this section are summarized in Table 2.1.



Author(s)	Focus	Tools/Method/Model	Result
Taner 2014	Artificial island shape and layout design	Simulations	Significant difference with different shape and layout design.
Petering 2009	Effect of block width and yard layout at seaport CT (non T/S) performance	A fully integrated and discrete event simulation model	Quay crane concave relates block width
Petering & Murty 2009	Effect of Block length and yard crane deployment at pure T/S CT	A fully integrated and discrete event simulation model	Quay crane rate concave relates block length ranges from 56 and 72 (20-ft)
Petering 2011	Yard capacity study at a non-automatic CT at pure T/S CT	A fully integrated and discrete event simulation model	GCR relates yard capacity, cranes and trucks, terminal system swap truck ability, and overall scale of the facility.
Liu 2004	Compare horizontal and vertical layout against berth line	Multi-attribute decision making (MADM) method	Similar traffic flow within yard block but vary with vehicles availability.
Lee & Lim 2010	Compare transfer point location and number against container block	YC cycle time estimation by four optimization models	Block parallel to quay berth line serves better than perpendicular
Imai et al. 2013	Berth line design and orientation for mega vessel	Gerneric algorithm: linear formulation (BAPM, BAPI), based on BAPE (non-linear programming)	Indented berth terminal (IT) less efficient than conventional
Imai et al. 2007	Berth line design and orientation for mega vessel	Gerneric algorithm: linear formulation (BAPM, BAPI), based on BAPE (non-linear programming)	Channel Terminal (CT) is the best for mega vessel berth terminal

Table 2.1 Summary of key research on terminal layout and design.

2.7 Information System

Functional User Groups

A well-designed terminal system affects terminal efficiency critically, but investigations into the effect of information system design on efficiency are rare. Terminal information systems serve a wide arrange of functional user groups: control tower staff in an office environment to outdoor users who communicate with the control tower and access terminal system information via wireless communication devices, such as handheld terminals. While system users in an office environment have a broader view of terminal status information, this is no guarantee of decision quality unless the system’s design is sufficiently robust. Such robustness is supported by proper standard rules, because critical business and operations rules that are applied in daily operations are applied automatically and with minimal manual intervention. Although different container terminals have similar operations, their information system designs and communication technologies can differ entirely. Moreover, a global terminal group’s system may be employed differently in each subsidiary terminal, which can result in differing efficiency levels. Exceptional case handling supported by a suitable system helps to ensure high efficiency without data recovery need and cost, when a terminal system is not sufficiently intelligent.

System Driven: Functional Decision-Making

The key decisions made by each functional team rely on timely updating and instant sharing of system information in a modern container terminal. For example, the berth allocation team decides berthing sequence, whereas the ship planning team plans outbound container pickup sequence to support the most up-to-date vessel berthing sequence in order to avoid rehandling or unproductive yard movement. The yard planning team plans the yard capacity usage for containers incoming to or outgoing from the terminal and coordinates with the ship planning team to ensure smooth operations. The resulting pickup sequence is executed by the control tower team, who try to achieve high real-time vessel operation efficiency. To ensure that the correct number of external tractors is entering the terminal while vessels are being operated, the gatehouse team ensures that each container receives the right priority to ensure the smooth running of vessel operations; high priority assignment is given to late-arriving containers that must be loaded onto a vessel about to depart. The function and contribution of each team in the operation department is discussed next.

First, the basic terminal operation consists of movement of two major types of customer assets: containers and vessels by the terminal facilities, equipment, and connecting tractors. Containers are moved by terminal tractors between lifting points; equipment, yard cranes, or quay cranes locate and lift the container to and from vessel or tractor.

Lifting is required at sea–land, land–sea, sea–sea, and land–land transportation hand-shaking points. Unlike containers, once a vessel is arranged to berth at a particular section along a terminal berth line, it does not normally move again until vessel operations are complete and the vessel departs.

Regardless of a terminal's size, the design of its information system includes a basic database that stores a few key data elements for the types of movement and their supporting resources. These data comprise container, facility and equipment, staff (including equipment operators), service voyage, vessel (individual vessel particulars), and service charge and tariff data. Again, regardless of the size of terminal, the key organization structures for daily operation are similar, consisting of berth allocation, ship planning, yard planning, control by control tower (overviewing the real-time operations at quayside), and gatehousing (safeguarding the vehicular flow to and from the terminal; the terminal is a restricted area). These functioning teams require a good terminal operation system to support their daily tasks, such as movement decisions down to the container level or up to vessel or even multiple vessel level. Data processing and usage frequency increases with container volume, whereas impact on terminal cost and efficiency is more related to the vessel level or the aggregated level, where multiple vessels within one service loop or standard service charge and tariff for each customer (shipping line) are covered. Once service charges and tariff have been established for a specific customer, the terminal's basic or fixed revenue—for example, vessel mooring and demooring charges—can already be estimated according to the latest and agreed operation period, whereas variable revenue mainly comes from container lifting charges and subsequent charges and/or surcharges imposed because operation performance depends on actual periodic or weekly actualization when vessels arrive.

Cost visibility is clear to the operation team, who has the input resources under their control but not the actual revenue generated by the container and vessel movement, such as container lifting, vessel dockage service charges, and any other service surcharges at the container or vessel level. Normally, only the berth allocation team at a terminal knows some of these confidential details because they need to arrange vessel arrival and priority in line with the commercial team. Other operation functional teams are sometimes able to make a partial enquiry regarding the service charges and tariff module in the terminal operation system, such as an enquiry requesting to know if a service is covered by the basic service agreement.

Data and Information Sharing: Generic versus Confidential Data

A lack of visibility prohibits leakage of confidential commercial information, such as customer service agreements, but also prevents teams from observing a decreased service level or the missing of a service requirement. For example, when the tractor of an important customer is served and ordered to queue for container pick up after it enters via the terminal's gatehouse, the customer or driver may be dissatisfied because they know that they should receive higher priority than other tractors arriving at a similar time. Higher priority may be given in terms of a shorter waiting time and a VIP customer arrival alert once the pickup order number is input to the terminal system by gatehouse staff when the tractor arrives at the terminal. Conversely, the commercial and marketing team of the terminal may expect VIP arrangement with correct level of priority as reflected in daily operation and resources planning processes. Unlike the clearer berth allocation priority at the vessel level, VIP tractors may be missed occasionally until a complaint is made. To clearly portray the situation, we highlight the key functioning units and corresponding decision-making functional teams in the coming paragraphs, and this is followed by a clear summary of key data elements and their usage frequency by different functional teams.

System Data Used in Berth Allocation

The key function of berth allocation is to decide the best berthing arrangement for all arriving vessels. The key decision is to determine the expected berthing times, berthing points (along the berth line; some studies use the term “berth section”), and expected departure times. The decision is not only based on the vessel arrival sequence, berthing times, and berthing points, as has been assumed in studies in the past two decades; more importantly, the critical impact on terminal efficiency of **terminal capacity**, **terminal resources** (such as equipment availability) and **vessel workload availability** (export and/or transshipment container) must be determined. These three considerations are key decision-making factors affecting terminal efficiency directly.

(1) Terminal capacity: when terminal yard capacity is nearly reached and traffic congestion occurs, which causes terminal efficiency to decrease, the berth allocation must make a good decision, such as arranging vessels with higher loading capacity earlier to decrease the pressure on yard capacity or allocating vessels with a high volume of containers to be discharged after the departure of some other major loading vessels, which may have taken away a large volume of export or re-export containers and freed up some storage capacity. This is especially important for small to medium-sized terminals.

(2) Terminal resources: a vessel’s departure time is calculated by the estimated port stay period after the vessel has berthed, and this vessel operation period is predetermined by the vessel’s associated workload: the number of containers to be discharged from

and loaded onto the vessel. This time period is normally assumed to be a constant in berth-allocation-related studies, but in real situations, the period is adjusted according to input resources, such as quay cranes, yard cranes, internal tractors, and even the operation process. Berth allocation may shorten the berthing period of one vessel by suggesting extra resource input, resulting in faster completion to create a favorable operating condition for subsequent vessel(s). This is especially useful when vessel congestion occurs and a minimum vessel berthing time is needed, even though it incurs higher operation cost.

(3) Workload availability: berth allocation must forecast berth availability and ensure vessels are operated without any stoppages that could lead to the idleness of resources. If a workload is not available, the vessel can be arranged to berth later or berth for a longer period of time but with less resources input in order to “wait” for the outstanding containers.

Unlike in many studies, which have considered them to merely perform the berth allocation function, the berth allocation team actually defines an overall planning timeline and execution priorities for subsequent terminal planning and operation processes. The team has a wider scope of vision than only vessel berthing arrangements; for example, a timely response to any ad hoc problem is needed in berth allocation to ensure no resource wastage. In many terminals, the regular communication meeting attended by all key function teams is named the “berth allocation meeting,” reflecting the importance of the work. The overall strategy, after the consideration and confirmation of all decision units, is sourced from this meeting and further distributed to all other functional teams for their corresponding planning, arrangement, and amendment of the existing execution plan. The berth allocation team communicates closely with the terminal commercial team for consistent vessel operation priority among the operation and commercial departments, and they know the best way in which to achieve vessel efficiency and effectiveness.

System Data Used in Ship Planning

The key function of ship planning is to plan the pick-up of in-yard containers by berthed vessels using the suggested set of specific quayside equipment in the way that achieves the optimal performance. Performance is normally measured by smooth and continuous vessel operation without quay crane idling time. A preplan is received by the ship planner from the shipping line before a vessel arrives and berths. The preplan serves as a standard rule regarding the container storage on board the vessel, whereas the exact details—which container is to be put in each specific stowage location—is decided by the ship planner. A skilled ship planner makes decisions that favor terminal efficiency when planning a vessel. This means that each choice regarding the picking up a container from one yard location is a critical decision unit: for example, picking up from a yard block closer to the vessel may affect efficiency differently than picking up a container from another yard location—even though the two containers have the same port of discharge (POD)—when an experienced ship planner considers the traffic flow at the terminal's peak hours. For example, shorter distances are preferred to avoid potential waiting time in the yard block and traffic in junction areas during peak hours, but longer distances are acceptable during slack hours. Given that multiple containers with the same POD exist and are eligible for container loading in the same container slot in a vessel, selecting the optimal container is complicated. Additionally, a vessel's particular characteristics are critical during ship planner's considerations. For example, picking up a refrigerated container must be completed within a predefined and short period of time because such a container requires a nonstop electricity supply, which if cut off, may result in degraded container content, complaints, and claims.

System Data Used in Yard Planning

The key function of yard planning is to plan the yard capacity allocation to incoming demand (containers) and monitor the actual usage for the best performance. The planning is critical for subsequent vessel operation efficiency despite the fact it is an ongoing fine-tuning process. Good planning is supported by a suitable yard planning strategy that divides the yard’s three-dimensional capacity into container unit sizes. For example, containers collected by the terminal for export or re-export arrive at the terminal progressively until or even after the vessel onto which they should be loaded arrives and even after it has berthed. Each choice of yard storage location—yard block, block lane, and even lane tier—for each individual container for a particular service vessel voyage is a critical decision-making unit; normally, these units should be defined before actual operation commences. The system suggests the best choice of preplanned location instantaneous for the yard’s overall workload in that moment in order to shorten the tractor waiting time and provide good service to customers, and more importantly, to avoid traffic congestion in some busy areas that are serving vessel tractor container pick-up or container grounding from or to the yard block. Normally, manual intervention is needed only when an unexpected situation occurs, such as if the yard planning staff override the system’s suggested location. Monitoring, performed by the yard planning team, also includes the best equipment allocation among all the yard blocks in serving all types of tractors: vessel tractors, intra-terminal transfer tractors, inter-terminal transfer tractors, and customer tractors that enter the terminal via the gatehouse or terminal boundary (for example, after delivery of a laden container at an adjacent terminal, the tractor directly enters the terminal to pick up another container, as per the agreement between the two cooperative and adjacent terminals).

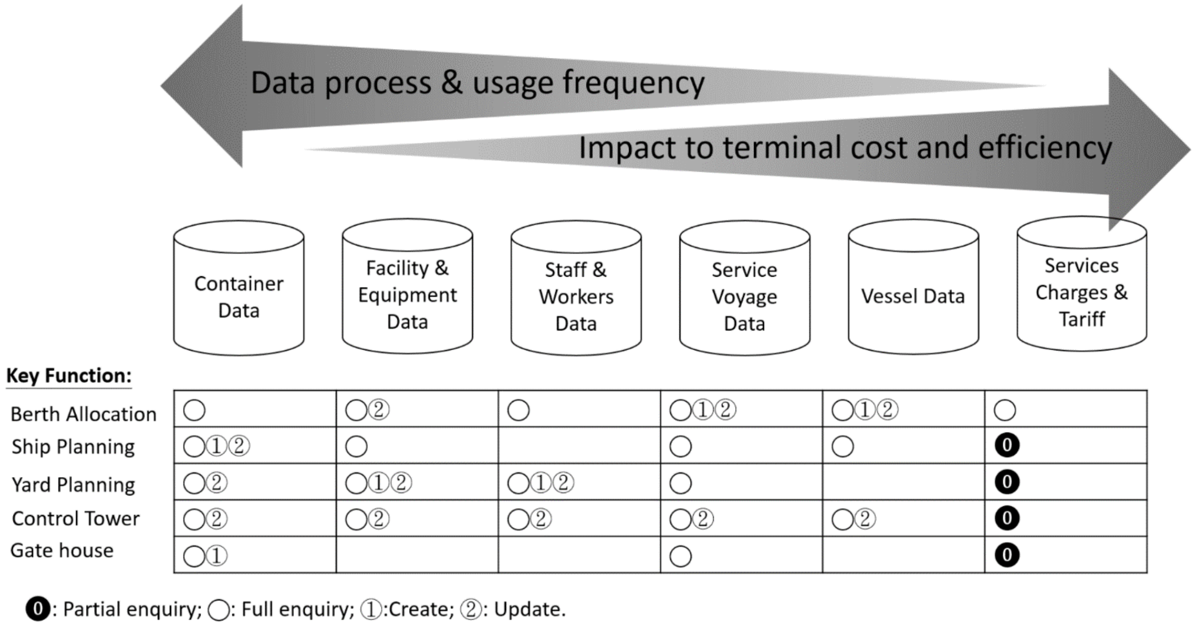
System Data Used in Control Tower Operations

The key function of the control tower is to plan and execute vessel operation of incoming vessels in terms of container discharge sequence and also container loading sequence. The vessel operation plan is one type of decision-making unit that considers the amount of equipment, such as quay cranes, to be deployed for one particular vessel and on top of the number preagreed with the customer. When vessel operation is underway, the control tower monitors the actual vessel operation process for the best performance and makes instant decisions to solve ad hoc problems that decrease performance to ensure on-time departure of the operating vessels. These real-time decision-making processes are critical in ensuring the success of a vessel operation and even a terminal. Habitual vessel delay not only incurs penalty costs, but also harms the company’s image and reputation. Customers select terminal operators that offer a reliable service in terms of good berthing and unberthing arrangements, especially departure without delay.

Despite its complexity, in numerous terminal-operation-related studies, the actual vessel operation process is oversimplified in terms of a target vessel processing period supported by only a planned set of lifting vehicular equipment. The actual important process is missed: the instant reaction of the control tower to maintain vessel operation efficiency. This reaction may be the deployment of more tractors during a short period of time to ensure continuous demand for the quay crane due to yard congestion; the deployment of more yard cranes to serve one vessel at the cost of the performance of other types of awaiting tractor; or even the deployment of extra quay cranes to share an outstanding workload as long as it is physically possible. These are possible real-time and ad hoc decision-making units and should be well-supported by the terminal’s operation system. Other than reacting to decreases in vessel operation performance and efficiency, the control tower must also make decisions to ensure correct container identity during all types of container exchange activities between vessels or external tractors and terminals. If a container's identity is incorrectly input into the system, the real container identity is missed until someone physically checks the container in the yard or quayside area. An even worse situation is if a container is sent to the wrong vessel and thus the wrong destination, while the real container is never found again. Wireless communication with frontline workers is thus heavily used to ensure that vessel operation is problem-free, and work order in moving each particular container to and from vessels to terminals or vice versa is executed clearly and properly by the equipment operator.

System Data Used in Gatehouse Operations

The key function of the gatehouse is to safeguard the movement of vehicles between the restricted terminal area and external area. Once a container is created upon its arrival at the terminal by land or by sea, it has a permanent record in the system until it leaves the terminal via a vessel operation or inter-terminal transfer. For land transportation in particular, the gatehouse must make timely decisions regarding the priority of all waiting containers carried into the terminal by a customer's tractor and must receive any complaints from drivers or customers directly. These are critical decision-making units despite the fact that the gatehouse is not directly involved in yard-side and quayside operations. Qualified judgement and decision-making is required by the gatehouse staff for good control of the number of external tractors entering the terminal area during busy vessel operation periods. When vessel operation performance decreases unexpectedly, more resources (yard cranes) are allocated to vessel operation at the expense of the longer waiting time of external tractors picking up import or transshipment containers. During such periods, the gatehouse staff must make smart decisions and strike a favorable balance between vessel operation performance (at the vessel level) and high-quality customer service (at the container level) via good communication with the control tower team. Key data elements are created and updated or enquired of by different functional teams in a container terminal during daily operations, with different data access rights assigned and update frequencies employed, as summarized in Figure 2.3.



Key Function:	Container Data	Facility & Equipment Data	Staff & Workers Data	Service Voyage Data	Vessel Data	Services Charges & Tariff
Berth Allocation	○	○②	○	○①②	○①②	○
Ship Planning	○①②	○		○	○	⓿
Yard Planning	○②	○①②	○①②	○		⓿
Control Tower	○②	○②	○②	○②	○②	⓿
Gate house	○①			○		⓿

⓿: Partial enquiry; ○: Full enquiry; ①:Create; ②: Update.

Figure 2.3: Data types, usage frequencies, and cost impact in a container terminal.

Figure 2.3 summarizes how key data elements are created and updated or enquired of at different times and by different functional teams in a container terminal. A high container volume increases data processing and usage frequency, whereas the data elements on the right-hand-side of Figure 2.3—such as service charges and tariff and vessel particulars—are expected to be updated less frequently but have a higher impact on terminal cost and efficiency.

System Comparison Studies

One recent study covering 65 European terminals (Michele and Patrizia, 2014) attempted to compare multiple systems among the terminal set but focused on tangible, countable, or visible setups and their corresponding values only. The variables under any visible operating system and the settings—such as berth length, yard size, number of quay and yard cranes, and labor cost—were direct and simple for empirical analysis, but did not address the decision-making part of the system, analogous to omitting the brain in a study of the whole body. The study concluded that three key variables—throughput, labor cost, and berth length—are the most influential independent variables affecting the level of development in a container terminal, as determined using multiple nominal methods; it did not consider the decision-making units nor terminal efficiency, such as average operation cost per container unit or average vessel or customer tractor waiting time during slack and peak seasons.

Given that information system design and usage are not addressed for its details whereas operation processes are similar, Michele and Patrizia (2014) assumed that all system designs are similar. However, different information systems may result in substantially different operation performances, which was not addressed by the authors explicitly. It may have been possible for the authors classify the terminal systems into different design groups in terms of decision-making unit fulfilment rate and correlate them with the actual performance per berth section to mitigate the size effect.

Case Study versus System Comparison

Research on the classification of function, nature, and maturity level of a container terminal information system or operating system is important but rarely found in the literature. When comparing or evaluating information systems, data are compared instead of the decision-making process. Superior data understanding should be acquired in terms of the effect of the data on the key efficiency-affected processes. Although it is difficult to compare different ports or terminal information systems using grading assignments, functional reviews, and usability or system response time analysis, a study was conducted by Wong et al. (2009) that investigated the successful operating system, called the “Next Generation Terminal Management System” (abbreviated as “nGen”), of the world’s biggest container terminal—Yantian International Container Terminal in Southern China, which is operated by the HWP group—based on the author’s profound and practical operations experience, which was acquired at the port of Hong Kong and other famous ports. Wong et al. (2009) identified that the successful factor of the operating system, which was self-developed by the terminal group, was its high capability to handle institutional pressure from customers, customs, and competitors, as well as the high business priority placed on mindfulness information technology management (ITM), where mindfulness is the state of being alert and aware. Mindfulness ITM was extended by Fiol and O’Connor (2003) to decision-making when organizations adopt an idea, technique, technology, or product because of pressure from organizations that have already adopted it. Wong et al. (2009) pinpointed that IT facilitates flow in transportation chains to enable compliance with transportation policies and regulations and also to enforce security. When adopting new computer software, a firm with such mindfulness ITM shall accomplish the transition easily and smoothly in order to link up with software used by its major suppliers and customers. Wong et al. (2009) concludes that high flexibility is needed when reacting to the changing business environment and that new pressure can be overcome with suitable IT resources and support. The paper did not address how the system development team prioritizes operation needs and sequences whenever parties at different terminals have competing or contradicting user requirements. It is believed that sharing the said competing or contradicting case with the related regulatory units or government bodies is vital. They are also critical when bargaining for a better operating environment or less operating constraints.

Success of the Singapore Port Authority's IT strategy

The Singapore Port Authority (PSA), which runs the successful port—the port has multiple world-class and efficient terminals—has been a classic target for specific case studies since the early 1990s. An introductory study performed by Ramani et al. (1995) investigated the transformation of the successful passenger transportation organization in Singapore, called the Yap Chwee Hock Distribution Park (YCH) in Tuas—into a rounded international logistics service provider. Another case study conducted by Lee-Partride et al. (2000) addressed the increasing throughput volume of the container terminals at the port of Singapore. The key success factor was favorable ITM, which offered a reliable information system (PORTNET) to all parties, from which they could obtain accurate data in a timely manner.

Airriess (2001) also studied the Port of Singapore's future development based on her strong understanding of information and communication technologies. Gordon et al. (2005) reported that regional competitors found it difficult to catch-up or compete with the Port of Singapore because of numerous factors, including the port's strong information technology and government support and ample investment. Without pinpointing the future berths in nearby area, the authors investigated the current berths and terminal resources and concluded that catching up with Singapore will be difficult for her competitors. Another PSA case study by Cullinane et al. (2007) showed that government support was a key factor affecting the port's success and that the departure of a major proportion of transshipment cargo volume from one alliance (Maersk–Sealand) in 2000 had a significant effect on the port of Singapore, forcing it to develop higher service standards via information technology development.

Port Comparison Using the Systems of Ports and Terminals

Similar to the study by Gordon et al. (2005), Yeo et al. (2008) investigated the strong competition for feeder cargo volume among Korean ports and gradually also shared with container ports in Northern China due to their close geographical locations. The sophistication level of port information and its application was identified as a contributing subfactor of the main factor, convenience, other than the other four factors of port competitiveness. The need to maintain a port information system was found to be crucial for a port's continuous development and remaining competitive relative to nearby competitors.

In a case study of the port and container terminals in and around Hong Kong, Wang and Cheng (2010) found that in the keen completion between Hong Kong and Shenzhen, Hong Kong had the competitive advantage because of its relatively mature information infrastructure and the assistance it receives from government bodies via the setting up of various linked system modules, which are collectively named the Digital Trade and Transportation Network (DTTN). This network helps the city to maintain its level of globalization. Wang and Cheng (2010) also reported that the Shenzhen terminals are catching Hong Kong quickly in terms of container throughput per annum. Other than being the port information system for Hong Kong port's internal business operation functions, the government support system (the DTTN) also allows terminal operators to make new transshipment intermodal arrangements, such as vessel–cross-border–land or land–cross-border–vessel arrangements. In short, container terminals (and air-freight cargo terminals) provide an integrated multimodel transport network with strategically located logistics centers (at dock warehouses, including bonded warehouses) that help customers to perform value-added tax refunds and expedited customs clearance functions.

Terminal Operating System: Critical Throughput and Efficiency Driver

A recent case study was conducted by Rios and Sousa (2014) and analyzed the competitiveness of various terminals in the ports in Brazil. Port or terminal information systems were still not identified as one of the key criteria affecting efficiency, even though the authors reviewed the literature and understood that such systems are crucial for terminal operations and service delivery. The authors listed the top ten ports in the country in terms of their terminal throughput (in TEU) and described the volume handled in Brazil as relatively low, even at the biggest container terminal operated by Tecon.

Another case study of ports and terminals in Turkey used fuzzy axiomatic design and methodology in addition to the conventional axiomatic design (Celik et al., 2009). The study pinpointed the need to achieve favorable product, software, or even information system design by having a clear view of its functional requirements. This was especially useful in application to the complex container terminal operations system design that is used by multiple parties. Although the authors did not explicitly list the identified competitiveness factors, the first SWOT factor—infrastructural characteristics—was included as an overall measure.

Terminal System: Increasing Capacity without Capital Investment

In the past studies, normally physical or tangible resources, such as berth lengths, berths, equipment and infrastructure such as yard capacity, as well as the resulting annual throughput volume in terms of TEU are key design specifications for a container terminal. Yeo (2010) indicated that most terminals are equipped with email (93%), a website (95%), and an information technology or system (90%); the end users in container terminals were discovered to be able to use an average of 4.39 functions in their terminal's computer system for daily operations. The study also concluded that improving operations and information technology can both increase capacity without making extra investments in equipment or physical space. The use of factor analysis is common when terminal systems are being investigated; for example, factor analysis by using structural equation modeling was performed recently by Cho (2014) and identified a positive relationship between information systems and a port's infrastructure and logistic costs. These findings indicate that customers of container terminals are always eager to select terminals with good information technology and terminal facilities.

Designing Business Rules in Terminal Operating Systems

Other than conducting an overall review of a particular terminal's information system, some studies related to information system improvement have investigated specific terminal services or operation function improvement, such as real-time decision-making or better resource allocation, which can include berth allocation, yard stack utilization, quay crane utilization, and external truck appointment systems. These studies are usually not visible to end users because they form the logic built into the system behind the user interface. Instead of using the classical linear programming models, some interesting berth allocation improvement studies have recently employed new approaches such as fuzzy logic to solve the classical operations problem that is berth allocation. Lokuge and Alahakon (2007) reported that most research in the subject area had employed various impractical limits or assumptions, such as assuming that all vessels are static during planning, all vessel berth periods are fixed, no equipment breakdown is possible, no change in vessel operation priority occurs, and all vessels arrive when scheduled. The authors state that their proposed logic related to hybrid is a much better agent with which to solve the problem.

Summary: Information Systems Promote Time Efficiency

In conclusion, much research effort has highlighted the crucial elements in setting up a good terminal system that promotes high terminal efficiency; however, the actual system designs and details that promote easy and efficient planning and operation decisions have not been elaborated upon in detail. Data elements have been listed in numerous studies on system design, but the corresponding key decision units that directly affect efficiency have not. A full picture of the key design elements in highly efficient container terminal planning and operations is missing. In particular, no papers have yet been published concerning efficient wireless data and verbal communication between the office staff, such as the operation team on control tower duty, and the quayside frontline staff and also equipment operators. Outdoor workers are critical efficiency-affecting parties who must be supported by well-designed and convenient system tools, but few studies on these workers have been found. Instead, interviews are usually conducted with office staff. Filling these research gaps would enable parties to determine the correct level of automation and operation rule setting, matching of decision-making to system user level, level of wireless communication, and level of response or by-pass mechanism usage, enabling a much clearer picture of the long-term development of a terminal. The key papers reviewed in this section are summarized in Table 2.2.

Author(s)	Focus	Tools/Method/Model	Result
Michele and Patrizia 2014	65 European terminals	Multinomial Logit (MNL), Typology of Operating System, Logistic regression, Goodness of Fit	Heavily regulated market favor less labor intensive terminal operation system.
Wong et al. 2009	nGen (HPH group terminal operating system) introduction	Case study. Institutional theory (IT).	Better IT system with firm mindfulness.
Ramani et al. 1995	Study of the starting up of PSA	Case study. Institutional theory (IT).	Strategic and innovative use of IT is important.
Lee-Partride et al. 2000	PSA System: Portnet introduction	Case study. Analysis based on four key management successful factors.	A CIO (or Director of IT) bring value than just IT or IS upgrade.
Airriess 2001	PSA: current and future development in terms of IT innovation	Case study	Port business dominated by few global port groups with good IT system.
Gordon et al. 2005	PSA competitors find difficult to compete with PSA due to PSA IT leading role	Case study. Resource based view strategy (RBV)	Port information affects Convenience, other than four identified factors for port competitiveness.
Cullinane et al. 2007	Government supportive role for CT IS in Singapore as key successful factor	Case study	Singapore remain dynamic and competitive with advanced IT system.
Yeo et al. 2008	Competition between Korean and Mainland China ports	Case study, Factor analysis	Port competitiveness via high quality port service and technology that focused port operations.
Wang and Cheng 2010	Competition between HKG and Shenzhen ports	Case study, Correlation matrix, R square	Business, gateway, and institutional as three key levels in hierarchical supply chain framework.
Rios and Sousa 2014	Review of Brazil Port such that the role of IT is not focused in the efficiency study	Case study, Hierarchical cluster analysis	Small or unspecialised terminal can be more efficient than big terminal equipped with the latest equipment.
Celik et al. 2009	Ports and terminals in Turkey and their comparison	Fuzzy axiomatic design (FAD) and TOPSIS methodology on top of the conventional axiomatic design (AD)	As a useful tools for container terminal or port management staff's decision making.
Cho 2014	Find out any relationship with port infrastructure and logistic cost	Factor Analysis (FA) and Structural Equation Modeling (SEM). A theoretical foundation, the transaction cost economics (TCE).	As comprehensive theoretical backgrounds to port capabilities related study
Lokuge and Alahakon 2007	Pin-pointed most researches on the area are completed with various impractical limits or assumption	Fuzzy logic system. Artificial Intelligence (AI). Beliefs, Desires and Intention (BDI) agent architecture (BDI), Knowledge Acquisition Module (KAM) in the generic BDI, Adaptive Neuro Fuzzy Inference System (ANFIS).	Adaptive learning algorithms builds adaptive intelligent agents.

Table 2.2 Summary of key research on terminal information systems.

2.8 Customer Service Strategy

Pro Forma as Contractual Template

Customer service strategy has largely overlooked the fundamental principle of setting up a pro forma. A pro forma is the master plan of berth allocation at the tactical level, whereas the actual berth allocation is done at the operation level but is expected to be an ideal copy of the master plan. Thus, in a situation without any uncertainty, the arrival time, vessel operating period, and departure time should be exactly the same or very close to the targets set in the pro forma. A few key assumptions are made in most terminal-efficiency-related studies related to customer services, as represented by the classical berth allocation problem:

Assumption 1. All vessels, once they arrive at the port, are arranged to berth at the terminal as soon as possible.

Assumption 2. The shorter the vessel processing time, the better the terminal efficiency.

Assumption 3. The earlier departure time, the higher the cost saving for the shipping line that operates the vessel, as this increases its chance to slow steam, which saves a vessel's bunker cost.

Assumption 4. Each vessel's operation is independent and not reliant on the berthing of other vessels.

The Pro Forma in Practice

The real operation in a terminal, however, does not always verify these assumptions. The actual situation is more complicated than the scope perceived by the authors of the papers reviewed herein, which have focused on customer service strategy and the corresponding terminal efficiency. The fundamental consideration when a commercial team creates, formulates, or revises its responsive customer service strategy for the right level of terminal efficiency is based on three key business considerations: utilization of all time windows, the precedence relationships between vessels, and the variability of the individual vessels' voyage and vessel particulars. The final objective is to maximize the overall terminal revenue. Each consideration is discussed in detail.

Key Business Consideration 1: Utilization of All Time Windows

It is the sum of each vessel's berthing window area divided by the total window area in pro forma. The vessel berthing window area is the vessel length multiplied by the vessel operating time, whereas the total window area is simply the total berth line multiplied by the total duration of one pro forma cycle, such as 1 week. In the most common ideal case, it is assumed that usage is perfect and no areas are unused, which is not realistic. A terminal may, in the case of adequate vessel demand, allow vessel berthing windows to overlap in the pro forma as an aggressive strategy for boosting business revenue. If no area is left over, or if the remainder area is smaller than the sum of the overlapping areas, the strategy is named overbooking. This strategy attempts to push operation to a higher efficiency, but if all vessels arrive at port and none omit the port, the cycle time is not sufficient for all the vessels within that cycle to complete their operations. Overbooking also attempts to ensure a higher handling volume in case any particular vessel’s cargo handling volume drops in any particular cycle and results in lower throughput than expected. In the under-booking situation, the overall terminal vessel demand is smaller than the terminal’s handling capacity during a pro forma cycle, and thus one or more vessels may be handled at less than the highest terminal efficiency because the berth will be empty once the vessel has departed. A lower terminal efficiency level is discussed between the commercial team and the shipping line and results in an agreed lower processing rate.

Key Business Consideration 2: Precedence Relationships between Vessels

Container movement from one vessel to another is extremely common in many transshipment ports. Shipping lines tend to arrange larger vessels to cross the globe horizontally, over the big oceans, and these vessels are known as mother carriers. When a mega vessel arrives at a hub port, it temporarily transfers containers to the hub port and picks up another group of containers for their onward transportation to another hub port. The temporarily discharged containers are put on various smaller vessels for subsequent transportation until the containers reach their final destinations on rivers or in coastal areas. As for mega vessels, the smaller vessels are, in principle, not empty when they arrive at the hub port but loaded with containers that are to be placed on that or another mega vessel. In other words, the sequence of berthing does matter. When a mega vessel departs, for example, it cannot take away containers from a smaller vessel that has not yet arrived. Therefore, the customer service strategy is to arrange for the mega vessel to arrive during the predefined time window that enables it to pick up the largest number of containers possible. If the mega vessel arrives earlier than expected and some of the smaller connecting vessels carrying containers for loading onto the mega vessel have not yet arrived, the mega vessel's total handling volume is decreased unless supplementary containers from another source can be loaded onto it. Terminals are thus eager to keep a predefined schedule for all vessels, as much as is possible, to avoid disturbing the precedence relationships between vessels because such disturbances eventually decrease the total handling volume.

Key Business Consideration 3: Variability of Individual vessels' Voyage and Vessel Particulars

Multiple shipping lines frequently form alliances and run the same service loop, resulting in different sizes of vessel on the same loop. The vessels, operated by different shipping lines, are normally operated by their corresponding contract terminal instead of one single terminal. This adds noise to the proforma's basic structure and results in possible open windows in a pro forma when one such vessel is operated in a competitor terminal in the same port. This indicates the need for terminals to be flexible in arranging the steady flow of all basic vessels or vessel-chains because the berthing arrangement at other terminals adds further uncertainty to the terminal efficiency. For example, when a vessel arrives at an adjacent terminal, the original terminal must make sure that all time-sensitive transshipments or special cargoes are carefully arranged, or else that temporarily stored containers are transferred progressively before their target vessel arrives at the adjacent terminal; the time required to control such inter-terminal transfers has a strong effect on costs.

Despite customer service strategy being the crucial foundation of all efficient operation plans, terminal-efficiency-related studies always overlook the key service requirements of such strategies, which are reflected in the pro forma; this includes all operations requirements, such as the number of quay cranes input, estimated arrival, berthing and departure times, estimated workload, previous and next port of call, and other relevant berthing information, including vessel length, breadth, and depth, number of cargo holds, exact location of vessel bridge tower, and vessel draft. For the near-full-capacity case illustrated in Figure 2.4(a), the pro forma, or more explicitly the master berth–time diagram, is filled with small rectangular boxes corresponding to particular vessels; in this case, the fundamental assumption that vessels wish to stay for the shortest period possible may be true as there may be awaiting vessels that arrive earlier or later during a particular realization cycle (for example, 1 week). Therefore, the earlier the operation of one vessel is completed, the more likely an awaiting vessel will have a short waiting time. However, there are two key considerations that arise when we review the logic: if all vessels arrive earlier than expected, and the vessel productivity rate is the highest possible, berths may be idle for some hours during the cycle, resulting in resource wastage. The commercial team may or may not be able to arrange additional customers and vessels to avoid resources being idle, and the good service to customers thus may result in high unit cost.

When determining the departure time of a vessel, the vessel's berthing period may be considered with other navigational constraints, such as tidal conditions and store and parts delivery by landside agents to the vessel in advance of its departure; the earlier completion of vessel operation thus may not result in an early departure. In practice, it is common for berth allocation to follow commercial instructions via the pro forma and for vessels to berth and unberth as planned, without large time deviations unless the vessel arrives much earlier or later than expected. This is done to keep to the overall schedule and sequence in every realization cycle. When the vessels in a cycle are not numerous and the pro forma is non-saturated, the operation team may also consider how best to utilize resources such as equipment operators and staff members working shifts. For example, if a vessel's departure time is the same as another vessel's arrival time, to minimize the number of frontline staff needed, the departing vessel may be arranged to depart earlier to release the resources for use in the subsequent vessel arrival operation process. This contradicts the common thinking that a less busy terminal may require longer vessel stays than a busier one. The situation depends on cost, time, and quality considerations, with agreements made with customers via customer service.

In busy seasons, a terminal tends to allow overbooking, which is represented by overlapping vessels in the pro forma, as illustrated in Figure 2.4(c). Overbooking is common in some terminals when vessel sailing schedules are frequently unreliable and when the terminal is aggressively pursuing higher business volume than it can achieve under a normal pro forma setup (without any overlapping). The operation team is expected to push its efficiency to a higher level to complete the first vessel (which is overlapped) earlier than its predefined departure time, which allows the second vessel to berth as scheduled. Sometimes, when business is not brisk at a terminal, a non-saturated berthing arrangement may include overlapping, as displayed in Figure 2.4(d). This occurs when it is difficult to agree an alternative arrival and berthing time with a customer. The commercial team wishes to secure more vessels in the first stage. In this case, it is even more difficult for the operation team to operate each vessel at the proper efficiency level: the fastest completion of the earlier overlapping vessel and elongation of the vessel stay of the second overlapping vessel saves costs, because idling resources is already unavoidable in the current pro forma.

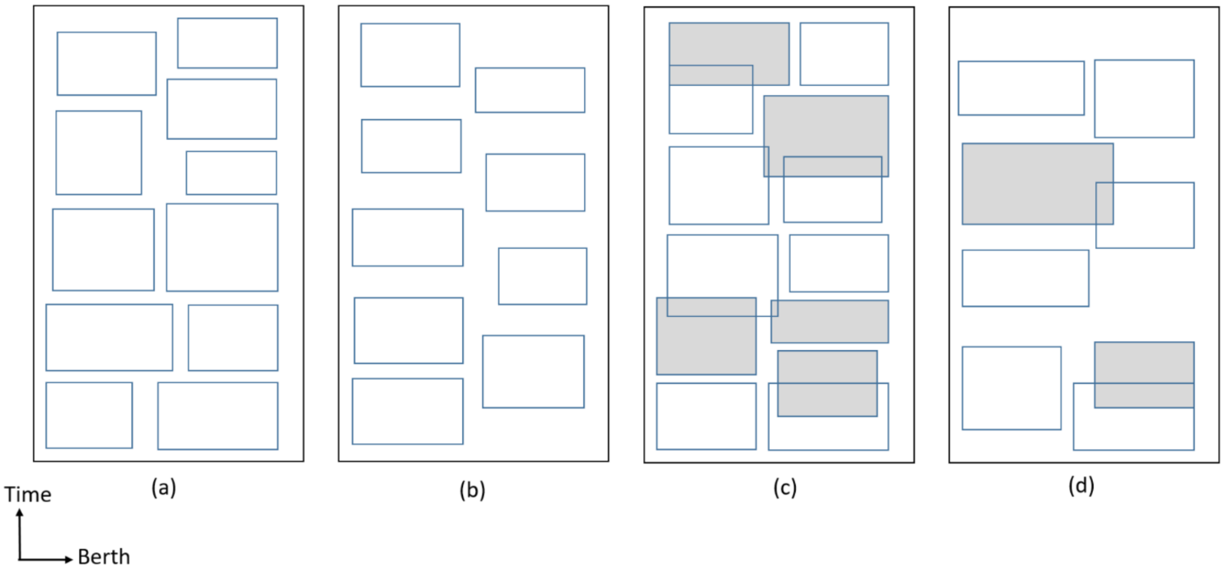


Figure 2.4 Proformas with different vessel frequency and arrival patterns.

Dominance of Survey Studies

The literature relevant to customer service strategies for maximizing terminal efficiency is dominated by survey-type and empirical studies rather than those which used mathematical cost minimization models using different service level settings or different levels of resource utilization and the resulting customer service level. This may be for confidentiality reasons, as explained by Tongzon and Heng (2005). The scope of studies has progressed from investigating primitive factors—such as port and terminal landscape, port and terminal ownership, and operating group and structure, as indicated in the studies by Cheon et al. (2010), Tongzon and Heng (2005), and Cullinane et al. (2002)—to addressing decision attributes in both the tactical and operational levels of customer service strategy (Sharman and Yu, 2010; Yuen, 2012; Ha, 2003). Yuen et al. (2013) investigated how the involvement of foreign and local ownerships, intra- and interport competition, and the hinterland affect the efficiency of container terminals in China and its neighboring countries and result in different customer service levels. The paper concluded that Chinese ownership is useful for improving efficiency but is not its strongest determinant. Intra- and interport competition may also be useful for enhancing container terminal efficiency. The paper also reports that efficiency growth is strongly related to increases in the hinterland's GDP.

Ownership Effect on Service Strategy Choice

The impact of institutional reforms on port efficiency changes in terms of ownership, corporate structure, and productivity changes was studied by Cheon et al. (2010); ownership restructuring was discovered to increase productivity, which benefits relatively large container terminals. Management teams in the private sector were found to be able to focus on terminal operation and service quality. The study employed the Malmquist productivity index (MPI) model to analyze data collected from 98 major world ports regarding the period 1991 to 2004. A similar study was conducted by Tongzon and Heng (2005) on the quantitative relationship between port ownership structure and port efficiency based on a sample of global container terminals, with the clear conclusion being that private sector participation can improve a port's operation efficiency and overall competitiveness by improving customer service. The changing demands of customers was also one critical determinant affecting the maintenance of high efficiency. An earlier study on the relationship between port ownership and port efficiency by Battese and Coelli (1995) was the first study to apply SFA to the port industry, despite SFA being applied to a number of other industries for the investigation of technical inefficiency. A similar study was not performed on terminals in Asia until

Cullinane et al. (2002) examined the influence of administrative and ownership structures on the efficiency of major Asian container terminals, additionally suggesting the “port function matrix” for use in the analysis of administrative and ownership structures. The study identified a strong correlation between terminal size and efficiency, and the transformation of ownership from the public to private sector was discovered to promote economic efficiency improvements. Cullinane et al. (2002) also indicated that private capital is commonly put into both existing and new facilities, and thus the level of market deregulation exerts a positive effect on efficiency. However, the actual customer service level or strategy was not explored using the port function matrix.

Statistical Tools Used for Empirical Analysis of Efficiency

Other than strategic decision attributes, such as port ownership as has been discussed, most studies have reviewed or compared estimations and measurements of the operations efficiency or inefficiency of ports and terminals by conducting surveys and statistical tools such as DEA, SFA, principle component analysis, the analytic hierarchy process, analysis of variance, and the Duncan test. Such tools have been employed to draw conclusions in a comparison of terminals regarding the list of attributes in different decision levels, in terms of efficiency. In particular, DEA has been applied in a number of papers to estimate efficiency indexes and compare the efficiency of multiple ports. DEA is a nonparametric approach that is commonly used but has various drawbacks, including high inaccuracy when sample sizes vary and other physical factors. Some authors have supplemented DEA with other methods to obtain better or more convincing results, whereas others have used it directly to sample data sets and draw conclusions. For example, Bichou (2013) investigated the operational efficiency of 420 container terminals from 2004 to 2010, hoping to identify a relationship between dynamic operating and market conditions, but did not share the corresponding customer service strategies that were used in response to different market conditions.

Effect of Port Groups

Dan et al. (2013) investigated 42 coastal container terminals in China using DEA; the terminals' comprehensive efficiency, pure technical efficiency, and scale efficiency were evaluated statistically, and scale inefficiency was concluded to be the primary reason for low efficiency in some coastal container terminals in China. The authors also demonstrated that efficiency tends to be higher in terminals on major navigation channels, such as Yangtze River Delta and Dohai Rim, than it is in terminals on the Southeast coast and Pearl River Delta. A substantial difference was identified in the efficiency of terminals belonging to different port groups. Some suggestions were offered, the most important of which was that terminal construction projects should be strictly controlled to avoid oversized terminals being built, which generally have low efficiency. However, the potential adverse effect of limiting terminal size on flexibility for future expansion was not discussed, and suggestions were limited to the study with short terminal lifespan without a reasonable scale of implementation and result measurement on business expansion.

Chinese Ownership of Terminals Worldwide

Wilmsmeier et al. (2013) investigated the evolution of the productivity and efficiency of 20 container terminals in 10 countries in Latin America, the Caribbean, and Spain for the period 2005–2011. They employed DEA to quantify the effects of the 2008 financial crisis and the subsequent economic development changes on container port productivity. Three commonly used indexes were used: the Fisher index (1922), Törnqvist index (1936), and MPI (1953). Of these three indexes, the MPI was suggested by the authors for use in analyzing productivity change in both the public and private sectors because it does not require behavioral assumptions or input prices, which are regarded as sensitive and confidential information in discussions of customer service strategy. The study identified effect breakdown due to technological change. Elsewhere, Yuen et al. (2013) summarized studies on container terminal efficiency (Tongzon, 2001; Turner et al., 2004; Cullinane and Song, 2006; Lin and Tseng, 2007; Gonzalez and Trujillo, 2008; Liu, 2009; Simoes and Marques, 2010a, 2010b; Wu and Goh, 2010). The authors applied DEA to estimate the samples' operation efficiencies and regression analysis to examine factors affecting terminal efficiency. In total, 21 ports in 12 locations were investigated, including various locations in China (such as Shenzhen and Shanghai), Hong Kong, Taiwan, Singapore, and South Korea. Efficiency scores were estimated and listed for each port from 2003 to 2007. Chinese ownership was concluded to be good for efficiency for most but not all terminals, and the study did not explain the impact on the corresponding customer service strategies, such as the priority with which vessels are served when the vessels belong to shipping lines with major Chinese shareholders.

DEA: A Commonly Applied Tool for Terminal Efficiency Study

Pjevčevića et al. (2011) reviewed DEA studies on port terminal efficiency by various authors (Tongzon, 2001; Valentine and Gray, 2001; Wang et al., 2002; Barros, 2003; Barros and Athanassiou, 2004; Cullinane et al., 2004; Min and Park, 2005; Cullinane and Wang, 2006; Kaisar et al., 2006) and indicated that DEA has been also employed to analyze the efficiency of dispatch rules by ranking them and providing a basis for decision-making (Braglia and Petroni, 1999; Kuo et al., 2008). To add to the literature, the authors applied DEA in a decision-making study of different dispatch rules and AGV configurations. The efficiency review aided definition of the objectives of planning under different operation conditions and service requirements. Sharma and Yu (2010) presented a decision-tree-based DEA model that enhances the capability and flexibility of classical DEA and applied it to the container port industry for productivity improvement. The application enabled decision-makers, especially those who deal directly with the customers of container terminals, to identify how to improve inefficient units to maximum capacity and make more favorable investment decisions. Hung et al. (2010) employed DEA to estimate the efficiency of 31 Asian container ports for benchmarking purposes. The ports were grouped by location—Northeast (9), East (12) and Southeast (10) Asia—without there being any differences in customer service strategy and vessel demand volume and pattern. The ports' operating performances, set-scale efficiency targets, and determined efficiency rankings were assessed using traditional DEA, the most productive scale size concept, the returns to scale approach, and the bootstrap method. Instead of using DEA only, some studies have applied both DEA and SFA in their efficiency analyses. For example, Cullinane et al. (2010) focused on the technical efficiency of container terminals by applying both DEA and SFA to the same set of data from the world's largest container terminal. They concluded that the results obtained using DEA or the distributional assumptions under SFA were more robust than those obtained using other methods. Efficiency estimates are not always reliable; thus, both approaches can be applied and their results compared. Cullinane et al. (2005) also investigated the relationship between port privatization and efficiency estimates by using DEA to determine the advantages and disadvantages of port privatization; an empirical examination of the relationship between privatization and relative efficiency within the container port industry was also provided. DEA is employed to analyze the relative efficiency of container ports and is applied to industry panel data in a variety of configurations. Cullinane et al. (2005) concluded with a rejection of the hypothesis that greater private sector involvement in the container port sector irrevocably leads to improved efficiency.

Shortcomings and Limitations of DEA

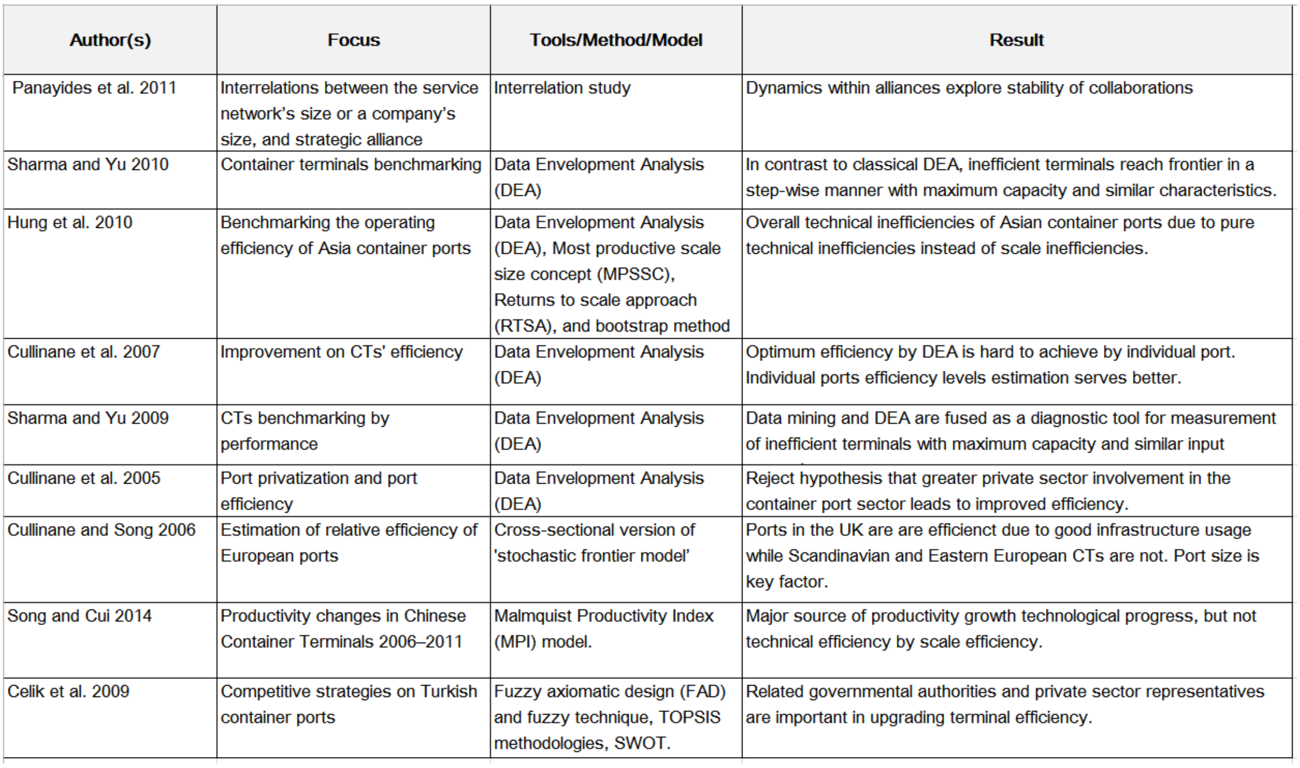
Sharma and Yu (2009) attempted to benchmark container terminals but reported that DEA should not be used to assess the relative efficiency of homogenous units and set benchmarks for inefficient units because the size, environment, and operating practices of the reference set may differ in reality. Ignoring these aspects of different container terminals introduces a bias into the DEA results. The authors proposed the use of DEA with data mining for more reliable results. Yan et al. (2009) also reviewed the use of DEA and SFA in terminal-efficiency-related studies, finding that these two approaches are commonly used. Correlations were addressed by Cullinane (2006) and indicated similar results. However, most studies have ignored the intrinsic characteristics of the port industry—the individual heterogeneity and changes in technical efficiency over time—and the maximum possible outputs may thus differ from existing study results. The differences in results are due to technological heterogeneity, which DEA cannot capture correctly and which no studies employing SFA have yet included. Cullinane and Song (2006) evaluated the relative efficiency of European container terminals using SFA; terminal size was found to be highly correlated with and critical in achieving relative efficiency, with geographical location also identified as a key factor. Scandinavian and Eastern European container terminals were found to have the lowest estimates of relative efficiency, whereas UK ports were discovered to be the most efficient in terms of infrastructure usage. The omission of labor aspects in related studies was indicated by Song and Cui (2014), who summarized recent studies on port and terminal productivity using DEA–MPI and demonstrated the high difficulty of obtaining accurate data. The paper argued that variables should be selected based on labor, land, and capital factors and filled this gap by using labor, land, and capital input variables and total TEU handled annually as the output variable. Some other studies have also reviewed port and terminal development, improvement strategies, or services. For example**,** Lu et al. (2010) studied the development strategies of a port in Taiwan by using factor analysis after collection of survey data from shipping academics, port authority employees, and shipping managers and executives. A total of 175 responses were useable out of 482 replies. SWOT analysis was first used to review the data, after which 21 attributes were established without pinpointing any differences in terms of customer service strategy. The formulation of competitive customer service strategies for container ports is also crucial when attempting to achieve the correct efficiency level. Celik et al. (2009) investigated a set of Turkish container ports by applying axiomatic design. Along the coast of the Black Sea and via the Istanbul Strait toward the Mediterranean, there are various sizes, types, and developing or operating container terminals. Only those terminals with an annual throughput of more than 100 thousand TEU were selected for investigation because of their relatively higher importance; those selected were Izmir, Mersin, Haydarpasa, Ambari, and Gemport. The axiomatic method was used as an efficient tool to solve multiple-criteria decision-making problems (Celik et al., 2007; Kulak, 2005; Kulak and Kahraman, 2005a, 2005b).

Summary: Customer Service Strategies Promote Cost Efficiency

In summary, a major proportion of the container terminal efficiency studies related to customer service have aimed to identify the key parameters that affect efficiency, as perceived by terminal management and customers, whereas another large proportion have tended to analyze competitive advantage due to ownership or organization structure. These are all valuable studies that have aided understanding of the importance of efficiency in a terminal, and they offer good demonstrations and developments of statistical techniques and methods. However, most of these studies did not consider the actual business situation: whether the pro formas of terminals were occupied by sufficient vessels and how many unused time windows there were.

In different situations, the corresponding customer service strategy could be entirely different and affect the level of direct effort and investment aimed at improving terminal efficiency.

For example, some terminals demand high investment in facilities and equipment, which is justified by their offering high efficiency to their customers, whereas other terminals prefer minimal operation costs at all times due to insufficient vessels and customers. Therefore, for a comprehensive and fair comparison of terminals' efficiency, the average handling volume per berth section or the average variable unit cost of a container may also need to be taken into consideration. It is also clear that many aspects are relevant when comparing terminals. For example, strategic decisions such as depth of navigation channels, geographical location, and terminal capacity; tactical decisions such as equipment availability, yard stack storage plans and arrangement, information system availability and robustness, and service charge settings; and operating decisions such as berth arrangement for a short upcoming period, refinement of current berthed vessel progress or estimated departure date and time, individual port stay setting, heavy lifting equipment (quay and yard crane) allocation, and transfer vehicle (internal tractors and straddle carriers) deployment. Currently, one terminal normally serves a few ocean carriers instead of a single liner only, and some of the customers it serves are alliance members (Panayides and Wiedmer, 2011), which jump across service loops weekly—from one terminal to another—due to a different member liner's contract with a different terminal operator. This further complicates customer service strategy and pro forma formulation. By reviewing the papers mentioned in terms of customer service strategy, a terminal can set up the correct operation efficiency level, customer demand pattern, priority settings, penalties and surcharges to and from customers, and customer and vessel size with or without the overbooking strategy being used; this will help them remain competitive over a long period of time and in periods of economy boom and bust. The key papers reviewed in this section are summarized in Table 2.3.



Author(s)	Focus	Tools/Method/Model	Result
Panayides et al. 2011	Interrelations between the service network's size or a company's size, and strategic alliance	Interrelation study	Dynamics within alliances explore stability of collaborations
Sharma and Yu 2010	Container terminals benchmarking	Data Envelopment Analysis (DEA)	In contrast to classical DEA, inefficient terminals reach frontier in a step-wise manner with maximum capacity and similar characteristics.
Hung et al. 2010	Benchmarking the operating efficiency of Asia container ports	Data Envelopment Analysis (DEA), Most productive scale size concept (MPSSC), Returns to scale approach (RTSA), and bootstrap method	Overall technical inefficiencies of Asian container ports due to pure technical inefficiencies instead of scale inefficiencies.
Cullinane et al. 2007	Improvement on CTs' efficiency	Data Envelopment Analysis (DEA)	Optimum efficiency by DEA is hard to achieve by individual port. Individual ports efficiency levels estimation serves better.
Sharma and Yu 2009	CTs benchmarking by performance	Data Envelopment Analysis (DEA)	Data mining and DEA are fused as a diagnostic tool for measurement of inefficient terminals with maximum capacity and similar input
Cullinane et al. 2005	Port privatization and port efficiency	Data Envelopment Analysis (DEA)	Reject hypothesis that greater private sector involvement in the container port sector leads to improved efficiency.
Cullinane and Song 2006	Estimation of relative efficiency of European ports	Cross-sectional version of 'stochastic frontier model'	Ports in the UK are are efficienct due to good infrastructure usage while Scandinavian and Eastern European CTs are not. Port size is key factor.
Song and Cui 2014	Productivity changes in Chinese Container Terminals 2006–2011	Malmquist Productivity Index (MPI) model.	Major source of productivity growth technological progress, but not technical efficiency by scale efficiency.
Celik et al. 2009	Competitive strategies on Turkish container ports	Fuzzy axiomatic design (FAD) and fuzzy technique, TOPSIS methodologies, SWOT.	Related governmental authorities and private sector representatives are important in upgrading terminal efficiency.

Table 2.3 Summary of key research on customer service strategy.

2.9 Operation Planning and Execution Strategy

Tactical and Operational Planning

Within operations planning and execution strategy, berth allocation has again attracted much scholarly attention for its clear value in terminal planning in the past few decades and has been deeply investigated for its obvious importance in terminal operation cost. The problem has been further classified into tactical and operational level problems. Tactical level problems have mainly focused on pro forma formulation, whereas operational level problems have focused on the realization of each operation cycle. It has been believed that the overall cost is minimized as long as the proposed objective function value, such as the total weighted vessel length of stay within a planning cycle, is minimized for a weekly period. A highly valuable follow-up survey by Bierwirth and Meiseal (2016) of the large number of berth allocation studies indicated the increasing complexity over time of the problem and also included consideration of quay crane schedule. Berth allocation at the tactical and operational level is certainly one of the most critical planning processes in a terminal. However, it is not the only critical process but rather the starting point of the overall operation planning and executive cycle, which also involves other crucial planning processes. These other planning processes and their interaction with berth allocation have so far been largely overlooked in the literature.

Berth Allocation as a Crucial Efficiency Driver

Berth allocation is an important starting point for planning each cycle; however, successful implementation requires strong and reliable support from close partners or functional teams—ship planning and yard planning. Without full planning support from these two planning teams, achieving the high terminal efficiency expected by the berth allocation team is difficult or even impossible and can result in a large discrepancy in cost and operation performance. Even if berth allocation is planned according to the best cost and efficiency level, the terminal operation conditions must be adjusted to reasonable and favorable levels to obtain the most favorable operation results and minimized cost. As illustrated in Figure 2.3, ship planning and yard planning are performed before vessels arrive at a terminal. During each team’s planning processes, crucial decisions are made in response to the latest berth allocation decision for all incoming vessels.

Critical Planning Processes behind Berth Allocation

When a vessel arrives at a terminal, its ship plan is executed in terms of container movement, equipment deployment, and vehicular tractor flow. Ideally, yard planning focuses on storage space preassignment before actual container pickup or grounding operation. In container pickups, containers are released from their yard block storage location to either a vessel or a pick up tractor, whereas container grounding is the receipt of containers from a vessel or external tractor and their storage in the yard block until the next step of their transport. Although they are named as a planning team, in real operations the yard planning team must also offer alternatives when the advanced planning cannot be actualized due to any ad hoc operation problems to ensure smooth yard operation in terms of equipment load balancing and vehicular traffic jam prevention. In the case of a one-berth terminal, the execution cycle may be simple, as illustrated in the upper part of Figure 2.5.

Terminals with Multiple Berths and Customers

Most container terminals have multiple berths and multiple vessels are planned at the same time once the berth allocation plan for each vessel's arrival, berthing, and departure is confirmed, as illustrated in the lower part of Figure 2.5. Thus, each vessel has its own ship plan and yard plan cycle before it is actually executed by the control tower team and a final result is obtained (e.g., on-time arrival, no "short-ship" case, on-time departure), and these cycles commonly overlap. For example, some vessels may be in the ship planning stage while others are starting the yard plan stage because they will arrive at the terminal and they thus receive higher priority in the planning stage.

Planning in Dynamic Situations

The ship planning team must catch up with the latest yard situation and plan vessels in such a way that does not affect the physical operations that are already or about to be underway. This helps to explain why multiple-berth terminals operate as multiple individual-berth terminals to avoid traffic jams or resource problems and further echoes our observation that rectangular and long terminal designs and layouts are the most common. The crossing-over of vessel execution cycles complicates the operation and adds variances for each vessel if the large set of resources is not properly managed. Moreover, the frequency of the berth allocation meeting is also critical for terminals because high costs are incurred if meetings are too frequent (e.g., hourly) whereas high penalties may result if they are too frequent (e.g., daily). Normally, at least two meetings should be held daily—for example, one in the morning before noon and another in the evening—to cover all the key decisions that must be made through communication and negotiation with the customer office, which keeps normal office hours only.

The two key planning teams perform planning tasks both for containers that are already in the yard and those "shadow containers" that will physically arrive later. They share the common objective of on-time vessel departure. Delay departure potentially incurs high penalties for the terminal, either directly and indirectly. Direct costs are normally focused on in studies, such as the penalty cost of a vessel's delay, whereas indirect costs, such as failure to arrange transshipment of a container from one vessel to another or failure to let an awaiting vessel berth and operate on time, are largely overlooked because of their complicated operation mechanism and penalty cost structure.

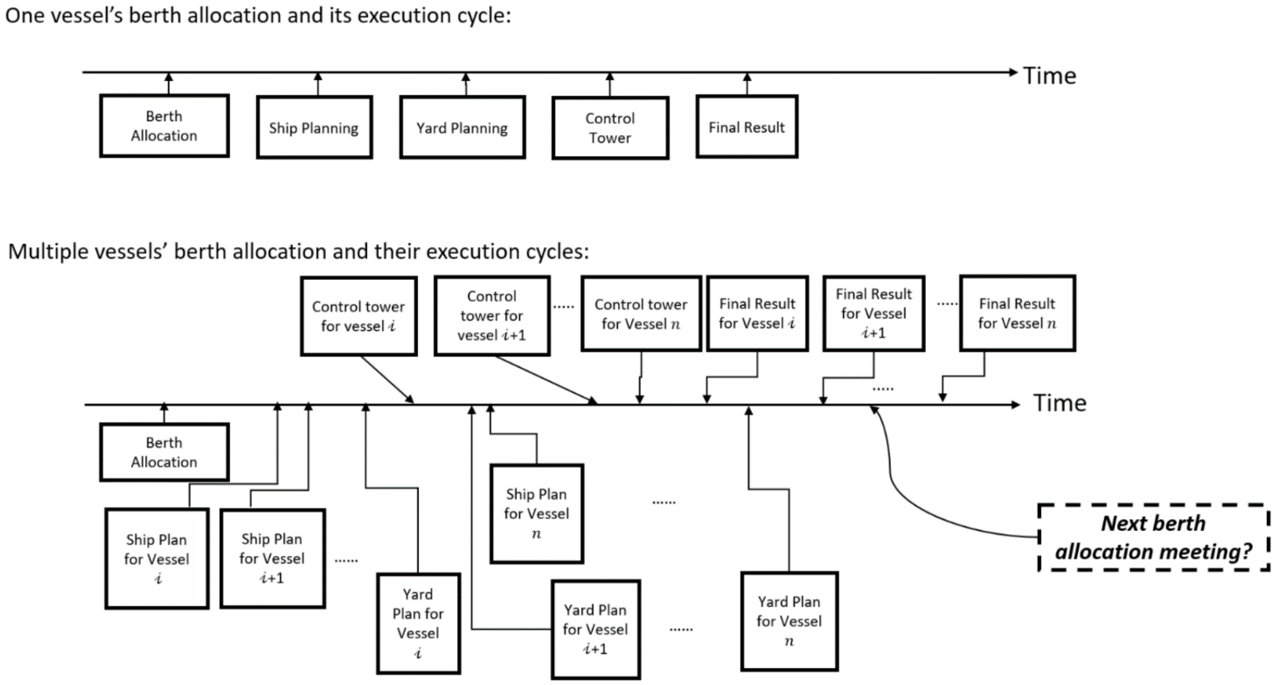


Figure 2.5: Berth allocation execution cycle for terminals with one and multiple vessel berths.

Mega-vessel Domination: Barge and Feeder Operations

In operations planning and production efficiency studies, it is clear that mega vessel handling has recently become a hot topic rather than the classical crane productivity and tractor dispatch optimization problems. Nishimura et al. (2009) studied the handling of transshipment containers in terms of different yard stacking strategies and terminal layouts. An optimization model was specified to investigate the flow of containers from mega vessels to feeder ships using temporary yard storage. A heuristic based on Lagrangian relaxation was formulated. The quality of the heuristic was tested in a number of experiments. Some basic assumptions were made in Nishimura et al. (2009). First, it was assumed that transshipment containers are carried by the first-leg vessel, which is the mega vessel, and that the second-leg vessel is a feeder vessel that delivers the containers to a smaller river port that is closer to the consignee. Such an assumption makes constructing the model easier but is not valid in real life because most transshipment ports act as two-way transshipment hubs, which means that the first-leg vessel could be the feeder vessel, not the mega vessel. This would add complexity to the model. Second, it was assumed that all loading boxes to be loaded onto the mega vessel have one unique loading start point, which means that concurrent loading activities could occur immediately after one time point only. This time point was defined as completion of total box discharge (all moved to yard), which is not practical for mega vessels, which have multiple bays requiring operation and the total number of containers to be discharged from each bay differs. Therefore, one vessel bay may only start loading after its discharge is fully or at least partially complete, but discharge from an adjacent bay may not have been completed at that time. Third, smaller vessels may be operated concurrently; for example, regional feeders may berth under one quay crane instead of waiting to berth and unberth sequentially, and some terminals arrange for three feeders to be operated concurrently under one quay crane.

Operations Planning: Extended Considerations on the Yard-Side

Transshipment of containers at container terminals has drawn some attention recently. In particular, Vis and Koster (2011) classified the decision problems that arise at container terminals. For various decision problems, an overview of relevant literature is herein presented and the quantitative models that attempt to solve the problems are discussed. Lee et al. (2011) reported an integer programming model for the terminal and yard allocation problem in a large container transshipment hub with multiple terminals. The model integrates two decisions: terminal allocation for vessels and yard allocation for inter- and intra-terminal transshipment container movement. The objective function minimizes the total inter- and intra-terminal handling costs generated by transshipment flow. A two-level heuristic algorithm was developed to efficiently obtain high-quality solutions, and computational experiments demonstrated the effectiveness of the proposed approach. Jiang et al. (2012) studied the storage yard management problem in a busy transshipment hub, where intense loading and unloading activities must be considered simultaneously. The need to handle huge volumes of container traffic and the scarcity of land in the container port area made it highly difficult for the port operator to provide efficient services. A consignment strategy with a static yard template was used to reduce the number of reshuffles in the yard that were necessary, but this sacrificed land utilization because of the exclusive storage space reservation required. Nishimura et al. (2009) investigated the storage arrangement of transshipment containers in a container yard to enable efficient ship handling operations at a terminal that served mega vessels. An optimization model was designed to investigate the flow of containers from the mega vessels to feeder ships using temporary yard storage. A heuristic based on Lagrangian relaxation was formulated. The quality of the heuristic approach was tested in a number of experiments. Various situations were analyzed with respect to mega vessel arrival rates, and some strategies for stack arrangements and terminal layouts were proposed. Sharif and Huynh (2012) studied storage space allocation at marine container terminals using ant-based control through a novel approach for allocating containers to storage blocks. The model of the container terminal was taken as a network of gates, yard blocks, and berths in which export and import containers are considered bidirectional traffic. Martin et al. (2014) evaluated the storage pricing strategies of import container terminals under stochastic conditions, presenting a model for determining the optimal storage pricing schedule for import containers. A generic schedule characterized by a flat rate and a storage time charge was adopted. The model considers analytically the stochastic behavior of the storage yard, because input and output flows are random variables, and it includes migration to an off-dock warehouse.

Market Conditions

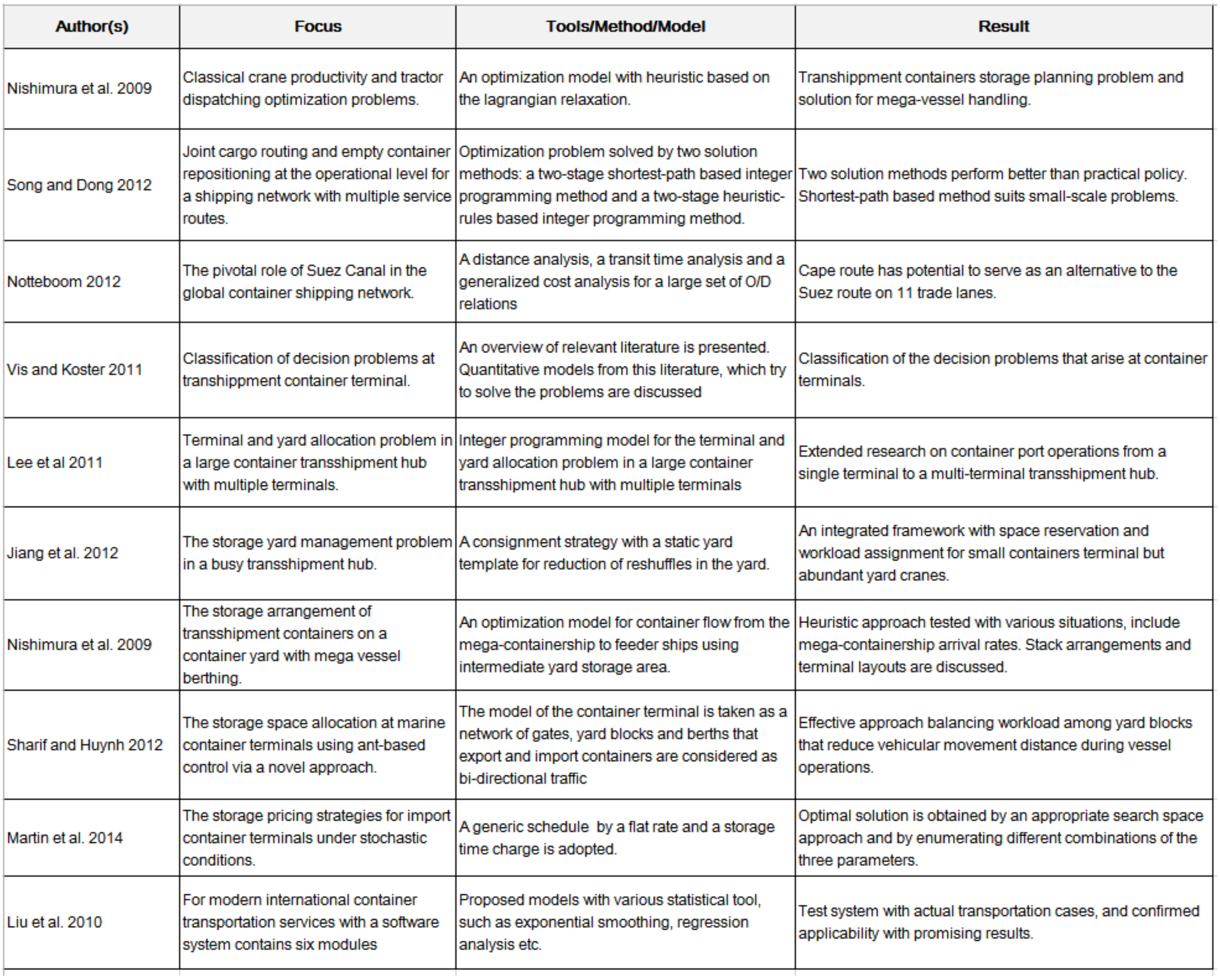
To fill a gap in the research, Bichou (2013) investigated the impact of operating and market conditions on container port efficiency and benchmarking. The author formulated a number of operational hypotheses to test the sensitivity of benchmarking results to a port's market and operating conditions; namely, production scale, cargo mixture, transshipment ratio, operating configurations, and working procedures. Additionally, Baird (2005) evaluated and compared competing seaport locations within a given region as the optimal site for international container transshipment activity. The main focus was on container transshipment hubs in Northern Europe. Transshipments were the fastest growing segment of the container port market at the time, and there was significant scope to develop new transshipment terminal capacity to cater for future expected traffic. Transport distances and associated shipping costs were calculated for existing hub locations and then compared with those of a proposed transshipment location in the region, in this instance the vast natural deep-water harbor at Scapa Flow in the Orkney Islands.

Research findings have revealed that the current container hub ports are not necessarily optimal for serving transshipment markets and that alternative port sites such as Scapa Flow could be superior and more competitive locations from which to support the quickly expanding transshipment market. Song and Dong (2012) considered the problem of joint cargo routing and empty container repositioning at the operational level for a shipping network with multiple service routes, deployed vessels, and regular voyages. Their objective was to minimize the total relevant cost on the planning horizon, including container lifting on and off costs at ports, customer demand backlog costs, demurrage (or waiting) costs at transshipment ports (for temporarily storing laden containers), empty container inventory costs at ports, and empty container transportation costs. Notteboom (2012) reviewed the pivotal role of the Suez Canal in the global container shipping network, in particular its role in accommodating vessels sailing the crucial Asia–Europe trade route. The details were analyzed, and it was concluded that the extent of development of trade lanes along the Cape route—as a competitive alternative to the existing Suez route—may severely affect the complicated terminal operation planning process.

Decision Support Systems

Decision support systems are increasingly investigated in studies related to container terminal operation and efficiency. For example, Liu et al. (2009) developed a decision support system using soft computing for modern international container transportation services; its software system contains six modules: demand forecasting, stowage planning, shipping line optimization, slot pricing and allocation, container distribution, and contribution analysis modules. The first three modules were presented in Liu et al. (2009). . Kim and Kim (2002) investigated the optimal size of storage space and handling facilities for import containers using a method that determines the optimal amount of storage space and optimal number of transfer cranes for handling import containers. A cost model was developed for decision-making. The cost model considers the space cost, investment cost of transfer cranes, and operating cost of transfer cranes and trucks.

Fan et al. (2012) studied congestion, port expansion, and spatial competition for US container imports. An intermodal network flow model was developed and used to analyze congestion in the container imports logistics system. The results indicated that congestion exists and increases costs at most ports, in some cases causing the diversion of traffic to other routes. Finally, if each of the ports were to be expanded, the marginal capacity would converge to zero and congestion costs and waiting times would be reduced. The key papers reviewed herein are summarized in Table 4.



Author(s)	Focus	Tools/Method/Model	Result
Nishimura et al. 2009	Classical crane productivity and tractor dispatching optimization problems.	An optimization model with heuristic based on the lagrangian relaxation.	Transhippment containers storage planning problem and solution for mega-vessel handling.
Song and Dong 2012	Joint cargo routing and empty container repositioning at the operational level for a shipping network with multiple service routes.	Optimization problem solved by two solution methods: a two-stage shortest-path based integer programming method and a two-stage heuristic-rules based integer programming method.	Two solution methods perform better than practical policy. Shortest-path based method suits small-scale problems.
Notteboom 2012	The pivotal role of Suez Canal in the global container shipping network.	A distance analysis, a transit time analysis and a generalized cost analysis for a large set of O/D relations	Cape route has potential to serve as an alternative to the Suez route on 11 trade lanes.
Vis and Koster 2011	Classification of decision problems at transhippment container terminal.	An overview of relevant literature is presented. Quantitative models from this literature, which try to solve the problems are discussed	Classification of the decision problems that arise at container terminals.
Lee et al 2011	Terminal and yard allocation problem in a large container transshipment hub with multiple terminals.	Integer programming model for the terminal and yard allocation problem in a large container transshipment hub with multiple terminals	Extended research on container port operations from a single terminal to a multi-terminal transshipment hub.
Jiang et al. 2012	The storage yard management problem in a busy transshipment hub.	A consignment strategy with a static yard template for reduction of reshuffles in the yard.	An integrated framework with space reservation and workload assignment for small containers terminal but abundant yard cranes.
Nishimura et al. 2009	The storage arrangement of transshipment containers on a container yard with mega vessel berthing.	An optimization model for container flow from the mega-containership to feeder ships using intermediate yard storage area.	Heuristic approach tested with various situations, include mega-containership arrival rates. Stack arrangements and terminal layouts are discussed.
Sharif and Huynh 2012	The storage space allocation at marine container terminals using ant-based control via a novel approach.	The model of the container terminal is taken as a network of gates, yard blocks and berths that export and import containers are considered as bi-directional traffic	Effective approach balancing workload among yard blocks that reduce vehicular movement distance during vessel operations.
Martin et al. 2014	The storage pricing strategies for import container terminals under stochastic conditions.	A generic schedule by a flat rate and a storage time charge is adopted.	Optimal solution is obtained by an appropriate search space approach and by enumerating different combinations of the three parameters.
Liu et al. 2010	For modern international container transportation services with a software system contains six modules	Proposed models with various statistical tool, such as exponential smoothing, regression analysis etc.	Test system with actual transportation cases, and confirmed applicability with promising results.

Table 2.4 Summary of key research on operations planning and execution.

Achieving the Correct Level of Efficiency

In summary, research on joint planning at ship and yard levels and the importance of such planning’s supporting roles in berth allocation has rarely been performed. Implementation using different yard and ship planning strategies up to the berth allocation or even customer service level by a terminal’s commercial team is critical but not investigated in the majority of the reviewed papers. Conversely, numerous valuable studies have been performed that have evaluated different yard stacking strategies, and some studies exist that have evaluated different ship planning strategies and their corresponding efficiency within a limited scope. The actual efficiency of a terminal is dependent on both types of strategy, rather than only one. Therefore, the benefits of the proposed sophisticated yard planning strategies may be diminished unless the corresponding ship planning strategy can be pinpointed. A terminal with experienced ship planners, however, may be able to prevent many potential operation problems—such as traffic jams or bottlenecks—when they review the export or transshipment container locations in the yard. Their work is sometimes praised as an art rather than a routine operation.

The actual execution of different operation strategies—such as cost minimization, highest productivity, or shortest vessel waiting time strategies—is also reflected clearly in the berth allocation process but not clearly in the planning process at the vessel and yard levels. Even if the yard planner is not highly qualified, the ship planner—with the strong support of the control tower team, who monitor the situation closely when vessel operation is underway—may be able to have a strong beneficial effect on the situation, resulting in smooth and continuous vessel operation. Therefore, many of the studies mentioned in this section could have been enriched by deeper consideration of the ship planning process in addition to the yard planning strategy, which would have identified a more reliable execution process and finally obtained the expected result in terms of cost, time, and quality. Such a result would determine the suitable input of resources over a definite planning horizon, the correct prioritization of customer demand, the appropriate feedback action, response, or reaction in terms of the revised resource input in the execution process, and benefit the terminal in the long term.

2.10 Perspectives of Decision-Makers: Port Systems

Broad Review of Port Systems

Different levels of scholarly attention have been given to different efficiency determinants, as seen in this review, and limited insight into future trends and development is also found for all proposed determinants. A critical review of container terminal efficiency must be comprehensive, strategic, and sustainable over time. With the clear objective to offer an optimal solution to a problem with a set of predefined constraints, operation research studies usually ignore qualitative influences. This may lead to oversimplification or over assumption when studying efficiency. A broader review perspective is thus essential to fill this research gap. Given the fact that container terminal problems are key and critical elements in port and maritime journals focusing on port management, port related studies were selected to review terminal efficiency in the big picture.

Port System and Efficiency Development

This review of the literature indicates that research on efficiency determinants requires a comprehensive understanding of port nature, location, and development during the port regionalization process (Hayuth and Fleming, 1994; Martin and Thomas, 2001; Robinson, 2002; Notteboom and Rodrigue, 2005), as viewed by serving shipping lines (Slack et al., 1996; Song et al., 2005; Fagerholt, 2004) and shippers (Nir et al., 2003). A terminal is no longer a standalone terminal operator, but instead serves as a total logistics and supply chain solution provider while attempting transformation with regional hub port development via port regionalization (Bichou and Gray, 2004; Lee et al., 2016). Terminal efficiency is not confined to operations efficiency within the terminal's premises (Dowd and Leschine, 1990)—represented by, for example, the gross crane rate quayside, productive movement ratio yard-side, or queuing time at the entrance—but is rather the efficiency of the overall solution when delivered to a customer (Carbone and Martino, 2003; Rodrigue and Notteboom, 2009; Zhang et al., 2014). An efficiency measure must thus cover door-to-door service route setting, end-to-end freight cost, and shipment time in the cargo handling time in the view of customers (Chou and Liang, 2001). A terminal is more than simply one of many nodes or checkpoints along the whole shipment cycle from origin to final destination (Rodrigue and Notteboom, 2009; Vermerien and Macharis, 2016). Good terminal performance and high efficiency—as defined in the past using measures such as the gross crane rate and annual throughput volume (Dowd and Leschine, 1990; Malchow and Kanafani, 2001; Medal-Bartual et al., 2016)—may not be able to counteract higher costs of deteriorating feeder or land-leg services (Robinson, 1998; Yang et al., 2014; Vermeiren and Macharis, 2016). Shippers view effective cost saving as the most critical selection criteria when choosing a shipping line. They select a service provider based on their service routes rather than choice of port or terminal (Slack, 1985; Nir et al., 2009; Vermerien and Macharis, 2016). The continuous cost-saving schemes of liners place direct pressure on terminal operators (Heaver, 1995; Cho and Perakis, 1996; Heaver et al., 2001; Song, 2003).

Port Systems: Limitations to Terminal Design

Terminal competitiveness, which is at least partially based on port performance, is in turn heavily based on “centrality” and “intermediacy.” These two key success factors were reported by Hayuth and Fleming in 1994 and used to explain the changing dynamics among top ranking ports. The two factors’ strong effects on terminal throughput volume and therefore the size of a terminal were indicated. Terminal size is thus clearly determined by throughput forecast when capacity is fully utilized, and breakeven is expected as investment is significant in the liner annual or regular report to shareholders. This applies to new building or expansion projects. Despite full efforts being made to estimate container handling volume to prevent oversizing and transshipment overarrangement, avoiding excess capacity in new terminals is not easy. A massive service volume may depart overnight and affect terminal business even when terminal efficiency is high. This happens when there is a critical change in service routes or port rotation by dominant customers (Cho and Perakis, 1996; Fagerholt, 2004). Liners or customers optimize fleet deployment using a well-defined problem set (Perkins and Jaramillo, 1991; Jaramillo and Perakins, 1991; Powell and Perkins, 1997). The situation worsens when new and cheaper inland or feeder legs are dominated by competitors who share the same hinterland (Rodrigue and Notteboom, 2009).

Port Nature and Development: Impact on Terminal Design

Increasing Cargo Flow

In addition to terminal size, terminal design and layout are also critically affected by the intrinsic geographical nature of a port, specifically whether the port is offshore or inland (Notteboom and Rodrigue, 2005). New offshore ports have higher flexibility when selecting their size, shape, and orientation than inland ports. Offshore ports comprise artificial islands extended from the natural landscape; they are surrounded by deep water but are far away from land transportation networks (railway and road transportation). Inland ports are constrained by the natural landscape, which mostly means that their waters are shallower. Offshore ports serve as pivot or hub ports and loading centers for megavessels in deep water channels, whereas inland ports and terminals, which normally serve feeder or smaller vessels, link cargo with land transportation, include railways (Notteboom and Winkelmans, 2001). A port system is required to offer continuous improvement in port and terminal efficiency for fierce intra- and interport competition in a region. Of the two types of port, traditional inland ports in particular are facing competition from offshore terminals (Notteboom and

Winkelmans, 2001), and expansion cost is high when normal operations remain unchanged (Notteboom and Rodrigue, 2005). Transformation in terms of terminal design and layout has not been investigated in detail for the world’s major deep water ports.

Decreasing Cargo Flow

Little and inadequate research has been conducted regarding ports undergoing downsizing, despite throughput volume decreasing continuously in some once-dominant ports (Suykens and Voorder, 1998; Baird, 2002; Xiao et al., 2016). Demand forecasting for both new buildings and expansions targets an optimal design and layout that will enable a terminal to breakeven, but such optimal designs have not been investigated or generalized due to the complex and unique geographical nature of each port region (Hayuth and Fleming, 1994; Chen, 1998). Different levels of automation result in large and irreversible design gaps and serve as a barrier to transformation unless a terminal site is extended or newly built. Smaller terminals are believed having lower barrier to achieve higher efficiency by Bichou and Gray (2004), who quote the conflicting results of terminal efficiency studies by Cullinane et al. (2002) and Coto-Milla’n et al. (2000). Building longer berth lines or bigger terminals to accommodate megavessels at hub ports, however, is considered absolutely necessary despite cargo handling volumes being subject to uncertainty, which directly affects operation efficiency. Customer details also affect terminal design and layout because of virtual partitioning in the case of a dedicated or home terminal (Heaver et al., 2000). Shipping lines may not be willing to be served by a port or terminal that is controlled by a competing operator.

Port Privatization: increasing efficiency

Port privatization can speed up efficiency improvements when privatization affects the organization, assets, and operations according to Baird (2002). Horizontal and vertical integration among terminal operators also affect terminal design and layout, with terminal sizes generally increasing after a merger or acquisition. When a shipping line has control over a terminal's operations, the terminal's design—at least in terms of berth length—is considered against the shipping line's vessel fleet. Dedicated berths, cranes, yard storage areas, and an on-dock agency office are possible for exclusive use of the new owner for high operational priority and efficiency (Fleming and Baird, 1999). This can have a particularly large effect in dedicated hub ports, at which the main sea routes intersect and the main flow of containers is split into individual feeder flows to and from river ports in the neighboring area. Higher priority should be given to smaller but frequent connecting vessels or feeders for transshipment cargo. Proper berths and yard design and layout are essential for the efficient movement of transshipment containers that must be lifted twice but occupy only one yard storage unit (Chen et al., 1998; Yang et al., 2014).

Port System: From the Classical Information System to eTransformation

Unlike physical aspects such as terminal land and design, the information systems of terminals previously had only a minor impact on efficiency, with information dissimilated through supplementary "News and Information" leaflets supplied to customers. Martin and Thomas (2001) compared port operations for break bulk cargo against those for containerized cargo and concluded that port operations efficiency is higher for containerized cargo, with operations completed substantially more quickly. Because of advances in information technology and Internet access, terminal information systems have developed rapidly and become a critical efficiency driver, as revealed in various efficiency studies (Carbone and Martino, 2003; Vermeiren and

Macharis, 2016). Lee et al., 2016 concluded the highest application scale in terms of eTransformation positively affecting both customer satisfaction and port competiveness. The authors suggested three key focus areas—the eWorkplace, customer relationship management, and security—if information system transformation is to occur and achieve the highest possible efficiency improvement.

Today’s Terminal: A Total Logistics and Supply Chain Solution Provider

Although the information systems of many terminal operators have become highly sophisiticated over the past two decades, there is an increasing need to broaden their context and have the networks of port authorities cover more decision-makers in the logistics and value-added supply chain (Notteboom and Winkelmans, 2001). A few articles have indicated that the port authority (Malchow and Kanafani, 2001; Song, 2003; Medal-Bartual et al., 2016) is the optimal party to foster information system development at the port or regional level to improve efficiency, and offer a framework for a complete terminalization process (Rodrigue and Notteboom, 2009). While most port authorities have been passive players in their previous responses to market changes (Robinson, 2002; Song, 2003; Notteboom and Rodrigue, 2005), port ownership changes and privatization (Baird, 2002) have resulted in faster response to market change and interport competition (Heaver, 1995; Heaver et al., 2000; Song, 2003).

Aggressive approaches are used to connect the hinterlands from which cargo originates, and infrastructure investment is financially supported by the corresponding port authority (Notteboom and Winkelmans, 2001), with intensive information system support also provided behind the scenes. Without proper and timely financing for both hardware and software, investment directed at building a bigger terminal for very large container carriers is not possible and the initiative may be quickly lost to competitors

(Slack, 1985; Malchow and Kanafani, 2001; Lee et al., 2016). The role of a port authority with a flexible economic policy (Goss, 1990) in developing a robust and “growth-oriented” information system governing the ultimate speed and target of terminal efficiency improvement is critical, despite terminal operators sometimes being reluctant to share information with a government agency.

Terminalization: Boosting Efficiency?

The customer service strategy of a terminal operator is affected by port regionalization, potential merger and alliance formation, and potential restructuring (Ryoo and Thanopoulou, 1999; Heaver et al., 2000; Midoro and Pitto, 2000; Slack, 2002; Song and Panayides, 2002). Despite the ranking of the top world ports having changed only slightly with time, the importance of securing cargo from the hinterland has remain unchanged for decades (Heaver, 2001). Terminalization is the current trend (Rodrigue and Notteboom, 2009), and the service scope of terminal operators has broadened from providing only traditional vessel operations to providing an all-round and comprehensive logistics and supply chain service. Terminal services and charges become part of the full service package when shipping lines negotiate with terminal operators a new or renewed service contract (Slack, 1985; Bichou and Gray, 2004; Vermeiren and Macharis, 2016). Despite having a long berth line, enabling servicing of longer vessels, a large container terminal may not be of a high economic scale if the intended terminal operations are not operated at their intended full scale.

Vessel Capacity and Terminal Efficiency

Vessel sizes are now reaching 20,000 TEU for very large container carriers, and the container shipping industry is facing an overcapacity problem in addition to historically low freight rates. When vessel utilization is not sufficient, it is natural for liners to consider a merger or alliance. Alliances affect the static customer base of a terminal operator. Stable customer space is a critical factor for resource planning in terminal yard operations, which require sufficient knowledge of cargoes' origin, volume, and seasonal pattern; unproductive yard movements result if this knowledge is not acquired (Chen, 1999, 2000), incurring higher costs. Chen (1999, 2000)The author indicated a clear difference between capacity utilization and economy of scale to vessel capacity. This implies a lower handling volume by a bigger vessel berthed at a terminal with a longer berth line, and it results in low berth–time utilization and affects efficiency. Conversely, numerous articles focus on competition (Slack, 1985; Heaver et al., 2000; Heaver, 1995; Fleming and Baird, 1999; Heaver et al., 2001) among a cluster of port or load centers (de Lengen, 2002)—such as the port of Hong Kong and the ports of Yantian, Shekou, and Chiwan—and the strong intention of these global terminal groups or operators to formulate a sustainable customer service strategy related to barge operational efficiency (Zhang et al., 2014).

2.11 A Broader Scope of Study: Research with New and Multiple Objectives

Operations planning and execution strategy are influenced by terminalization and result in a more complex terminal decision-making mechanism. Planning and execution of the activities performed within a terminal are affected by diversified activities outside the terminal area when the total logistics and supply chain solution is given high priority. In terminal operations priority assignment, for example, vessel berthing sequences become much more complicated than the standard FCFS approach of vessel waiting time minimization. For example, arranging for a late-arrival vessel to berth with the highest priority is logical when the vessel's cargo must be loaded onto a scheduled train while other on-time-arrival vessels are assigned a lower priority. Terminal management decisions sometimes change from classical vessel-level decisions to container-level or even cargo-level decisions if on-dock cargo handling facilities exist.

Resource Sharing among Neighboring Terminal Operators

To maximize company gross profit, a terminal must adopt a comprehensive approach in all key resource planning problems, resulting in higher cost of performing unavoidable and unproductive moves in the yard area (Chen, 1999, Chen et al., 2000). Even if the extra cost can be offset by the saving in land-leg delay, terminal needs to pay for a higher variable cost of daily terminal operations. Top levels of management are increasingly exploring the concept of resource sharing with adjacent terminal operators, especially when operators have common shareholders. Sharing terminal resources but not customers requires a clear definition of the right type of resources that should be shared to achieve the goal of cost saving, rather than cost increases (Yi et al., 2000). This adds extra pressure on midlevel terminal management. Operations planning on key resource allocation problems such as berth allocation may also extend to water channels (Dragovic et al., 2006).

The Port Authority: A Long-Term and Robust Efficiency Driver

The port authority has an active role in facilitating timely vessel berthing and the smoothness of operations including ocean–feeder, feeder–ocean, ocean–rail, rail–ocean, ocean–truck, and truck–ocean transfers. The port authority is no longer a passive landlord or government body that only reacts to serious and ad hoc incidents and accidents. By taking a vital role in supporting terminal operators in the port area through various time- or cost-saving measures—simplification of the customs process, provision of an online port-charge system, infrastructure investment, and subsidies for environmentally friendly vessels—ports remain competitive unless liner service routes are restructured (Notteboom and Winkelmans, 2001). A port authority in one region, if not a city or a relatively small country, interacts with other port authorities for both cooperation and competition, and this is named “co-petition” (Song, 2003). The business activities with an authority are simplified and more effort is made to satisfy advanced customer service requirements.

2.12 Summary

The efficiency of a modern container terminal is indicated by more than its throughput or gross crane rate. Cost-saving initiatives driven by liners with a wider scope of operations and services must be considered to secure highly loyal customers. Operational activities are no longer limited to terminal internal activities, but instead extend to activities that take place in hinterlands. The critical activities along the logistics and supply chain that affect the cost of a shipment are centrally controlled by the terminal planner rather than a liner’s individual service provider. Global shipping lines are transforming themselves into total transportation solution providers on paper, whereas physical cargo flow and arrangement with new value-added services remains centered on the port and terminal area. The shipment transfer process to and from hinterlands once vessel discharging has been completed is now executed by the terminal’s unique resource planning teams. Terminalization allows terminals to operate with a broader service scope but also adds uncertainty in efficiency setting in many more areas. It also implies that shippers and shipping lines have more choice when considering at which terminal to berth. A terminal cannot keep a customer unless it achieves high efficiency for the shipment’s operational activity out of the terminal area. Liners value high-quality solutions and make corresponding “stay or go” decision.

When a terminal’s customers are not loyal and global liners are intent on continuous cost saving, the terminal business becomes risky and potential for undesirable downsizing until a complete set of customers is resumed. Aiming for optimal operational efficiency is crucial in the high demand season, whereas lower efficiency may be adopted in the low season as far as possible. Downsizing a terminal or the planned efficiency downgrade of operations are worth consideration despite being difficult to top management team. When service routes are changed and customers leave at short notice, it becomes even more crucial for a terminal to use resources to ensure that highly loyal customers are retained. A robust mechanism for setting the right level of efficiency would ensure that effort spent improving terminal costs, process times, and service quality does not adversely and unexpectedly harm business profit. Terminal efficiency could be optimized selectively at the correct time, rather than the highest level being the objective at all times. With their expanded geographical and service scope, covering both terminal and hinterland operations, terminals need to redefine efficiency and develop a customized set of values for sustainable business growth. The four key efficiency determinants form a comprehensive picture for critical decision-making regarding efficiency and can ensure that excessive work is not performed or particular factors are overlooked.

CHAPTER 3 BERTH ALLOCATION WITH REBERTH CONSIDERATIONS

3.1 Introduction

Despite the fact that container terminal efficiency is affected by multiple factors, as explained in Chapter 2, the terminal berth allocation problem remains a key research topic for efficiency improvement. Many studies have attempted to improve terminal efficiency through cost minimization in the berth allocation problem. Typical berth allocation assumes the full availability of vessel workload for every vessel and ignores the significant variation in vessel schedules. Because numerous shipping procedures on the shipper side are performed according to the published vessel schedule, they may not be performed in time if the vessel arrives much earlier or later as was scheduled. Thus, in reality, loading containers may not be available when a vessel arrives at a port and terminal.

Although significant variations in vessel scheduling do not incur penalties for liners directly, a prolonged wait before the vessel can be operated after berthing is unavoidable. To achieve the highest vessel capacity utilization in the shortest vessel operation time, transshipment replanning and export container swapping among vessels are often initiated by liners that are in a hurry and have a limited choice of containers. Impromptu decisions made by liners must be physically supported by the terminal, which has no control over vessel schedules and lifting volumes. If a large number of containers must be quickly moved, terminal operational efficiency is decreased. Both liners and terminals have been negatively affected by this problem for years, given that no solution has been available. To solve this problem, a new method named “vessel reberthing” is introduced in this research to support both liners and terminals. A mathematical model is proposed to formulate the problem and obtain the best allocation and result. In the model, every vessel is reviewed strategically for its possibility to be split into two operation time periods and completed at their best time points. Experimental results indicate a clear improvement in penalty cost and terminal operational efficiency when the method is employed. This paper explores a new method of arranging berth allocation. Alternative types of carriers with divisible workloads can be applied and will benefit from the method, which can respond to quick and sudden changes in shipping demand.

Little research has investigated vessel operation waiting time in the past decade, despite this time directly affecting costs. A comprehensive solution for both liners and terminals is required so that they can make strategic decisions. When the length of stay of a vessel in a terminal is estimated, it is usually determined through an estimated equipment productivity rate for the predefined workload. The workload consists of loading containers that must be sent to different destination ports. Containers are always assumed to be available before the arrival of the vessel onto which they must be loaded. As the intended berthing time of their vessel approaches, all containers should reach the terminal and be stored in the best location for their loading and thus efficient vessel operation. Vessel scheduling and berth allocation are based on this assumption and are critical when calculating the penalty cost of a delayed departure and also the penalty cost of allocating the best berthing position. The best performance is achieved when the lowest operation and penalty costs are incurred. In practice, the ideal situation may not occur because of numerous uncontrollable and external factors. When a vessel does not arrive as defined on its schedule, the corresponding workload is not available as planned. Business decisions are made jointly by the liner and terminal. Various options may be considered, such as allowing the vessel a prolonged berthing period, arranging the delayed berthing of the vessel, or simply revising the vessel loading plan. Liners usually prefer not to waste vessel time or anchorage after they have arrived at port unless no berths are available. Once a vessel arrives at the port, it should be arranged to berth as soon as possible for the earliest possible discharge of operations and non-cargo-related activities, such as stores and parts delivery, bunker replenishment, and crew exchange. Transshipment replanning is thus performed more frequently than prolonged or delayed berthing. The vessel, SOA, or parent liner shall perform a detailed review and revise the list of containers to be loaded to maintain the planned vessel capacity utilization. During this process, some available containers are swapped in with increased priority whereas some containers that have not yet arrived are swapped out and rolled over to a subsequent vessel. This process affects not only the liner but also increases the burden on and administration cost to all parties related to the vessel, including the terminal and related member lines that share the vessel's capacity under an alliance agreement. Even if vessel capacity utilization is maintained after the replan, there are adverse effects on the shipper or consignee. The unexpected change of loading vessel or loading arrangement, represents low service reliability and bad operation management by the liner and terminal. This gives back impression to shipper and also to the customers of liners. Various important shipping, trading, and legal documents, such as the bill of lading, must be amended with the revised vessel name and transportation plan, potentially affecting the image of the company in the eyes of counterparts of the next level of customers.

Although replanning is common, some liners prefer their vessel to wait after berthing. Terminals may agree only if there is no vessel waiting behind it in the berthing queue. If one or more vessels are waiting, the terminal efficiency is affected adversely, At the terminal level, the vessel(s) that were scheduled to berth after the problematic vessel shall be delayed. A ripple effect is created in the schedule that affects multiple vessels within a short period of time. The terminal must then increase productivity by using more vessel transfer tractors to decrease the operation times of the affected vessels; otherwise, the ripple effect shall continue further along the schedule and affect even more vessels. At the liner level, prolonged berthing time incurs not only a higher berthing charge but also delays the vessel’s arrival at subsequent ports and terminals. This prohibits liners from using bunker cost-saving schemes, such as slow steaming, and results in a higher voyage cost. As a result, terminals tend to persuade liners to opt for replanning, and liners usually accept such a proposal. Even if it involves substantial container transfer, reshuffling, and rearrangement, the impact lasts a relatively short time and a smaller area of the terminal is affected. Replanning is a compromise solution and common practice whenever vessel schedule fluctuates widely enough to even affect the end shipper and consignee. The impact was further magnified when the three global alliances reformed and took effect in early 2017. More vessel capacity sharing among alliance members leads to higher replanning costs because replans affect more people in the industry. Alliance formation is thus triggering a deep reconsideration of new and better solutions to the common vessel scheduling problem in all ports and terminals.

An improved solution should benefit both liners and terminals through controllable cost, increased flexibility, and high applicability. Controllable cost indicates that key cost items are well-defined and controlled when new operational practices are adopted; one such key cost item is berthing charge per vessel berthing. Increased flexibility allows more options when operational decisions are being made, such as the berthing position of a vessel. High applicability ensures that a robust solution can be obtained for any vessel and without any prerequisites. One effective and quick solution to vessel scheduling problems is to arrange a vessel reberth. This solution does not require extra investment in the terminal's infrastructure and facilities or require investment by liners. An out-of-schedule vessel can first discharge containers with no or short waiting time and berth at any available position instead of a predefined berthing section that is adjacent to the yard-side loading containers. After the discharge operation is completed, the vessel temporarily departs and later returns to the terminal once the required workload (containers for loading) is ready. When the vessel reberths, its berthing position is arranged to be the closest berth to the loading containers' yard storage location. Because the majority of the loading containers were not available when the vessel first berthed, the yard storage area can be amended according to the berth section at which the vessel reberths. This new practice benefits terminals in several ways. First, it avoids sizeable container transfer within the terminal and maintains low operation cost as planned. A terminal's yard planners do not need to replan the storage location reserved for the discharged containers; the ship planners do not need to replan either as they plan for the containers after they have physically arrived at the later stage. In addition, reberth can increase resource utilization rate. Smaller berthing windows with shorter vessel staying time can be applied to the same vessel, resulting in a shorter port stay. These smaller berthing windows, even though they are physically long enough by berth length for a vessel to berth, are not used due to their being of insufficient time duration. Liners do not need to replan or coordinate with related member lines regarding the changes. From the shipper's or consignee's perspective, the vessel is normally operated and any late containers are arranged to be loaded as planned according to the latest vessel departure target time.

In summary, reberthing has benefits for both liners and terminals, increasing the overall operation efficiency of the terminal. A literature review of reberthing is presented in

Section 2, and the formulation of the vessel workload waiting problem is elaborated in Section 3. The mathematical model proposed for the investigation of the problem is detailed in Section 4, and the computation and analysis results are presented in Section 5. The paper is summarized and concluded in Section 6, with potential research directions suggested for further study.

3.2 Literature Review: Berthing Arrangements

Focus on Megavessels

Increasing numbers of berth allocation studies have addressed the crucial impact of megavessels in the past 10 years. However, no papers on vessel operation waiting time or reberths have been published. Indented berths for megavessels are considered to result in higher operating rates than conventional berths because of the shorter average distance between vessel and container yard for the same number of input yard trailers (Imai et al., 2007). Imai et al. (2007) was based on the assumption that all loading boxes are available when the mega vessel arrives, which is not true in practice. In transshipment terminals, the interaction between vessels is crucial. Imai et al. further extended their research to channel berth designs for megavessels. Higher flexibility and utilization were discovered when channel berth design was used compared with when the indented berth design was employed (Imai et al., 2013). A similar assumption was made about the mega vessel's priority: they were considered to berth upon arrival and not leave the terminal until vessel operation was completed. Vessel workload requirement was again not addressed; rather, it was assumed that the workload is always ready for loading. Imai et al. (2013) also suggested that megavessels do not visit a terminal often, which is not the case, as shown since megavessels have begun operation in the past few years. Vessel length has increased gradually from about 300 to about 400 meters, and the vessel carrying capacity has increased from about 10,000 to 18,000

TEU. Other than mega vessel considerations, there are two main types of berth allocation problem studies: (a) studies of berth allocation at the tactical level and its realization at the operation level; and (b) studies that consider berth, quay cranes, and other resources simultaneously to achieve an optimum solution, such as the lowest operation cost in terms of lowest vessel waiting time, optimal berth section matching, and flexible quay crane assignment.

Excessive Vessel Calls

For the berth allocation problem at the tactical level, Imai et al., (2014) investigated excessive vessel call when a new service contract is being negotiated. The selection of vessel among the existing planned vessels was studied for its high importance in subsequent daily operational berth allocation arrangements. The problem is called the berth template berthing strategy. However, transshipment requirements are not considered in the problem, even though they are a critical operation factor in practice; the requirements are skipped because of their high complexity. The allocation strategy in Imai et al. (2014) was therefore based on limited information. Nonetheless, the authors provided a clear definition of the berth template problem (BTP) and berth allocation problem (BAP), highlighting the main difference between them. The cycle time is limited in the BTP, whereas in the BAP, no time limit or end to the cycle time is established. A similar problem was considered by Zhen (2015), who defined the unloading and loading volume to be handled of each vessel in terms of uncertain operation times. Stochastic programming was employed to solve the problem, with arbitrary probability distributions assigned to the vessel operation times. The optimal solution was found using a robust formulation and without considering transshipment between vessels or vessel workload waiting time.

Minimization of In-Yard Container Storage and Transfer Cost

For the BAP at the operational level, instead of minimizing the operation cost, as is usual, one interesting study optimized yard performance. Gialombardo et al. (2010) had the objective of yard operation cost minimization in terms of the number of yard cranes employed and yard storage capacity usage. The housekeeping demand due to transshipment containers was minimized. However, high flexibility was assumed in the vessel operation time period to allow the terminal's cost saving, without incentives assumed to be given to liners to ensure their support. Therefore, the assignment of vessel operation time periods as multiples of the container terminal work shift is difficult in practice. Additionally, it increases the number of quay cranes required to work on the longer-port-stay vessels and also leads to high operation cost at the quayside. A final cost saving for the terminal as a whole is not guaranteed. Nonetheless, Gialombardo et al. (2010) offered a hint of how berth allocation and vessel operation time periods can be adjusted in favor of both terminals and liners. Busy container terminals do not prefer prolonged vessel operation times unless they are of obvious benefit to liners; if they result in a higher loading volume per vessel berth, for example. The operational problem was further expanded, considered at the tactical level, and solved using a biased random-key genetic algorithm by Lalla-Ruiz et al. (2014) instead of the Tabu search operation embedded in the heuristic algorithm used by Giallombardo et al. (2010). The advancement in the solution algorithm was limited to operation practice without reberth consideration.

Key Attributes in Berth Allocation Studies

The tactical-level BAP is normally solved using mixed integer programming (MIP) without the consideration of detailed equipment and manpower schedules. The connection between the tactical and operational levels was investigated using a simulation optimization framework by Legato et al. (2014). Randomness in discharge and loading operations was taken into consideration using an event-based simulator. The results of the study indicated a clear connection between the BTP and the BAP, but transshipments were again ignored at both levels. In a follow-up survey paper on the same topic (Bierwirth and Meisel, 2015), the BAP formulation was summarized using four attributes: spatial factors (berth layout and water depth; problem inputs), temporal factors (vessel arrival process; problem input), handling time (vessel's port stay; problem input), and a performance measure (the objective function of the problem, such as minimum waiting time before berthing, minimum port stay, or minimum late vessel departures. The measures are applied to all vessels, with weights assigned to combined performance measures in the objective function. New issues within berth allocation planning have also been summarized: environmental factors or tidal constraints, such as tidal access (Xu et al., 2012), fuel consumption and emissions (Raa et al., 2011), and direct transshipments (Liang et al., 2012). In particular, a simplified direct transshipment study by Liang et al. (2012) assumed that transshipment demand is limited to a unique pair of vessels; the supply and demand vessels were not expanded to one-to-many or many-to-one or finally many-to-many scenarios. Nevertheless, Liang et al. (2012) represented a favorable starting point on which a generic model can be constructed. Vessel arrival and departure time, vessel port stay, desired berth section, and quay crane assignment were considered simultaneously to obtain a complete solution.

Quay Considerations

The berth and quay crane problem is classified as an integrated problem because the quay crane assignment and scheduling problems themselves comprise a type of scheduling problem, named the QCSP. This problem does not consider berth section but aims to solve the BAP for a single vessel when a set of assigned quay cranes (QCs) are used to load and unload containers. Four attributes are defined in this problem: the task attribute (the complexity of aggregation of container stowed on the arrived vessel for unloading or vice versa), crane attribute (the properties of the crane resources, such as their start time and initial position or any restriction on the QCs' available time window), interference attribute (QCs cannot pass each other if they are mounted on rails; the safety clearance for two adjacent QCs at work), and performance measure (task completion time, crane finish time, or more explicitly, the throughput of cranes, which is defined as the number of TEU per hour.) Studies that have attempted to solve the QCSP have mainly focused on QC performance. QCs are assumed to be stationary while vessel operation is underway. However, this is not true in real life; a QC can move a certain distance during vessel operation. New issues in the QCSP have included the indented berth design, where QCs are installed on both sides of a mega vessel (Boyen et al., 2012), mobile crane platforms (Nam and Lee, 2013), crane ranges (Monaco and Sammarra, 2011), yard congestion (Choo et al., 2010), and double cycling (Lee et al., 2014), but they have not been investigated in detail in terms of vessel temporary departure after the discharge operation or the increasing need to wait for vessel workload.

Transshipment Cargo Assumptions and Limitations

Because of the increased number of attributes affecting berth allocation, integrated planning has been performed for a more reliable estimate of possible facility, equipment, and resource settings. The BAP, QC allocation problem, and QCSP were solved jointly by Bierwirth and Meisel (2015), but the high complexity added difficulty to the merged problem. Merging problems into one overall and large problem can obtain the best solution, but various integration mechanisms must be developed to solve the problem stage by stage. A favorable feedback mechanism must be set up that is performed until a criterion is met, even if the obtained solution is not guaranteed to be optimal. To ensure that the optimal solution is obtained from a given initial solution, a cutting plane technique can be applied when QC assignment and sequence are taken into consideration during berth allocation. It is proved that a cutting plane technique could yield an optimal solution. Instead of berth allocation of ocean-going vessels, feeder vessel management at a transshipment container terminal was investigated in a recent study (Lee and Jin, 2013). The arrival times of feeders were adjusted with respect to their mother vessel, which was considered fixed once the arrival time was reported. Transshipment and container exchange between the megavessel and smaller vessels (but bigger than feeder vessels) were ignored. Lee and Jin (2013) considered both berth allocation and transshipment flow but limited the schedule of the mother vessel. The problem was formulated as a mixed integer problem and solved using a mimetic heuristic (a hybrid metaheuristic) to efficiently obtain near-optimal solutions. This was done by combining a genetic algorithm and Tabu search operation. Transshipment container movements within a terminal (not between vessels) as well as between terminals were considered a terminal and yard allocation problem by Lee et al. (2012), who suggested a two-level heuristic algorithm to efficiently obtain high-quality solutions. Direct transshipment between vessels was again ignored, but the optimal yard location for the temporary storage of transshipment containers was identified. The results were elaborated upon by the same authors in another recent study (Jin et al., 2015). The problem was viewed as an integration of three individual tactical decision problems in container terminals—berth, yard, and schedule template design—and the study aimed to solve the quayside berthing congestion problem by improving workload distribution. The method used was mixed integer programming (Lee and Jin, 2013). A column-generation-based approach was employed to obtain near-optimal solutions. The recent popular branch-and-bound step was used after a basic column generation through an extended column generation procedure. Jin et al. (2015) briefly addressed vessel workload but did not directly focus on it. In summary, vessel workload waiting time has not yet been investigated in detail, and nor has berthing flexibility in terms of a vessel reberth.

3.3 Problem formulation

Cost Justification

To illustrate the problem caused by vessel workload waiting time and justify the feasibility of arranging reberths to decrease costs, the reberth and resource idling costs for a typical-size vessel in the port of Hong Kong are used as an example. The vessel considered is the OOCL Atlanta, which is 323 m long and has a registered gross and net tonnage equal to 89,010 GT and 59,077 GT, respectively.

The total reberth cost consists of the five major cost items listed in Table 3.1. Pilotage comprises the flat charge, HKD4,700 per vessel, plus a variable charge, HKD0.0625 per gross ton per vessel. Therefore, the variable pilotage charge on the vessel equals HKD0.0625 multiplied by 89,010 GT, which is HKD5,200. The total pilotage cost thus equals HKD9,900. For simplicity, this is rounded up to HKD10,000. The service charge per tug boat depends on the tug boat’s power in units of brake horsepower (BHP). A normal tug boat’s power ranges from 3,200 to 5,000 BHP. A tug boat consumes petroleum differently based on its power design. The resulting cost is reflected through different service charge rates. The service charge is approximately HKD3,800 to HKD7,000 per hour per tug boat. Our example vessel requires one and two tug boats when departing from and arriving at the terminal, respectively. The tug boat power required varies depending on the cargo volume on board the vessel. To be conservative, we assume that two tug boats are required for both departure and arrival to avoid cost underestimation. The average cost per tug boat is assumed to be HKD5,000. Thus, the total tug boat cost is estimated as HKD20,000. For mooring cost, which is charged by the container terminal, and two gangs of labor are needed for both departure (unmooring) and arrival (mooring). Five to six men form one gang, and the cost of each set's shift is approximately HKD4,000. The shift period is normally 12 h. Because mooring and unmooring tasks require less than 1 h, full shift payment is normally replaced by partial payment, as agreed on beforehand by the gang service company (contractor) and container terminal. We estimate that the total cost of mooring and unmooring is HKD4000 multiplied by 4 and divided by 2; this means that half of the shifts of the four gangs are paid for, equaling HKD8,000. Thus, we estimate the cost as HKD10,000, which is a relatively conservative estimation because some terminals pay the actual labor requirement (normally 3 to 4 men only). Regarding bunker cost, the estimated bunker volume of our example vessel when it departs from the terminal and sails to a waiting area is approximately 8–10 tons. Assuming a cost of USD430 per ton (average market rate of bunker), the estimated bunker cost is HKD35,000 for departure and the same amount for arrival. This gives a total bunker cost of HKD70,000. The anchorage cost is charged by the port authority; there is no service charge for the first 12 h. Thus, if the example vessel temporarily stays in the port's waters for less than 12 h, it does not pay an anchorage charge. The hourly rate for each subsequent hour is HKD0.015 per net ton per vessel. Therefore the hourly cost for our example vessel is HKD886. Because it is unlikely that the vessel will wait to rebirth in the water area for more than 24 h, we assume that the vessel stays for a maximum of 24 h. The estimated anchorage cost is then HKD886 multiplied by 12, which equals HKD10,633. We assume that the cost is HKD10,000. This is also a conservative estimation that we hope covers all possible eventualities in terms of different lengths of temporary stay.

Re-berth cost (HKD)

Cost item	Charges
Pilotage	10,000
Tug boat	20,000
Mooring	10,000
Bunker	70,000
Anchorage	10,000
Total	120,000

Table 3.1 Reberth cost for a typical 323-m vessel in the port of Hong Kong.

Idling Cost: Opportunity Cost

We estimate the resource idling cost in terms of the opportunity cost when a QC operates and lift normally. If the QC is not idle, it is in operation and generates income for the container terminal. The lifting rate ranges from 20 to 28 containers per QC per hour, depending on the operating conditions including the operator's skill, terminal operation input resources, and physical position of containers in the vessel. We take a conservative lifting rate of 24 in our calculation. One lifting unloads one 40' or two 20' containers from the vessel to the quay deck, and the loading operation is similar. The service charges for lifting vary, depending on the size of the container and its destination. The average service charges for a fully loaded 20' container for long haulage and with an intra-Asia destination are approximately HKD1,500 and HKD800, respectively; in the case of 40' containers, the charges are not doubled but multiplied by 1.5. The total estimated lifting cost for 20' and 40' containers are HKD1,150 and HKD1,725, respectively. We assume that the terminal handles similar volumes of long haulage and inter-Asia containers. The total estimated cost is listed in Table 3.2.

Lifting per QC per hr	20	22	24	26	28
Resource idling cost (HKD)					
20' container	23,000	25,300	27,600	29,900	32,200
40' container	17,250	18,975	20,700	22,425	24,150
Total	40,250	44,275	48,300	52,325	56,350

Table 3.2 Resource idling cost per QC per hour in the port of Hong Kong.

Breakeven Analysis

Now that the reberth and resource idling costs have been established, we can estimate the number of hours that vessel would hae to wait away from a berth to make a re-berthing worthwhile (Table 3.3). The results show that in the situation where a vessel is awaiting a berth, if our example vessel stops operation for approximately 2.5 h, the resource idling cost is already equal to the cost of a reberth even if only one QC is deployed to serve the vessel. Generally, three or four QCs are deployed to serve a vessel of the example vessel's size (323 m). This means that one QC normally serves every 80 to 100 m of quay length. Therefore, we focus on the breakeven hours in the case of three or four quay cranes, which are both shorter than 1 h.

QC	**Idling cost per hour**	**Breakeven hours**
1	48,300	2.48
2	96,600	1.24
3	144,900	0.83

4	193,200	0.62
5	241,500	0.50

Table 3.3 Vessel resource idling cost in the port of Hong Kong.

This finding reveals shows that reberthing is applicable and justifiable for a typically sized vessel. Once the vessel has ceased operation for approximately 1 h, the cost of a reberth is already less than the terminal resource idling cost that would have been incurred. Theoretically, the QC that would have otherwise been idle may move to serve another vessel. However, it could only move within a limited scope. Because of the length of the example vessel, only a limited number of QCs could be moved out and serve another vessel. Additionally, this could only be performed if there was appropriate supplementary workload for the QCs. For a typical terminal with continuous vessel berthing demand, vessels are assigned dedicated QCs. Extra QCs may not always be helpful but instead a burden. Because temporary vessel departure is not common practice in normal daily operation, equipment idling time could not be avoided. In the next section, we develop a cost model that aims to solve this problem with reberth consideration to free up idling resources for employment on other vessel(s).

3.4 The Model

In our proposed mathematical model, i is a positive integer with a unique value from 1 to V where V is the number of the last vessel to be handled in this berth allocation process. It also indicates the total number of vessels in the berth allocation process. Reberth of vessel v_i incurs a cost for the vessel's shipping line of R_i. For our example vessel of length 323 m, this cost is equal to HKD120,000, as listed in Table 3.1. If vessel v_i waits at the berth line, a cost is charged by the container terminal. The hourly rate

h_i is the cost for each unit of berth length and is estimated by the total resource idling cost divided by the length of the vessel. For example, h_i is estimated as [(144,900 + 193,200)/2]/323 and equals HKD523 per meter per hour for the terminal at which our example vessel berths. The vessel arrival time a_i is decided by the shipping line and is communicated to the container terminal. A penalty cost C_i is incurred by the terminal if the vessel must wait. The penalty cost varies by port and by shipping line, directly or indirectly. For example, one shipping line may not charge a penalty but requires its vessel to depart at the preagreed departure time. This implies that more input resources are required for the operation of delayed vessel. Other shipping lines charge penalty costs in terms of a discount on the overall payment. The estimated penalty cost in our case is estimated to be HKD10,000 per delayed hour per vessel. Vessel size, s_i, is the length of the vessel in units of meters. The vessel priority weighting, w_i, is the weight assigned to vessel i. If all vessels have equal weight, all weights are equal to 1. In reality, some vessels are more important than others because of the higher penalty cost that is incurred if their arrival or departure is delayed, or for other reasons that have been explained; in such cases, the vessels have a priority weight of more than 1. The higher the weight, the higher the penalty cost that could be incurred. For simplicity in our study, we assume that the maximum weight is 2, which implies that the importance or penalty cost of one vessel may be double that of another vessel. The weights thus range from 1 to 2.

Model formulation

Parameters

i : positive integer with unique value from 1 to V

L : total berth length (m)

T : total planning period (h)

V : total number of vessels for planning

p_1^i: processing period for vessel i for its first berth

p_2^i: processing period for a vessel i for its second berth (reberth)

l_i: length of vessel i (m)

a_i: arrival time of vessel i

β_i: initial waiting period required before loading can begin (workload waiting time) of containers for vessel i (h)

h_i: cost per unit waiting time period per unit berth length

R_i: cost of reberth for vessel i (HKD)

w_i: priority weighting of vessel i; $1 \leq w_i \leq 2$

C_i: cost per unit time delay for the first arrival of vessel i

D_i: cost per unit time delay for the second arrival of vessel i

M, N: two large positive numbers

Variables

u_1^i: mooring time of vessel i in its first berthing

u_2^i: mooring time of vessel i in its second berthing

v_1^i: starting berth position of vessel i in its first berthing

v_2^i: starting berth position of vessel i in its second berthing (reberthing)

α_i: final time required before loading begins of containers to a berthed vessel i; positive or zero

$\sigma_{il,jk}$: 1 if the kth berthing of vessel j is completed before the start of the lth berthing of vessel i; otherwise 0.

$\delta_{im,jn}$: 1 if the tail of the nth first berthing of vessel j is located closer to berth line starting point than the head of the mth berthing of vessel i; otherwise 0.

x_i: 1 if vessel i is arranged for a reberth; otherwise 0

Objective function:

$$\text{Min. } \sum_{i=1}^{V} \{[(1-x_i)\alpha_i\, h_i\; l_i + \; x_iR_i] + C_iw_i\big(\, u_1^i - \; a_i\big) + x_iD_i\; w_i(u_2^i - (u_1^i + p_1^i + \alpha_i))\} \tag{1}$$

Subject to:

$$u_1^i \;\geq\; a_i \tag{2}$$

$$u_2^i \;\geq\; \; u_1^i + \; p_1^i + \alpha_i \tag{3}$$

$$0 \leq \; v_1^i \leq \; L \; \text{-} \; l_i \tag{4}$$

$$0 \leq \; v_2^i \leq \; L \; \text{-} \; l_i \tag{5}$$

$$|v_2^i - \; v_1^i\,| \leq \; x_i\;\; M \tag{6}$$

$$|u_1^i - \; u_2^i - p_1^i - \alpha_i\,| \leq \; x_i\;\; \mathrm{N} \tag{7}$$

$$x_i - 1 < \; \alpha_i \tag{8}$$

$$\alpha_i - \Big(a_i + \; \beta_i - \big(\, u_1^i + p_1^i\big)\Big) \geq 0 \tag{9}$$

$$u_2^i - \big(u_1^i + p_1^i\big) \geq 0 \tag{10}$$

$$(1 - x_i\,)(\,R_i - \; \alpha_i\; h_il_i) + \; x_i(\alpha_i\; h_il_i - \; R_i) \;\geq 0 \tag{11}$$

$$u_s^j - \big(\; u_t^i + \;\; p_r^i\big) \geq (\;\; \sigma_{il,jk} - 1\,)M \tag{12}$$

$$v_s^j - \big(\, v_t^i + \;\; l_r\big) \geq \big(\,\delta_{il\,,jk} - 1\,\big)N \tag{13}$$

$$\sigma_{il\,,jk} + \sigma_{jl,ik} + \; \delta_{il,jk} + \delta_{jl,ik} \;\; \geq 1 \tag{14}$$

$$where\; s, t, r, l, k, m, n \;\; \in \{\,1, 2\,\}$$

The objective function (1) minimizes the summation of the three major operation cost items for the container terminal for each vessel i. Each item is elaborated as follows:

The first item $[(1 - \; x_i)\alpha_i\; h_il_i + \; x_iR_i]$ is the cost of a reberth R_i when x_i equals 1 or the cost of workload waiting caused by vessel i. In particular, if α_i equals 0, x_i is smaller than 1 by inequality (8), and therefore the first cost item is always 0. If, however,

α_i is larger than 0, x_i is smaller than $1 + \alpha_i$. This means that x_i equals 0 or 1 depending on the vessel's arrival time, final workload waiting time (if any), and the processing times of the vessels under consideration.

The second item $C_i w_i(u_1^i - a_i)$ is the cost of the delayed arrival of vessel i when it berths for the first or the only time. When a vessel is arranged to berth-on-arrival (BOA), u_1^i equals a_i, which itself is equal to or greater than 0. w_i equals 1 if all the vessels are assigned equal weights. Otherwise, any vessel with w_i bigger than 1 has higher priority than the other vessels and is scheduled earlier in the time–space diagram. This ensures that the high priority vessel berths on arrival.

The third item $x_i D_i\, w_i[u_2^i - (u_1^i + p_1^i + \alpha_i)]$ is the cost of the delayed arrival of vessel i when it berths for the second time. This item equals zero when x_i equals 0 and is nonzero when x_i equals 1. When x_i equals 0, no reberth is arranged and vessel i is arranged to berth once only; when x_i equals 1, a reberth is arranged and any delay of this second berthing also incurs a cost. The vessel could berth any time later than $u_1^i + p_1^i + \alpha_i$, which is the time point at which the workload becomes available. This time point is estimated only after vessel i has completed the first part of the operation that uses time period p_1^i after its first berthing at time point u_1^i and waited for a period α_i outside the terminal (at the terminal's nearby anchorage area).

Inequality (2) ensures that the first or only berthing time of vessel $i,$ u_1^i, is always equal to or later than the vessel's arrival time a_i, whereas inequality (3) ensures that the second berthing time of vessel i if applicable, u_2^i, is always equal to or later than the time point $(u_1^i + p_1^i + \alpha_i)$, which is the time point at which the workload becomes available for the second part of the operation of vessel i. The second berthing time is selected depending on the decision of how to minimize the objective function. To ensure the berthing point of vessel i, inequalities (4) and (5) are required because regardless of whether the first and only or second berth of vessel i is considered, the berth length L is constant. If it is decided that the vessel will not reberth, the berthing point of vessel i does not change and thus inequality (6) is needed; x_i equals 0; $|v_1^i - v_1^i| \leq 0$; and the only possible choice of v_2^i is the value of v_1^i when x_i equals 0. On the other hand, if x_i = 1, a reberth is arranged for vessel i and the second part of berthing for vessel i must be arranged. The berthing position could be the same as the first berthing point or could be any other position, depending on the decision of how to minimize the objective function.

Again, if a reberth is not considered, inequality (7) is needed to ensure that the second berthing time of vessel i occurs at $(u_1^i + p_1^i + \alpha_i)$. When a reberth is not arranged, x_i equals 0; $|u_2^i - (u_1^i + p_1^i + \alpha_i)| \leq 0$; and the only possible choice of u_2^i is $(u_1^i + p_1^i + \alpha_i)$, making the value $|u_2^i - (u_1^i + p_1^i + \alpha_i)|$ equal to 0 when x_i equals 0. Conversely, if x_i = 1, a reberth is arranged for vessel i and vessel i berths again at time u_2^i, which is free to be any time point after $(u_1^i + p_1^i + \alpha_i)$. Thus, the second berthing time is selected depending on the decision of how to minimize the objective function. When there is no workload waiting time (α_i = 0) for vessel i, inequality (8) is needed such that when α_i equals 0, $x_i < 1$, and the only possible value of x_i is 0. Conversely, when the final workload waiting time α_i of vessel i is positive and nonzero, x_i can take the value 0 or 1, depends on the decision of how to minimize the objective function.

The required value of α_i is always equal to or larger than 0 for each vessel, as ensured by inequality (9). Inequality (10) ensures that the start of the second operation always comes after the end of the first operation for each vessel i. Finally, inequality (11) is needed to suggest a vessel i for a reberth if and only if the cost of reberth R_i is lower than the cost that would be incurred by the vessel waiting at the terminal for the final workload waiting time α_i.

In the following, we present and prove two propositions:

Proposition 1. A berth allocation case (namely, a basic case) wherein there is a final workload waiting time α_i and a reberth is planned always incurs the same or a lower cost than a case for which a reberth is not planned.

Proof. Two cases are considered:

Case 1. If $\alpha_i = 0$, no reberth is needed or could possibly be arranged, and the objective function becomes

$$\text{Min. } \sum_{i=1}^{V} C_i w_i\left(u_1^i - a_i\right) \tag{1a}$$

This is the target for berth allocation with reberth consideration and execution, if applicable.

Case 2. If $\alpha_i > 0, x_i = 1$ or 0.

When $x_i = 1,$ two additional and nonnegative cost items—R_i and $D_i\, w_i \left(u_2^i - \left(u_1^i + p_1^i + \alpha_i\right)\right)$—are added to the objective function, and the value of the objective function is higher than that in (1a).

When $x_i = 0,$ an additional nonnegative cost item—($\alpha_i h_i l_i$)—is added to the objective function, and the value of the objective function is again higher than that in (1a).

Therefore, when a final workload waiting time α_i exists for any vessel(s) in the vessel set V under the berth allocation arrangement within the planning time period T, the final cost is always lower than a similar case that does not consider the existence of the nonzero nature of α_i for any vessel i. □

Proposition 2. A multiberth terminal always has a lower average cost than a single-berth terminal because the single-berth terminal has higher difficulty arranging BOA due to limited resources and flexibility.

Proof. In one extreme—for a container terminal has unlimited resources—if all the vessels are arranged to BOA, the second term in the objective function, $C_i w_i\left(u_1^i - a_i\right)$, is close to zero and the major contribution to the objective function depends on the reberth decision. If the container terminal attempts to arrange all vessels to BOA and never considers a reberth, $x_i = 0$; the third term, $x_i D_i\, w_i(u_2^i - \left(u_1^i + p_1^i + \alpha_i)\right)$, is zero; and the objective function becomes

$$\text{Min. } \sum_{i=1}^{V} \alpha_i\, h_i\, l_i \tag{1b}$$

This implies that, for a given h_i and l_i, the longer a vessel's workload waiting time, α_i, the higher the cost. Additionally, for the same set of α_i and h_i, if l_i increases by θ%, the same percentage increase is directly reflected in the value of the objective function.

At the other extreme—when a container terminal has very limited resources and can berth only one vessel at a time (one-berth or single-berth container terminal)—the

BOA arrangement is less likely than at multiberth terminals, and thus the sum of $C_i w_i\left(u_1^i - a_i\right)$ is higher than that for a multiberth terminal. If the single-berth terminal does not or never considers a reberth, $x_i = 0$; the third term, $x_i D_i\, w_i(u_2^i - \left(u_1^i + p_1^i + \alpha_i)\right)$, is zero; and the objective function becomes

Min. $\sum_{i=1}^{V} \{\alpha_i\, h_i\, l_i + C_i w_i\left(u_1^i - a_i\right)\}$ (1c)

This again implies that, for a given h_i and l_i, the longer the vessel workload waiting time, α_i, the higher the total cost. Additionally, for the same set of α_i and h_i, if l_i increases by θ%, the same percentage increase is directly reflected in the value of the first term of the objective function. However, it is always difficult for a single-berth terminal to arrange BOA for all vessels due to its limited flexibility. Therefore, a single-berth terminal always has a higher average cost than a multiberth terminal with a similar set of vessel arrival patterns for every berth section. Single-berth terminals could avoid the extra cost caused by vessel workload waiting time by reducing the number of vessels they operate, but this decreases revenue, which is not recommended.

We thus conclude that single-berth terminals always have a higher average cost than multiberth terminals for a similar set of vessel arriving patterns for each berth section. This is always true based on the assumption that terminals located in the same port are affected to similar degrees by variation in the arrival times of vessels (early or late arrival). The arrival pattern of all vessels at any time for both types of terminal is arranged in such a way that all the time windows are occupied and profit is maximized.

□

3.5 Computational Results and Discussion

Key Considerations when Selecting Weights

To illustrate our proposed mathematical model, which calculates the impact of workload waiting time and reberth arrangements for cost-saving purposes, we perform three sets of computations. Each set includes subcases to enable detailed computation and analysis. The first case identifies the effect of the selection of the constants C and D in a basic berthing situation where there is one berth section. The second group determines the impact of the number and berthing pattern of vessels with effective vessel waiting times α_i on the cost saving in the value of the objective function. The third group investigates the effect of the number of berth sections and corresponding number of vessels on the cost saving in the value of the objective function.

In each testing group, the berth length, number of vessels, workload waiting time β_i, and ratio of reberth cost is varied. Re-berth cost is determined by liner to the terminal resource idling cost determined by terminal management. Sample berth allocation data for the basic computational setting—number of berths equals 1, and thus the corresponding total number of vessels is 1 for a given planning period—are displayed in Table 3.4. The corresponding output result and key required decision variables are presented in Table 3.5. The value of the objective function for each vessel is shown in Table 3.6.

Splitting the Vessel Operation Period into Two Logical Parts

Vessel arrival times are generated to reflect the workload waiting times β_i of a practical situation in a real terminal. β_i is 0 or another number and is calculated as a fraction of the total port stay period P, which is assumed to comprise two consecutive time periods that do not overlap: parts 1 and 2 for discharging and loading operations, respectively. This matches the real daily operation in which individual cargo storage partitions in a container vessel are emptied before loading commences. After a removal or unloading operation is completed, the imported and/or transshipment containers are stored in the container terminal's yard. Then, the loading of the same cargo hold commences. If multiple QCs are deployed for one vessel, they complete their discharging operations at different time points. The cost of a reberth of vessel i, R_i, is determined by the prorated cost of a reberth of a vessel with the corresponding vessel length. R_i is a minimal and basic value according to liners, whereas the cost of resource idling per unit time per unit berth length, h, is determined by the terminal's management. Finally, each vessel is assigned a berth allocation priority. The most commonly employed FCFS approach is applied, although different priorities and sequences may sometimes be assigned. A Matlab program is developed for computation and to enable trend and pattern analysis. We consider different values and combinations of the input parameters: the number of berths and unit cost of berth idling h, as well as the input data for each vessel, β, and R. The Matlab program is the 2014 version and is run on a computer with an Intel i8 core and a 2.40 GHz CPU.

To simplify this introduction of the programming details, the key steps performed by our solution algorithm are highlighted as follows:

1. Read input vessel data set in descending order of priority;
2. Check the value of the reberth decision variable while scanning for possible berth allocation time–space windows;
3. Assign vessels to berth partially or fully according to the value of the decision variable;
4. Output the vessel operation data set for computation of the value of the objective function.

Computation 1

First, we vary the values of the two constants, *C* and *D*, in the objective function equation and use the basic vessel set (number of berth sections = 1 and number of vessels = 16). Table 3.4 displays the input vessel set, and Table 3.71 presents the different settings used and objective function values (OFVs) we obtain for different values of *C* and *D* and workload waiting times, which are expressed as a percentage of the overall port stay period for every vessel.

Priority	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Arrival Time	1	10	21	32	42	56	65	67	79	88	96	107	119	132	138	158
Vessel Length	300	320	350	320	300	280	300	330	350	320	360	380	350	320	330	320
Port Stay	12	14	12	10	10	8	11	14	18	14	12	19	16	10	12	12
Part 1 Port Stay	5	6	5	4	4	3	4	6	7	6	5	8	6	4	5	5
Part 2 Port Stay	7	8	7	6	6	5	7	8	11	8	7	11	10	6	7	7
Beta upon arrival	10	11	10	8	8	6	9	11	14	11	10	15	13	8	10	10
Re-berth Cost	111455	118885	130031	118885	111455	104025	111455	122601	130031	118885	133746	141176	130031	118885	122601	118885

Table 3.4 Input vessel data for a single-berth terminal and multiple vessels.

Sequence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Priority	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
first arrival time	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
first finish time	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
first berth head position	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
first berth tail position	301	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
second arrival time	11	19	34	47	58	69	78	90	105	124	139	152	172	189	200	213

second finish time	18	33	46	57	68	77	89	104	123	138	151	171	188	199	212	225
second berth head position	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
second berth tail position	301	321	351	321	301	281	301	331	351	321	361	381	351	321	331	321
Alpha	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Re-berth Decision Variable	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 3.5 Output vessel operation data with FCFS berth allocation logic applied.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
First term	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Second term	0	80000	160000	200000	220000	160000	160000	360000	420000	620000	760000	800000	960000	1040000	1140000	1000000
Third Term	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	0	80000	160000	200000	220000	160000	160000	360000	420000	620000	760000	800000	960000	1040000	1140000	1000000

Table 3.6 Output objective function values when FCFS berth allocation logic has been applied.

Beta (% to P)	OFV (C=10, D=10)	OFV (C=20, B=20)	OFV (C=30, D=30)	OFV (C=40, D=40)	OFV (C=50, D=50)	OFV (C=60, D=60)	OFV (C=70, D=70)	OFV (C=80, D=80)	OFV (C=90, D=90)	OFV (C=100, D=100)
10	4,040	8,080	12,120	16,160	20,200	24,240	28,280	32,320	36,360	40,400
20	4,040	8,080	8,080	16,160	20,200	24,240	28,280	32,320	36,360	40,400
30	4,040	8,080	8,080	16,160	20,200	24,240	28,280	32,320	36,360	40,400
40	4,040	8,080	8,080	16,160	20,200	24,240	28,280	32,320	36,360	40,400
50	26,300	30,340	30,340	38,420	42,460	46,500	50,540	54,580	58,620	62,660
60	37,430	41,470	41,470	49,550	53,590	57,630	61,670	65,710	69,750	73,790

70	48,560	52,600	52,600	60,680	64,720	68,760	72,800	76,840	80,880	84,920
80	83,434	87,474	87,474	95,554	99,594	103,634	107,674	111,714	115,754	119,794
90	106,436	110,476	110,476	118,556	122,596	126,636	130,676	134,716	138,756	142,796
100	152,440	156,480	156,480	164,560	168,600	172,640	176,680	180,720	184,760	188,800

Table 3.71. OFVs for different values of *C* and *D* and different initial workload waiting times.

Figure 3.1 plots the linear combination of the three cost terms in the objective function equation.

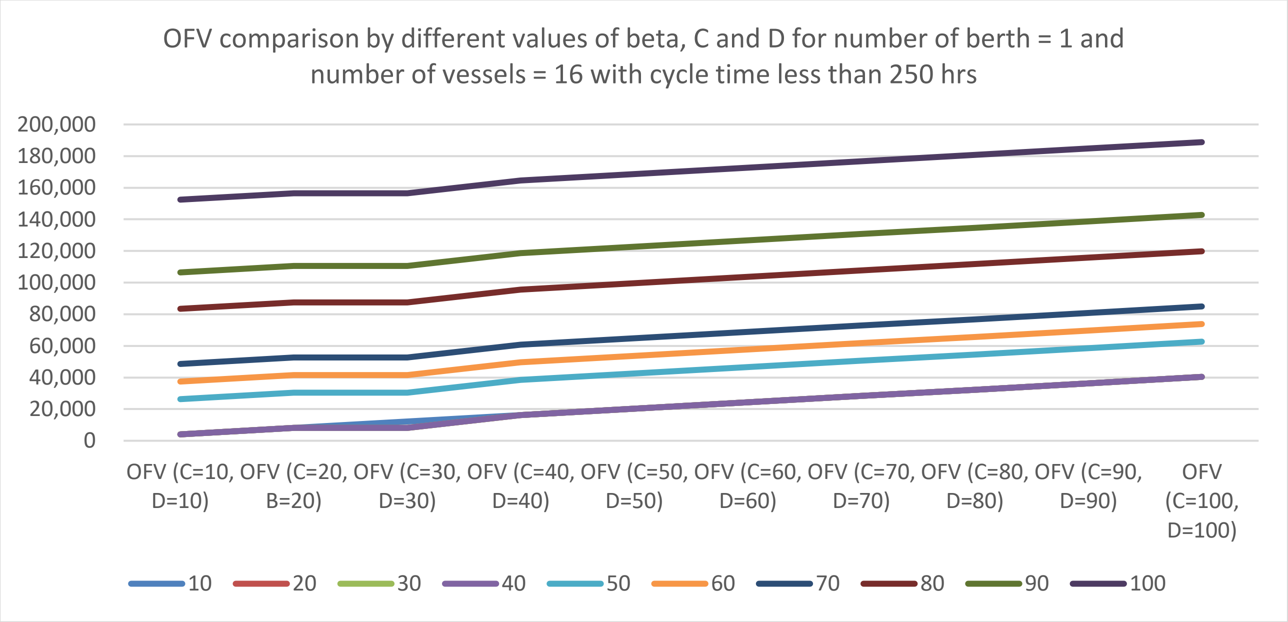


Figure 3.1 OFVs for different values of *C* and *D* and different initial workload waiting times.

We further consider a tenfold increase in the two constants, confirming that the OFV is not negatively affected by constant choice (Table 3.72 and Figure 3.2).

Beta (% to P)	OFV (C=10, D=10)	OFV (C=50, D=50)	OFV (C=100, D=100)	OFV (C=1000, D=1000)
10	4040	20200	40400	404000

20	4040	20200	40400	404000
30	4040	20200	40400	404000
40	4040	20200	40400	404000
50	26300	42460	62660	426260
60	37430	53590	73790	437390
70	48560	64720	84920	448520
80	83434	99594	119794	483394
90	106436	122596	142796	506396
100	152440	168600	188800	552400

Table 3.72 OFVs for higher values of *C* and *D*.

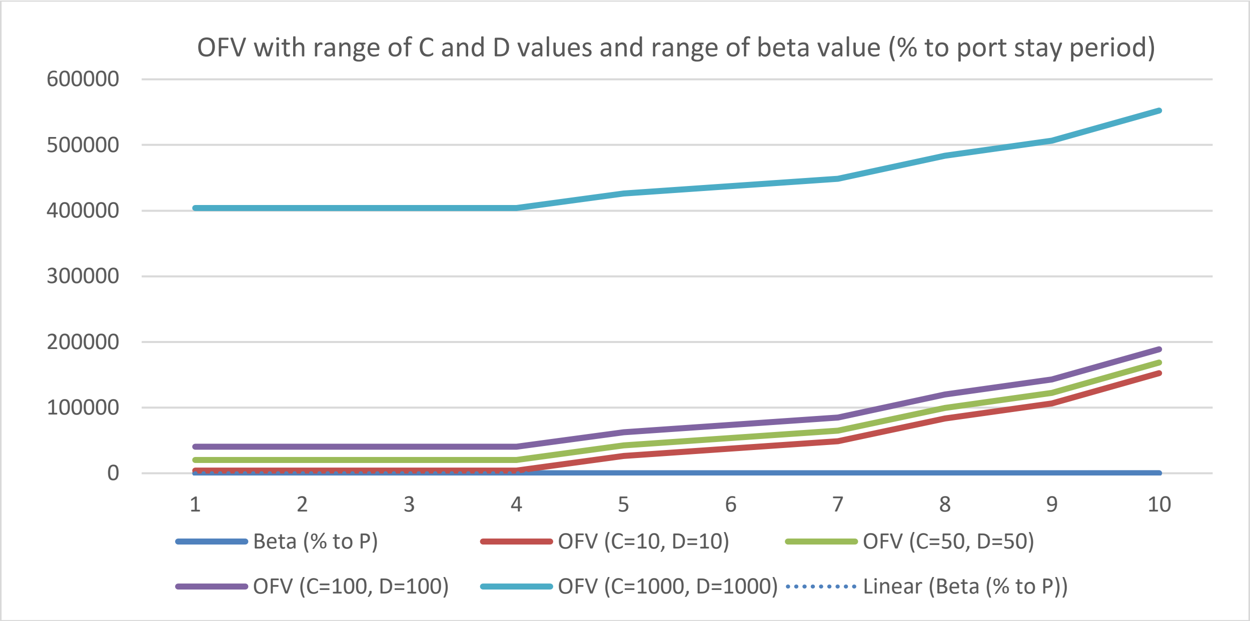


Figure 3.2 OFVs obtained using higher values of *C* and *D*.

Computation 2

Next, we illustrate the effect of reberths with the cost-saving objective for the basic case where the number of berths is 2 and number of vessels is 32. The input vessel data shown in Table 3.4 are replicated for computation 2 for the purpose of consistency in the vessel arrival pattern employed. A terminal with two berths is chosen as the basic case because only a limited number of terminals worldwide have just one berth; the majority have two berth sections or more. A total of 144 business cases are defined for each number of berths investigated. In particular, the parameters used are the number of berths = 2; berth length = 800 m; number of vessels = 32; cycle time = 300 h or shorter; C = 2,000; D = 1,000; h = 371 $\mathrm{m}^{-1}\ \mathrm{h}^{-1}$; R = vessel length × 371; β = 12, 24, 36, 48, 60, and 72 h; β = 40% of the total vessel port stay in hours; and percentage of vessels with β values = 10%, 20%, and 30%.

The OFV in the case of a berthing arrangement with reberth consideration is again compared against the default situation of ignoring the possibility of reberthing, which is common in daily operation. We summarize our key observations by analyzing the resultant cost difference (cost of no reberth minus cost of a reberth) for different combinations of parameters while using a consistent input vessel data set to eliminate the noise that could be generated by an extreme vessel arrival pattern. In particular, the percentage of vessels with a β value is suggested to be from 10% to 30% of the number of vessels to be handled within the cycle time. The considered possible arrival patterns of these vessels include front, middle, end, and random patterns.

Operation cost saving by assigning berthing arrangements using the reberth consideration is found to increase as β increases, as shown in Table 3.8 and Figure 3.3.

Beta (hr)	OFV without re-berth (A)	OFV with re-berth (B)	Cost Difference (A-B)	Cost Difference (%)
12	0.58	0.58	0.00	0.00%
24	1.40	1.29	0.11	7.59%
36	2.23	1.73	0.51	22.66%

48	3.07	1.73	1.34	43.65%
60	3.91	1.66	2.24	57.42%
72	4.67	1.67	3.00	64.23%

Table 3.8 Cost savings when reberthing is used for various vessel waiting times.

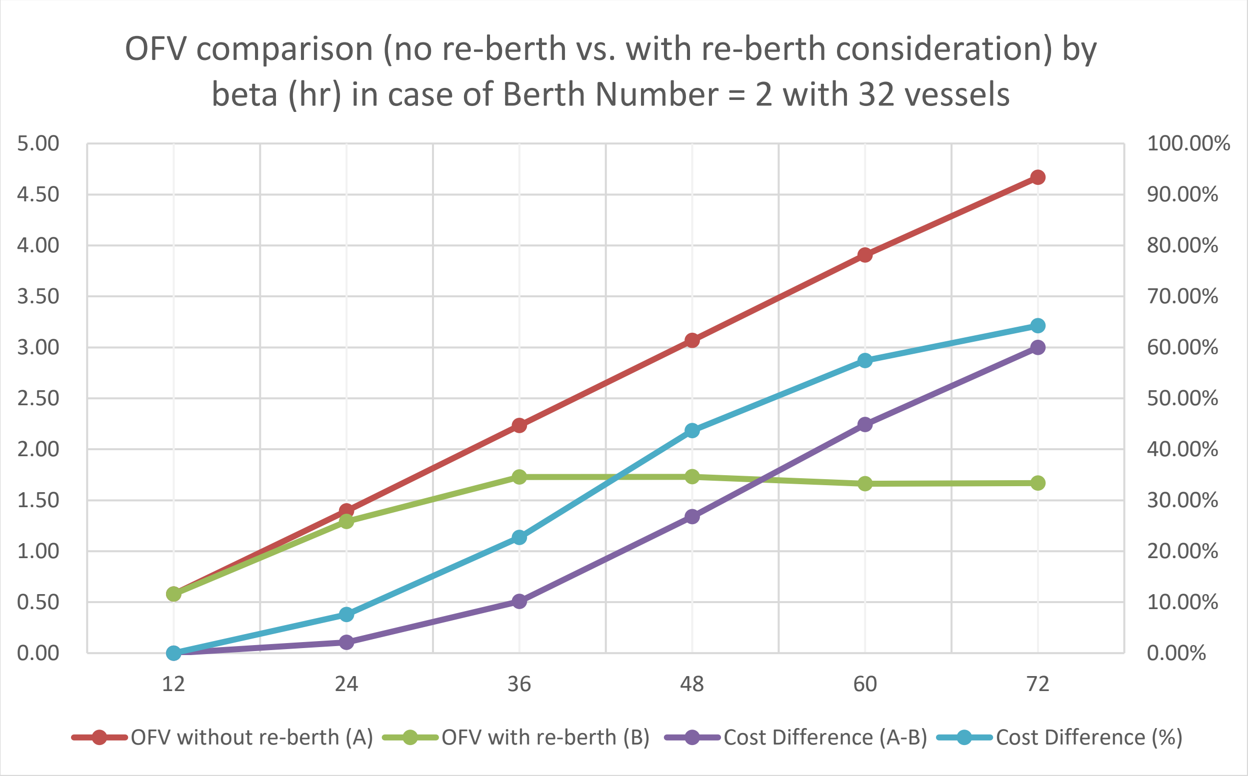


Figure 3.3 OFVs when reberthing decisions are made for different vessel waiting times.

Unsurprisingly, the savings increase as β is increased and the time required to complete vessels with a vessel workload waiting time, α, is increased, resulting in a higher value of the cost component in the first term of the objective function: $\sum_{i=1}^{V} [(1 - x_i)\alpha_i \, h_i \; l_i + \; x_i R_i]$. The possibility of reberthing ensures a lower cost in terms of the prorated reberth cost R_i. The saving curve in Figure 3.3 gradually flattens as β is increased up to 72 h for the 32-vessel cases. A similar pattern is observed when the number of vessels is increased (to 48 and 64 when the number of berths equals 3 and 4, respectively, in our subsequent test cases) because of the presence of the proposed third term in the objective function: $x_i D_i \, w_i(u_2^i - (u_1^i + p_1^i + \alpha_i))$.

Figure 3.4 compares the OFVs we obtain when the percentage of vessels with a nonzero β is varied (10%, 20%, and 30%). The average operation cost saved by assigning berthing arrangements using the reberth consideration is discovered to increase substantially up to 60% or higher when β is increased from 36 h. The cost savings increase with β most quickly when the percentage of vessels with β is 30%, followed by 20%. For 10% in particular, the savings decrease when β equals 48 h before increasing again. Conversely, when β is 36 h or shorter, the savings are minimal and even negative if β is 24 h.

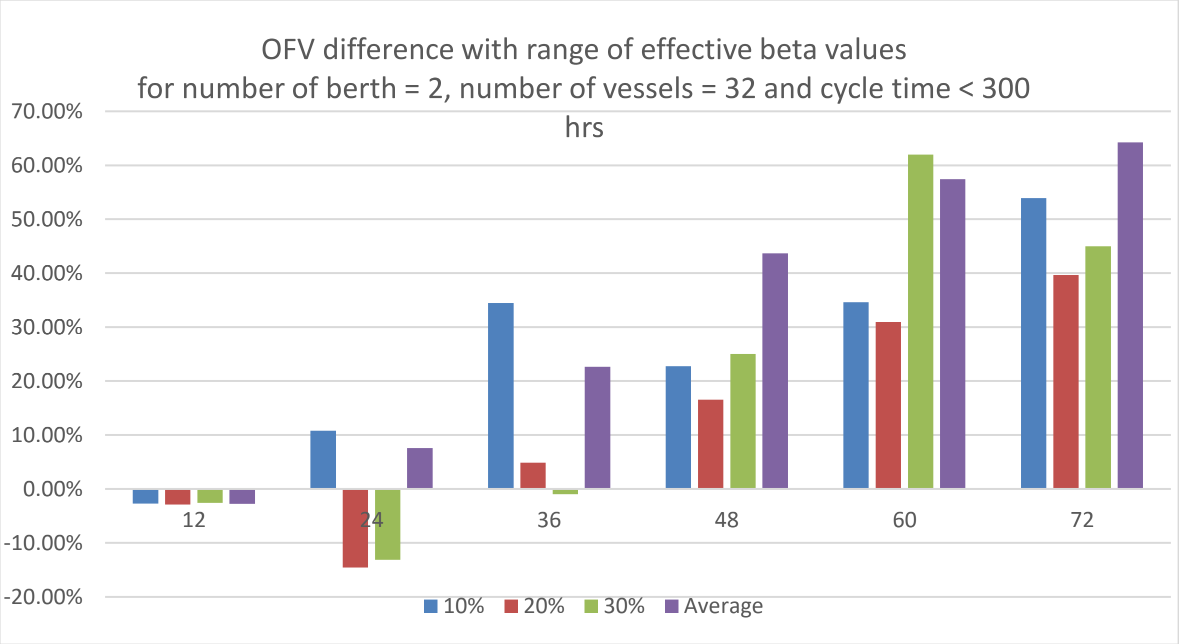


Figure 3.4 OFVs for a range of values of β.

It is also unsurprising that the savings increase as β is increased, the percentage of vessels with such a β is increased, the time required to complete vessels with a vessel workload waiting time is increased, resulting in a higher value of the cost component in the first term of the objective function—$\sum_{i=1}^{V} [(1 - x_i)\alpha_i h_i l_i + x_i R_i]$—because of more contributions made by vessels with β values. The possibility of reberthing ensures a lower cost in terms of the prorated reberth cost R_i. In particular, for a lower β value (24 h or shorter), the savings are not substantial because reberthing further constrains α_i to a higher value. α_i must be equal to or larger than the average value of a port stay divided by 2 for all the vessels to avoid a reberth operation being handled over an infeasible timeframe in practical situations (less than 8 h). However, this problem does not affect the pattern as β is increased from 36 to 72 h. A similar observation is made in the cases of 48 and 64 vessels in our subsequent test cases.

Figures 3.5.1, 3.5.2, and 3.5.3 respectively plot, for each of the fixed percentages of vessels (10%, 20%, and 30%) with β values (equal to 24 h), the cost saving for different late workload patterns. When the vessels with a β value account for 10% of the total number of vessels, the operation cost saved by assigning berthing arrangements using the reberth consideration increases as β increases, but the degree of increase differs from when 20% of vessels have a β value. When β is equal to or shorter than 24 h, the savings are low at less than 30% and are even negative when the front pattern is used. When the percentage of vessels with β values is increased to 20% and further to 30%, the cost savings decrease for all the selected values of β. The pattern corresponding to the end pattern shows the highest magnitude of decrease as β is increased from 24 to 36 h.

This can be explained by the amount of vessels with β values affecting the OFV by generating the extra third cost term in the objective function; this term is absent when reberths are not considered. This extra cost diminishes the saving in the first cost term in case of reberths, whereas the second cost term in the case of reberths is not strongly affected when the vessel arrival pattern is steady and without ad hoc clustering of vessel arrivals comes in the specific concerned β occurring pattern period. This implies that the selected C and especially D are critical. If a terminal focuses more on first arrival timeliness than second arrival (reberth) timeliness, defined by $D = 0$, the saving incurred by the reberth is much larger and not masked by the extra and third cost terms. Conversely, if the reberth requirements are tight such that the second arrival time must be strictly controlled and, for example, $D = 10{,}000$ or higher, the benefit of a reberth shall be diminished.

Given the potential uncertainty in vessel operation in practice, terminals may not be willing to arrange reberths to avoid the value of third term from being high, which generates high ad hoc pressure to control costs subsequently during the cycle to achieve the average cost of operation required in terminals that do not consider reberths in their basic cost calculations. This could explain why reberth operations are rarely observed in many ports even when cargo availability is not satisfactory. The berth allocation team may either persuade the vessel to berth later to decrease the value of a or to fasten the second part of the period (i.e., the loading part) by more resources input once cargo available is ready. Otherwise, the berth allocation team may sometimes proactively suggest that the vessel rolls-over the late cargo to subsequent vessels, which eliminates the need for waiting for the required cargo before loading can begin. This is a difficult suggestion to make because it involves extra and intensive coordination among staff—not just in the terminal, but also in the customer office—to rearrange all the export cargo plans of multiple vessels, including some vessels without cargo operation waiting times.

In short, terminal management teams consider reberths when a large number of vessels (e.g., 30%) have an extremely high β (e.g., 48 h or longer), but not for lower values of β (Figure 3.5.3). Conversely, in the case of a small number of vessels with β values (Figure 3.5.1), it is always beneficial to make reberth arrangements when β is longer than 36 h. Unless β is shorter than 24 h, the vessel arrival pattern does not matter and savings of 20% or more can be made. When β is 24 h or shorter, the terminal may need to consider reberths carefully by examining the vessel arrival pattern; only if the pattern is random are reberth arrangements justified. This requires the terminal management to make favorable decisions using the value of β.

The vessel arrival pattern (front, middle, and end) may be affected by ad hoc external factors, such as severe weather in nearby ports such that vessels must wait before departing (e.g., waiting for the end of a foggy or stormy period) and the port entrance or control policy of ports near the terminal in question; random patterns, however, may be driven by other commercial ad hoc factors, such as the breakdown of vessel operating equipment at the port last visited by the incoming vessel. Therefore, these arrival patterns are meaningful and should not be ignored.

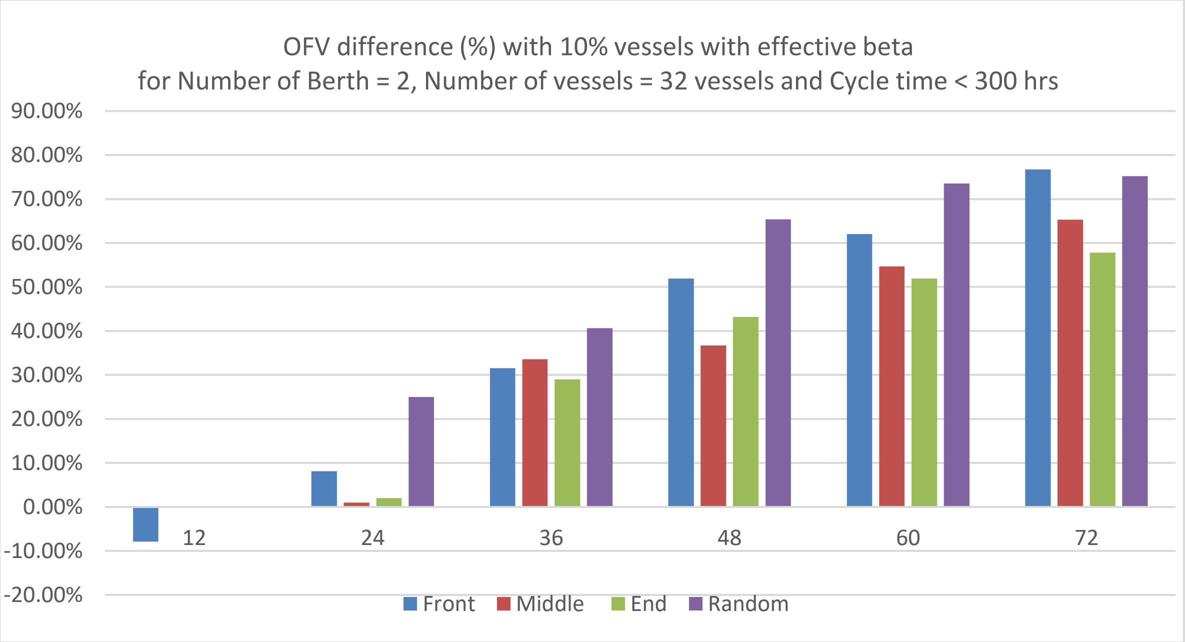


Figure 3.5.1 OFVs for different vessel arrival patterns when 10% of vessels have β values.

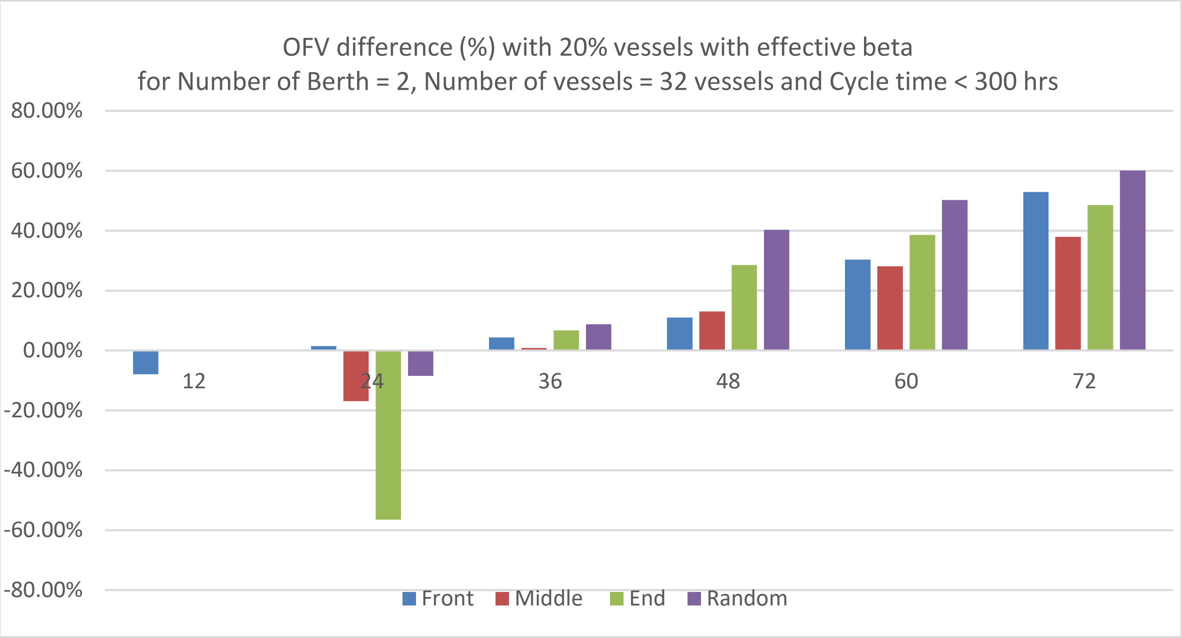


Figure 3.5.2 OFVs for different vessel arrival patterns when 20% of vessels have β values.

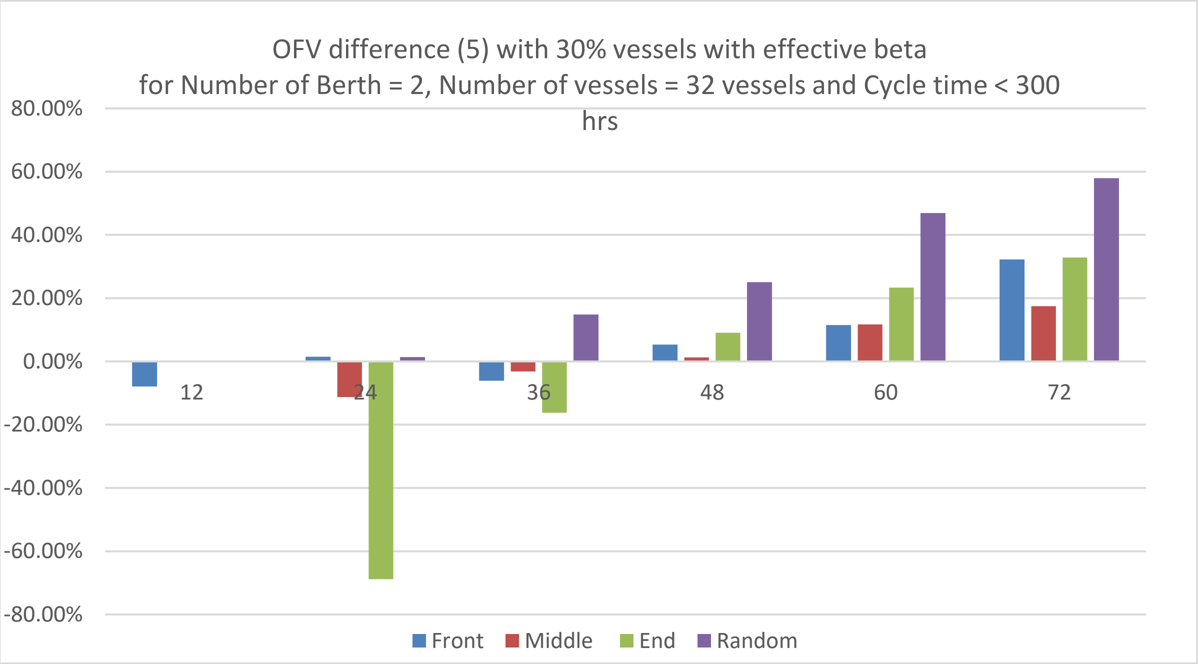


Figure 3.5.3 OFVs for different vessel arrival patterns when 30% of vessels have β values.

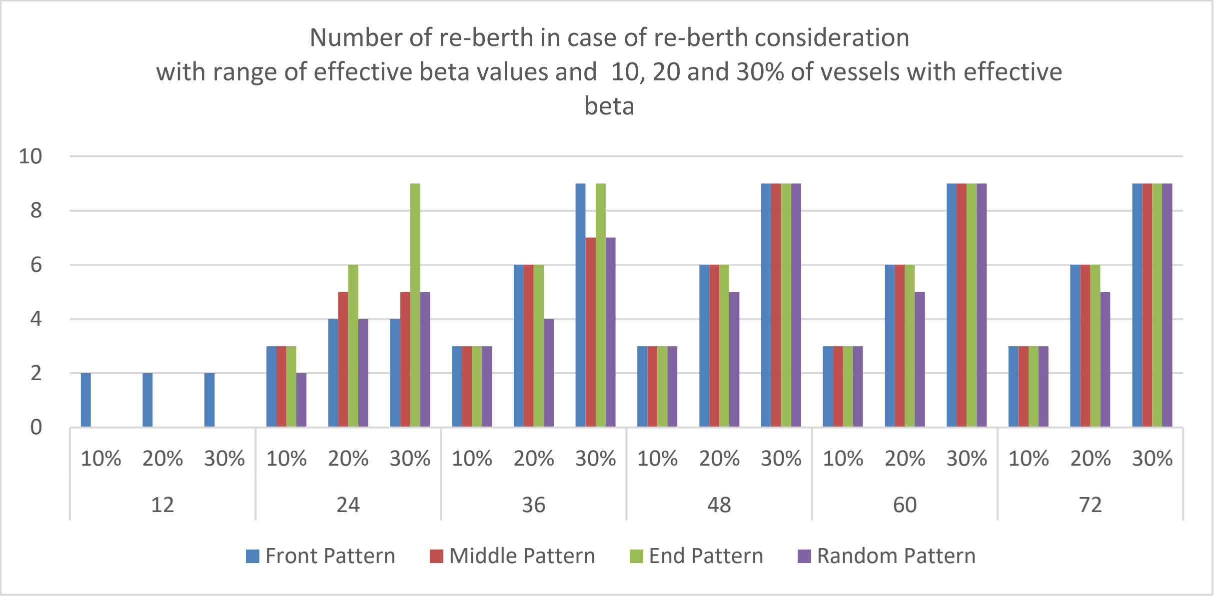


Figure 3.6 Number of reberths for different β occurring patterns.

The number of reberths increases with β and the percentage of vessels with β values, as is illustrated in Figure 3.6. When β is increased from 12 to 72 h, the number of reberths for vessels with β values increases and reaches the same value of number of vessels with β values. In particular, when β equals 24 h, the end pattern results in more reberths than the front or middle patterns, whereas when β is 12 h, similar to the average port stay of all the vessels, only the front pattern requires reberths.

Computation 3

The final computation further illustrates the effect of reberths with a cost-saving objective on a basic case wherein the number of berths is 2, 3, and 4 and the number of vessels is 32, 48, and 64. A total of 144 × 3 business cases are formed for each number of berths. In particular, the parameters used are the number of berths = 2, 3, and 4; length of berths = 800, 1,200, and 1,600 m; number of vessels = 32, 48, and 64; cycle time = 300, 400, and 500 h; C = 2,000; D = 1,000; $h = 371\ \mathrm{m}^{-1}\ \mathrm{h}^{-1}$; R = vessel length × 371; β = 12, 24, 36, 48, 60, and 72 h; β = 40% of the total vessel port stay in hours;

and percentage of vessels with β values = 10%, 20%, and 30%.

Comparing the OFVs, we find that when the number of berths and vessels is increased, the cost savings increase substantially. However, the savings are marginal when the final workload waiting time is 24 h or shorter, as illustrated in Figures 3.7 and 3.8 when the number of berths is 4 and number of vessels is 64. Figure 3.7 further indicates that reberths are always worth consideration, even when the workload waiting time is 24 h or slightly less, and especially when the vessels with such waiting times arrive in a random pattern, followed by pattern of head to middle part (head and middle pattern). If the vessels with workload waiting times arrive late—that is, in the tail pattern—no cost saving is obtained and a higher cost results from reberthing. This result indicates that terminal management has a long time window during which to more favorably arrange berthings before the cycle ends, helping it to eliminate workload waiting times and costs. Further tests are performed using similar input parameters but adjusting the numbers of berths and vessels from 4 and 64 to 2 and 32, and 3 and 48, respectively. Similar curves are observed, but a longer final workload waiting time—24 and 36 h—is required to break even in operation cost, as illustrated in Figures 3.9 and 3.10, respectively. This is an interesting result, indicating that the smaller the terminal, the larger cost impact a shorter vessel workload waiting time has compared with a longer waiting time. This also means that terminals must be highly responsive during decision-making when other late vessel arrival patterns—instead of the pure head, middle, tail, or random patterns—occur with vessels having different workload waiting times, such as 12 h for some vessels but 36 h for others. The optimal decision requires thoughtful and careful consideration of the proportion of vessels with shorter vessel workload waiting times.

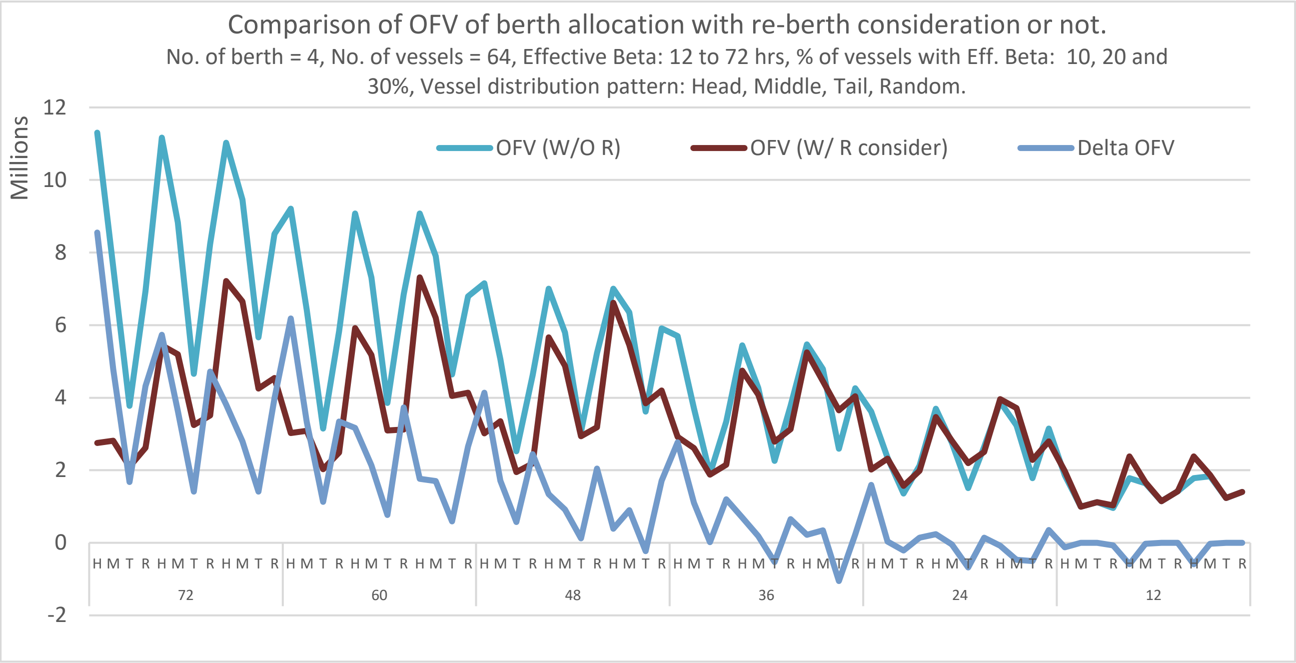


Figure 3.7 OFVs for different values of β when 4 berths and 64 vessels are considered.

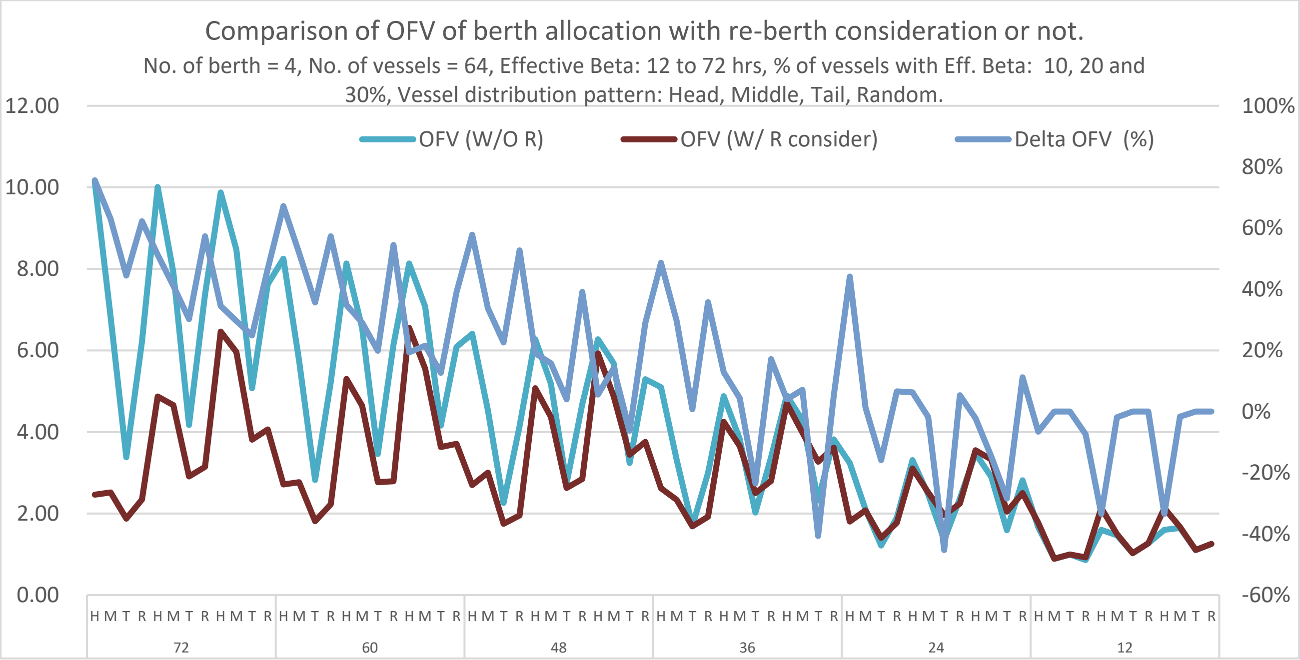


Figure 3.8 OFVs (%) when 4 berths and 64 vessels are considered.

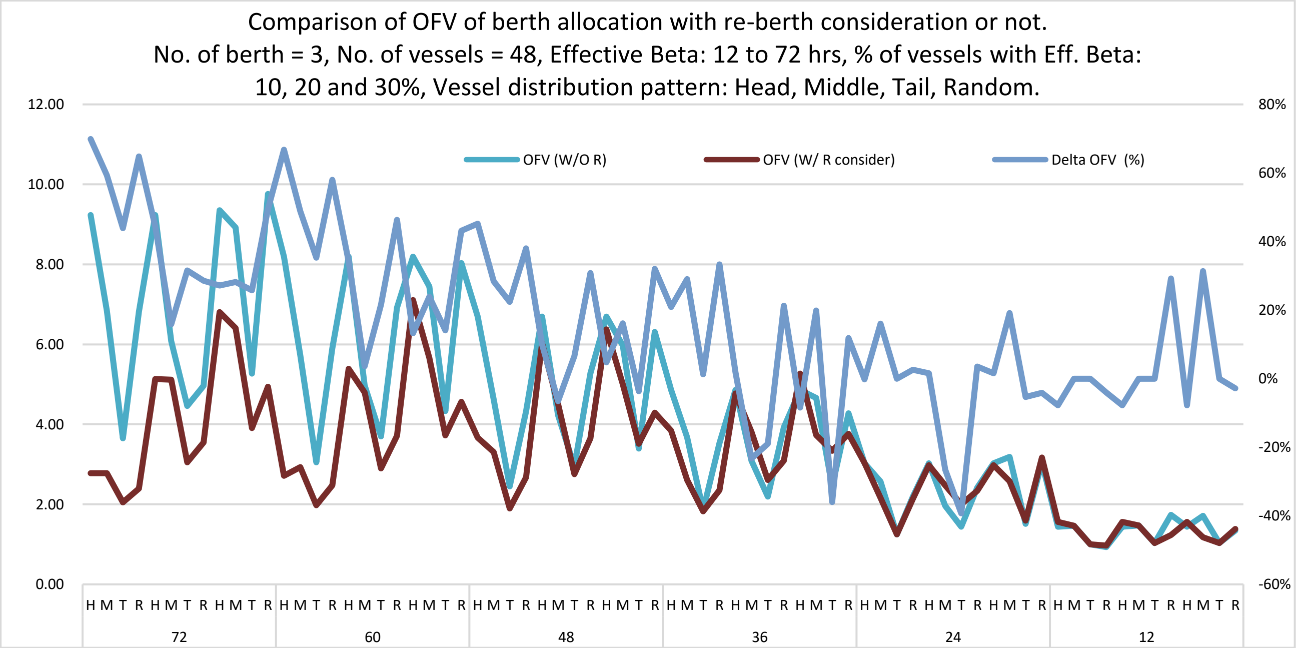


Figure 3.9 OFVs (%) when 3 berths and 48 vessels are considered.

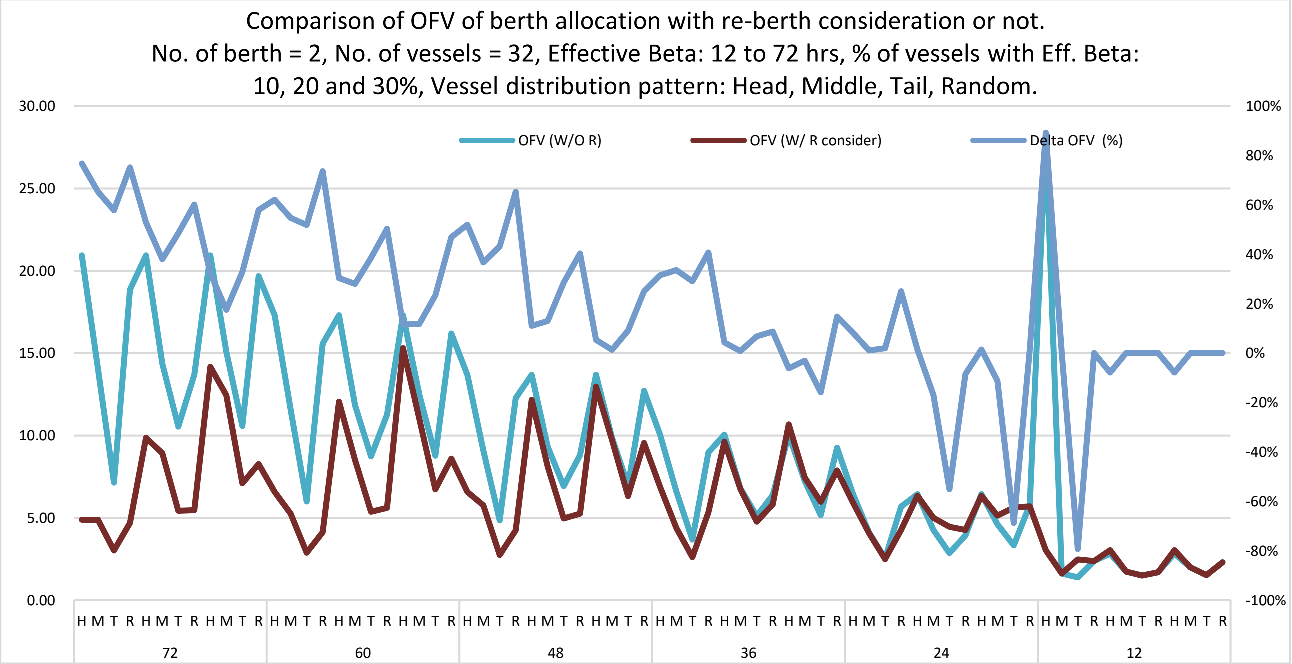


Figure 3.10 OFVs (%) when 2 berths and 32 vessels are considered.

3.6 Conclusion

For terminals with a small number of berths, such as two-berth terminals, only longer vessel workload waiting times justify reberth decisions in terms of a positive cost saving. Decision-making is more robust and direct for terminals with more berths; when the number of berths equals 4, for example. For such terminals, the cost saving of reberth decisions is significant providing that the workload waiting times are 24 h or longer. The longer the average waiting time, the higher the cost saving. Reberth arrangements can enable the vessel pattern to resume promptly after a severely delayed vessel arrival. They also allow multiple vessels to discharge deadline-sensitive inbound or transshipment-out boxes and promptly pick up the required outbound and transshipment-in boxes. The selection of different logical values of constants *C* and *D*, which are multiplied by the first and second arrival time–related cost terms, may affect the result slightly; however, they do not prohibit the stated discussion because vessels are assumed to be handled by the terminal in question, with the possibility of transferring to competitor(s) ignored. Container terminals, especially smaller ones, that have substantial vessel workload waiting times but do not employ reberthing are under high pressure regarding both operation cost and service quality. They may be forced to stop operating some profitable vessels to ensure the favorable performance of other crucial vessels. This affects the terminals' business in the long term, even if it does minimize operation costs. This paper provides a new perspective with which to view the BAP when vessel operation waiting times exist, as is common in practice. The reberth consideration offers a new method for terminals to create room for bargaining, discussion, and ultimately cooperation with liners in resistance to the dominance of mega terminal operator(s) in ports. Recent increases in vessel size and thus vessel workload waiting times make this research even more meaningful. Vessel schedules fluctuate because new alliances are formed from time to time, in addition to because demand volumes are seasonal. Reberth decision-making effectively helps terminal operators to become more robust and sustain high flexibility in both terminal operation and customer expectation management. Further research opportunities exist regarding ship and yard planning in cases of repeated or planned reberths, which could make breakthroughs in both terminal cost improvement and long-term business profit.

CHAPTER 4 BERTH ALLOCATION WITH UNPLANNED VESSEL AND SERVICE DEMANDS

4.1 Introduction

Traditionally, berth allocation is a planning process that must organize a fixed number of vessels that arrive at a terminal periodically. Each vessel is given the best possible berthing arrangement; that is, the arrangement that minimizes operational and penalty costs. Usually one vessel serves one regular shipping service loop and arrives at a given terminal once in each cycle. Cycle time is 1 week for most international service loops. A terminal prepares for the best-case scenario of each vessel before its arrival. For example, adequate storage space is reserved for the import containers that will be discharged from the vessel, and the vessel is arranged to berth closest to the vessel’s export containers for subsequent efficient vessel loading operations. Although the exact handling volume per vessel call varies, the general planning is similar for all regular vessels. Each vessel’s arrival pattern—in terms of its arrival time, size, container volume, and cargo origins and destination—is stored and available for planning subsequent cycles with a certain level of reliability. Thus, the general task of terminal berth allocation is to fine-tune the details for a fixed set of vessels with well-known operational requirements and lifting demand patterns.

In reality, terminals often handle unplanned vessels on an ad hoc basis. Vessels can simply appear outside of planning and control. When a vessel is damaged and not able to sail, it finds the nearest terminal to berth and unload all of its containers before it dry-docks and begins the repairing process. Additionally, whenever gaps in operation exist after berths have been allocated such that resources are idle, terminal management searches for candidate vessels and employs the idle resources accordingly. Resources idle regardless of seasonal characteristics and economic situations. Whenever a vessel arrives outside of its scheduled window, a resource idling will occur. However, when the delayed vessels arrive during the late stages of a cycle, the terminal may not be able to find additional vessels to prevent resource idling as agreed contractually between liners and terminal. At this time point, the terminal must ask adjacent terminals to handle some of the vessels before they are kept waiting or if they have been waiting for too long. This demonstrates that idling time causes numerous problems, and idling resources are an immediate problem that causes low resource utilization over short periods and vessel congestion subsequently. The problem is worsened if multiple vessels are involved, resulting in larger wastage.

Preventive action is crucial but not always effective. The berth allocation team persuades vessels to arrive earlier when resources are available. A more proactive approach is to find new or short-term vessels to use the resources directly. This requires a clear presentation of the available resources to neighboring terminal operators and comprehensive checking for any prolonged-wait vessels that require berthing during the proposed time period. The process is usually performed intuitively by terminal management, as opposed to using a systematic approach and solution method. When a candidate vessel is found, it is usually served without review of its operational impact on the regularly operated vessels. When multiple candidate vessels are found, no tool is available to select the vessel that would be optimal to serve. An efficient and effective method is thus needed for determining acceptance and rejection decisions.

Other than avoiding excessively long idling periods, some terminals attempt to increase business volume without making any capital investment. Thus, they need a reliable method of reviewing the possibility of serving more vessels on an ad hoc basis without causing a serious offset in vessel scheduling, but rather short and scattered idling time periods in their berth line. By considering candidate vessels on their stable but relatively scattered vessel map, a terminal could review its regular vessels' berthing arrangements to enable further negotiation with liners on berthing arrangements down to the vessel level. Even though idling time gaps are relatively short, they add up to expensive wastage and are also worth comprehensive consideration. However, no useful tool or solution method is available for such critical reviews in terms of short-term but continuous business volume improvement. In this paper, we bridge this research gap by introducing a new concept; that of the spare vessel window and unplanned vessel. The term "unplanned vessels" is used because of their unplanned nature in the long-term planning of resources. Such vessels increase the size of the vessel set but have minimal adverse impact on the periodically served vessels in terms of berthing time and sequence. Their cost impact is considered herein and found to be compensated by the extra business revenue they bring. The flexibility in vessel berthing point for unplanned vessels is leveraged for the best allocation results.

Handling unplanned vessels is indeed familiar to container terminals. Terminals support each other from time to time when vessels are unable to berth on-time due to numerous natural and operational factors, such as adverse weather conditions, vessel schedule delays, and liner port rotations. Off-schedules situations are not limited to peak season but also occur in low season whenever vessel schedules fluctuate and it is necessary to avoid vessel congestion. Terminals handle unplanned vessels offered by neighboring terminals and also offer their own unplanned vessels to other terminals. The key driving force behind these exchanges is pressure from liners concerning cost and time saving in terminals. The total time saved in terminals along the service loop is critical if slow steaming is subsequently to be used, which results in significant bunker cost savings. To eliminate undesirable vessel waiting times, unplanned vessel handling is common in the industry. Nevertheless, no systematic approach that defines and addresses the problem has been developed by either academic or industrial expert groups.

The need to handle unplanned vessels has been further intensified by the progressive growth of the shipping merchant fleet in the past 15 years. Although the economic crisis of 2009 affected shipping demand for a few years, the total carrying capacity—as defined by the deadweight tonnage—has continued to increase. The dominating container ships show a leading role in the 10-year interval average (121.8%), followed by bulk carriers (105.1%) and oil tankers (45.2%). The overall fleet size has increased more than 75% over the same time period (UNCTAD, Review of Maritime Transport 2016 and Statistics). This steady growth in fleet size and carrying capacity implies an increasing demand for port and terminal services, but port and terminal expansions of an equivalent scale have not been observed. This mismatch is best explained by the high uncertainty in the shipping market. Ports and terminals remain conservative when considering expansion because freight rates and terminal lifting charges are decreasing.

A higher container lifting volume is needed by terminals if they are to maintain their business revenue, and this is achieved through better resource utilization with minimal wastage. One of the improvements that can be made is the handling of more unplanned vessels on an ad hoc basis and in addition to regularly operated vessels. Some terminals, especially those without sufficient vessels to operate, request unplanned vessels from their competitors in the same port by offering choices of spare vessel windows. The success of this tactic, however, is subject to vessel availability from competitors in addition to the quality of the proposed spare windows. The formation of spare vessel windows is not well-considered, but rather performed intuitively and according to the terminal management's experience.

Because of the fierce competition among terminals, achieving high productivity and outstanding efficiency over a fixed set of vessels is not sufficient to attract customers and to maintain success too. Terminals must demonstrate high competence in response to ad hoc demand. Liners assess terminal performance using both routine vessel performance and ad hoc request handling. They are concerned and exert pressure on terminals when the berthing of alliance vessels in adjacent terminals is delayed. These vessels carry their important containers, and liners have the important role of facilitator in ad hoc vessel arrangement processes to upkeep their benefit. Terminal business has become more complicated than ever: liners are now concerned about vessel berthing performance down to the container level. If their containers are affected, they exert invisible pressure on terminals. Terminals are unwilling to give up operation of a vessel until the last moment, even if the vessel's schedule is highly variable. Dilemmas related to these issues require a quick approach to decision-making in response to ad hoc requests or else the best time at which to make a decision will be missed. This important problem has not been addressed in berth allocation studies.

Herein, this research gap is filled using a new berth allocation approach. To recap, traditional berth allocation studies allocate spaces to a given set of vessels on a berth–time diagram. In reality, both berthing supply and demand are uncertain. On the supply side, more berthing resources appear when vessel schedules fluctuate due to numerous uncontrollable weather and operational factors. On the demand side, there are unplanned vessels for three main reasons. First, the vessel arrives at a port on an ad hoc basis and requires terminal services because of the need to make an urgent vessel repair, unload a dangerous container, or clear extra containers to avoid additional storage and handling costs. Second, the vessel is attracted by a terminal that has idling berthing resources. Third, an adjacent terminal must offload a vessel to avoid long vessel waiting times. These demands have all been neglected in past research and are handled in an ad hoc manner in practice. The present research considers these overlooked demands and their effect on terminals. After a literature review on related and recent BAPs is introduced in Section 2, the problem is formulated in Section 3 using a revised berth allocation model based on Legato et al. (2014). In Section 4, a solution procedure is proposed with which the optimal solution to the problem can be obtained. In Section 5, numerical experiments are detailed and followed by a discussion. We summarize the study in Section 6 and provide suggestions for future research on the topic.

4.2 Literature Review: Idling Time Consideration in Berth Allocation

Little scholarly attention has been devoted to the investigation of idling time in the BAP. Instead, the critical impact of increasing vessel lengths on required berth lengths has been evaluated, and studies have been performed that consider different berth shape designs. A new berth design, the indented berth design, has been proposed for the effective quayside productivity of megavessel operations through the shortening of the yard access distances that must be traversed by container transfer tractors (Imai et al., 2007). Although the study that proposed this design did not consider the possibility of ad hoc megavessel demand, productivity was discovered to be higher for megavessel operations when using indented berths. More idling time periods could be obtained to enable the serving of extra vessels. A follow-up study was performed by the same authors that proposed a channel berth design (Imai et al., 2013). Compared with the indented berth design, the channel design was discovered to have several advantages. One of these advantages was higher flexibility for smaller vessels' arrival and departure, which results in higher productivity and potentially increases the prevalence of idling times.

Outside of megavessel considerations, there are two main streams of BAP studies: (a) tactical berth allocation planning and (b) operational berth allocation with simultaneous consideration of berths, QCs, and other resources. Both streams aim to achieve cost minimization, even though they may define the cost structure or objective function differently. Tangible entities—vessels, berths, quay and yard cranes, and equipment—and the transfer of staff members' tractor and work shifts are often considered to make the optimal assignment. The lowest possible operation cost is achieved without consideration of berth idling times. Liners' requirements regarding timely vessel arrival and departure are addressed, but not the idling time in between vessel berthings. A definition of idling time and its arrangement was not available until a recent study by Imai et al. (2014) was completed, which considered excessive vessel calls. Vessel priority was studied for berth allocation arrangement (Imai et al., 2014) to formulate a new and effective berth template berthing strategy. A similar problem was also considered (Zhen, 2015) by using the lifting volume to forecast uncertain operation times, with arbitrary probability distributions assigned. The method yielded an optimal solution without consideration of the potential for extra vessels to berth during idle periods and the impact of such vessels on the uncertain operation times.

The tactical-level BAP is normally solved using MIP without consideration of detailed equipment and manpower schedules. The connection between the tactical and operational levels was investigated using the simulation optimization framework by Legato et al. (2014). Randomness in discharge and loading operations was taken into consideration using an event-based simulator. The results of the study indicated a clear connection between the BTP and BAP. Again, idling times were not considered at either level. In a follow-up survey paper on the same topic (Bierwirth and Meisel, 2015), the BAP formulation was summarized using four attributes: spatial factors (berth layout and water depth; problem inputs); temporal factors (vessel arrival process; problem input); handling time (vessel's port stay; problem input); and a performance measure (the objective function of the problem, such as minimum waiting time before berthing, minimum port stay, or minimum late vessel departures). The measures were applied to all vessels, with vessel priorities assigned. New issues within berth allocation planning have also been investigated, for examples, environmental factors or tidal constraints, such as tidal access (Xu et al., 2012), fuel consumption and emissions (Raa et al., 2011), and direct transshipments (Liang et al., 2012). However, such studies have not focused on idling time usage but instead only touch upon terminal resource utilization.

For the BAP at the operational level, minimization of operation cost is the principal objective of much research. An interesting study was conducted on yard performance optimization through flexible vessel operation times (Gialombardo et al., 2010). Although liners do not support terminals when the timing of vessel operations differs significantly from the agreed schedule, the study introduced a new concept to lower terminal cost in terms of yard operations. The operational problem is further expanded, considered at the tactical level, and solved using a biased random-key genetic algorithm by Lalla-Ruiz et al. (2014) instead of the Tabu search operation embedded in the heuristic algorithm used by Giallombardo et al. (2010). The advancement in the solution algorithm was limited to operations practice without new business opportunity consideration.

The BAP and QC assignment problem in particular are classified as an integrated problem—the QCSP. Four attributes are defined in this problem: the task attribute, crane attribute, interference attribute, and performance measure. The relevant studies have mainly focused on QC performance. QCs are assumed to be stationary while vessel operation is underway. Using QC performance as an indicator is difficult in practical situations because QC performance is not a service index commonly evaluated by liners. Despite being assumed to be stationary, QCs can move a certain distance during vessel operation. New issues in the QCSP have included the indented berth design, where QCs are installed on both sides of a megavessel (Boyen et al., 2012), mobile crane platforms (Nam and Lee, 2013), crane ranges (Monaco and Sammarra, 2011), yard congestion (Choo et al., 2010), and double cycling (Lee et al., 2014), but they have not been investigated in detail in terms of idling time management. In summary, the BAP has been studied regarding service demand when there are clear service requirements but not regarding idling times or the spare windows generated after the berth allocation process. Such spare windows are critical for their extra business potential. No strategic review or study was found related to this topic. This confirmed our intention to investigate the problem and contribute a new concept: the spare vessel window and unplanned vessel.

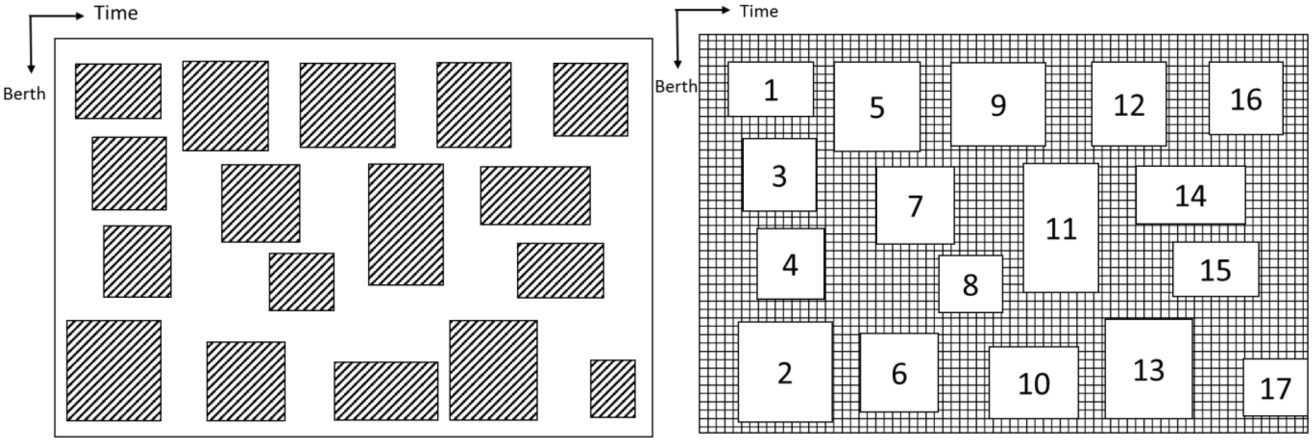
4.3 Problem Formulation

Idling Times

Figure 4.1(a) presents a typical berth allocation diagram for a four-berth terminal. Each of the striped rectangles represents one vessel. The length of each vessel is indicated by the length of the vertical sides of the rectangle, whereas each vessel’s operation period is indicated by the length of the horizontal sides of the rectangle. Berth allocation studies usually focus on vessels and their parameters: arrival time, operation period, and target berthing position. Figure 4.1(b) displays the same berth–time diagram as that in Figure 4.1(a) but with the idling times highlighted and quantified using squares. This gives a visual sense of the idling times and resource wastage that commonly occurs. Each square has units of time multiplied by berth length. The sum of all of these squares indicates the total resource wastage. Conversely, Figure 4.1(b) also indicates the difficulty of finding suitable small vessels. If an extra vessel is sufficiently short and requires a sufficiently short berthing period, it could be handled within these idling areas. In practice, however, vessel sizes are increasing and resources are increasingly idle because of fluctuations in vessel schedules and variation in vessel sizes.

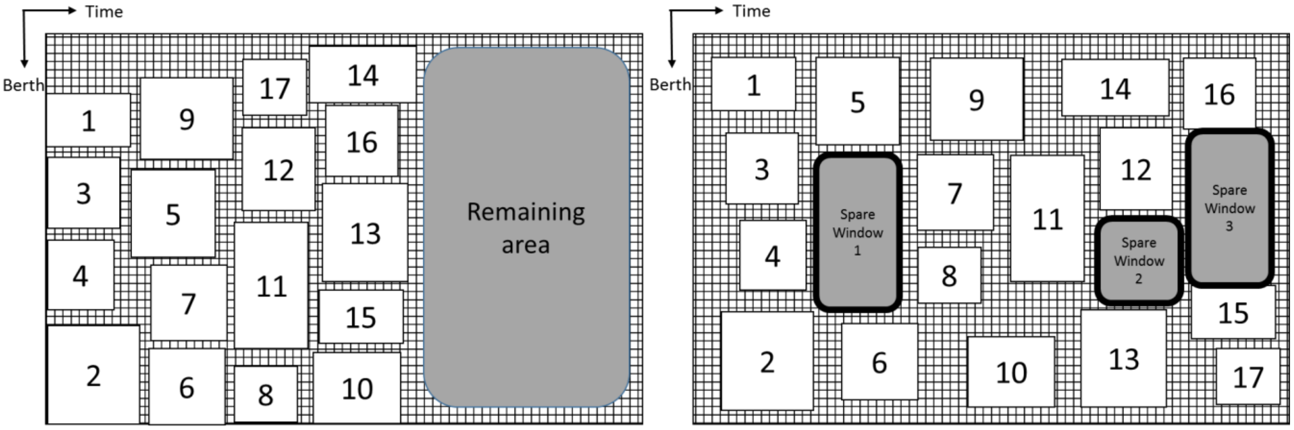
Unit Spare Windows

The groups of small and unused squares illustrated in Figure 4.1(b) are herein defined as “unit spare windows.” They can be combined and applied differently according to different vessel demands and the discretion of the decision-maker. For example, the spare window located between vessels 6 and 7 in Figure 4.1(b) could be used to berth two or three feeders or barges. It could also be used to serve a bigger vessel if the vessel’s operation time was sufficiently short and depending on the detailed ad hoc demand requirements. Different diagrams for the same set of vessels are presented in Figures 4.2(a) and 4.2(b). By consolidating all of the service demands into the left-hand side of the diagram, as shown in Figure 4.2(a), the remaining area occupies a significant proportion of the total berth–time area. Wastage is serious and a terminal should find new vessels to fill this large empty berth–time area. In practice, scheduling all vessels so closely is not possible, despite being terminals’ preference, because of liner complaints. A more conservative approach with minor changes is displayed in Figure 4.2(b). The berth allocation for some vessels is changed slightly in this configuration without relocating the remaining vessels. Three possible spare windows are laterally created that are of a large size and able to serve ad hoc vessels of practical sizes. The surrounding planned vessels—such as vessels 1, 3, 4, 5, 6, and 9—are not affected too much in terms of their berthing time and position. Only vessel 7 must be shifted to a later time (i.e., to the right-hand-side) for the creation of spare window 1. The situation is similar for the creation of spare windows 2 and 3; their surrounding planned vessels—such as 11, 13, 16, and 17—are not required to change their berthing times and positions.



(a) (b)

Figure 4.1 (a) Vessel-focused and (b) berthing resource wastage–focused representations of the same berth allocation diagram.



(a) (b)

Figure 4.2. (a) Compact vessel allocation and a large remaining area; (b) three possible spare windows created by slight allocation movements.

Spare Vessel Windows

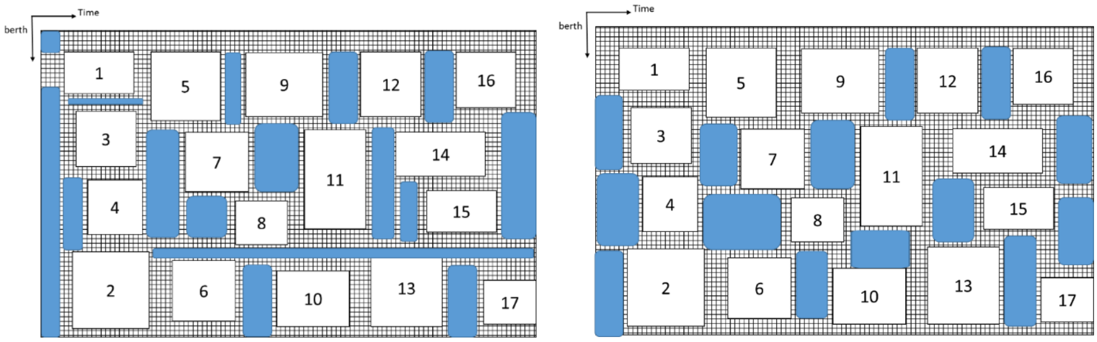
Although the consolidation shown in Figure 4.2(a) is not employed in practice, the large unoccupied area in the diagram indicates a strong need for further investigation into idling time. The spare windows in Figure 4.2(b) are suitable for meeting the ad hoc demands of vessels of practical sizes rather than feeders or barges only. Spare windows could be created freely with different penalty costs. The key problem is to find a vessel that is suitable for using the created spare window. Additionally, there are operational constraints on spare vessel window creation; too many spare windows within the same time period could cause yard congestion because extra containers must be transported within a short period of time. This places extra pressure on the terminal yard operations and strongly affects vessel performances. Spare windows that are too small will not increase resource utilization. Terminal staff work on a shift basis. A too low frequency of ad hoc vessel handling increases operational errors in downstream operational activities in terminal planning sections. Therefore, a good starting point is to have multiple spare windows in the same berth allocation plan, with a unique starting time for each spare window.

Application for Ad Hoc Demand

The BAP in this paper focuses on berth allocation decisions considering both vessels and idling resources, instead of vessels only, as is the case in classical berth allocation studies. Such classical studies are conducted using other tangible and countable supporting resources—such as QC quantities and assignment—but all focus on vessels only and not idling resources. Idling resources can be employed to serve vessels diverted by neighboring terminal operator(s). Terminals divert vessels because prolonged waiting times caused by vessel congestion within a planning cycle in both peak and nonpeak periods. Because liners are increasingly eager to slow steam their vessels to substantially lower voyage costs, it is becoming less possible to request that vessels arrive earlier or later than stipulated in their latest arrival plan. Liners request to BOA and expect short operating periods at terminals. Therefore, if a terminal cannot arrange for a vessel to berth on time or with minimal waiting time, such as 2–3 h, the terminal assesses whether a neighboring terminal could assist and handle the vessel instead to avoid the high penalty cost incurred by a prolonged waiting time at the vessel level.

Nature of Vessels

“Planned vessels” are defined as vessels with berthing time and berthing point requirements. “Unplanned vessels” are defined as vessels without berthing time and berthing point requirements at the berthing arrangement level. They are also defined as vessels without the possibility to plan ahead because they are handled once only. Herein, they are considered and included in berth allocation similarly to planned vessels in order to fill idling times or spare windows. The berth–time diagram is thus occupied by both planned and unplanned vessels. Without any strategic arrangement, spare windows vary in size from one unit square to a relatively bigger area that is similar to the average size of a planned vessel, as illustrated in Figure 4.3(a); they cannot be occupied by unplanned vessels because unplanned vessels have similar sizes to planned vessels. Too small, big, narrow, and wide spare windows are not practical or useful. Only windows of a suitable size can be filled by the unplanned vessels proposed by service demanding parties such as liners or neighboring terminals. Such proposals usually have strict berthing times but not berthing points.



(a) **(b)**

Figure 4.3 (a) Awkward spare windows, and (b) spare windows of practical sizes.

Spare Windows for Unplanned Vessels

In a proper arrangement, spare windows of a proper size can be created, as illustrated in Figure 4.3(b). If a spare window is filled by an unplanned vessel, the number of vessels increases by 1, and the total business profit is expected to increase proportionally in a normal business situation in terms of port charges, lifting charges, and any other surcharge(s). Spare windows can take different practical forms, and service requirements are needed to ensure a favorable match between a spare window and unplanned vessel. Therefore, unplanned vessels are included with their berthing time and berthing point requirements. The penalty cost is high if the berthing time of an unplanned vessel is not achieved, whereas no berthing-point-related penalty costs can be incurred. Our objective is to maximize resource utilization while minimizing overall operation cost.

Time at which an Unplanned Vessel is proposed

Too early a proposal for a spare window is impractical because vessel schedules will change at a later time point. However, too late a proposal for a spare window is not executable either. When all the outbound (export) containers for loading onto an unplanned vessel are stored at an adjacent terminal, the cost to transfer them to the proposed terminal is high. Additionally, the transshipment arrangement at the container level for a vessel being considered for diversion is already complete; substantial effort is required to alter the whole plan at such a stage. Vessel transfer among terminals leads to a higher cost for and operational impact on both terminals. Therefore, there is generally an optimal period during which planners should be aware of all possible sizes of spare windows. Herein, for simplicity, we restrict the time period during which a proposal can be made to be short.

Investigating the possible time required for differently sized vessels is also possible in terms of penalty cost recovery. The first factor is the number of containers that must be transferred from the source terminal to the proposed terminal, and the second factor is the operation efficiency of the individual pair of terminals when the transfer takes place.

Penalty Cost for Late Decision-Making

Penalty costs are considered a step function of berth position and time and also a negative addition to the estimated extra business profit. Regarding berth position, it is assumed that a lowest-cost berthing location (measured in integers representing the practical mooring point of a vessel) is given to all planned vessels and that the required QCs (in cases of multiple crane sizes in a terminal), berth depth, and steering hindrance (for oversized vessels) are also provided. For unplanned vessels, the allocated berthing position is not restricted and is taken as the middle point of the full berth length. If there is a derivation in a planned vessel’s berthing position, a penalty cost is incurred. Regarding berthing time, it is assumed that the terminal management team has some room to manipulate the arrival times of some vessels, if not all, through advance coordination with liner port captains or regional offices. This crucial assumption about planned vessels’ arrival times enables minor plan adjustment that could foster the formation of spare windows without incurring any extra cost. However, out of the agreed service window boundaries, penalty costs will be incurred and increase with time.

Rewards of Serving Extra Vessels

The more unplanned vessels are included in a berth allocation plan, the higher the business profit that can compensate for incurred penalty costs. The OFV for a berth allocation plan that does not include unplanned vessels is to be compared with one that does include unplanned vessel(s). A lower OFV is obtained if the penalty costs remain unchanged but unplanned vessel(s) are included. The handling of ad hoc vessel demand incurs an extra service charge that is paid by the requesting party. Before an expansion, a terminal is willing to pay an extra cost to handle unplanned vessel in order to show the terminal's high ability in ad hoc arrangement. By doing this, thye could possibily secure a bigger set of regular and ad hoc customers. Therefore, a budget for spare window creation is suggested.

Cost and Budget Considerations

When the budget for spare window creation is zero, the degree of freedom for planned vessels to be moved in the berth–time diagram is relatively low (but not zero), whereas when the budget is high, the degree of freedom is high. This degree of freedom must not be overused because existing customers must not be affected as the terminal attempts to create extra profit. At one extreme, the berth–time diagram is full of planned vessels and no unplanned vessels and identifying spare windows is not required; in this case, the budget is zero. At the other extreme, the berth–time diagram does not have any planned vessels and the entire diagram comprises spare windows with no need to pay penalty costs; the budget is again zero. A budget is only given when planned vessels exist.

Vessel Priority

A vessel priority is included in the model for each vessel and is expressed through a weight. Generally speaking, the priority is low for all unplanned vessels; planned vessels always have higher priority. By allocating the highest number of unplanned vessels and incurring zero or the lowest possible penalty cost, the maximum number of spare windows and corresponding berth allocation plan shall be obtained in the corresponding budget cases. In Figure 4.4, the vessel priorities of vessels 8 and 13 are upgraded to enable the creation of more spare windows next to the optimal time of ad hoc vessel berthing close to either the left- or right-hand side.

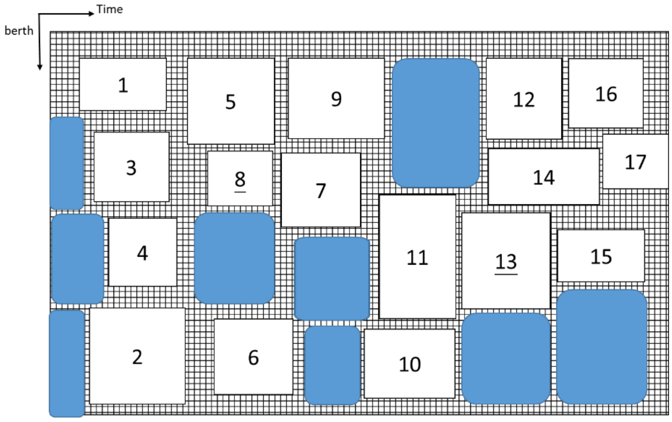


Figure 4.4. Some spare vessel windows cluster around the optimal time of proposal.

Vessel priority is normally dictated by the FCFS berthing strategy for planned vessels. We also follow this convention in our model because of increases in the potential variation of vessel arrival time as the cycle advances from its start point (time = 0 h). However, for the arrival time assignments of unplanned vessels are critical. If the arrival time is set to time = 0 h, the berth allocation team has little time to change and cater for an unplanned vessel because more vessels are berthed than at other times and allocated a place on the berth–time diagram in normal cases. If the arrival time is set to be the total planning period *T* minus the required time period of one spare window, the possible scenario might be infeasible because the schedule of all vessels due to berth in the later stages of the realization cycle could change. Therefore, the arrival time is set to be close to the optimal berth allocation time in our algorithm.

4.4 The Model

The model proposed herein is a revised version of the berth allocation solution proposed by Legato et al. (2014). The original problem aims to minimize penalty costs when vessels' departures are delayed and/or vessels are berthed at undesirable positions. The model by Legato et al. (2014) formulates an NP-hard problem that is solved using an annealing heuristic algorithm to overcome the limitation on vessel number. Vessels are assumed to be able to berth at all possible berthing points, although a penalty cost is incurred if the final berthing point deviates from the desired point. The study by Legato et al. (2014) placed an additional constraint on the target berthing segment for each individual vessel; only a limited set of berth segments are allowed for each vessel, which may lengthen the total cycle duration.

A revised formula for the objective function is proposed in our model that takes three key penalty cost items into consideration: (1) penalties for vessel berthing delay after coastal arrival, (2) penalties for deviation of vessel berthing position from the desired position, and a new cost item, (3) penalties for the delay of unplanned vessel berthing in a created spare window according to the corresponding ad hoc vessel request. Unplanned vessels, which have tight berthing time but not berthing position requirements, are included in the vessel set that consists of all the regularly operated vessels in a planning cycle. To simplify the model, the negative cost of extra benefit is handled if the vessel is an unplanned one. Berthing position could be driver from a berthing point, with vessel length added to it.

Consider a total number of vessels V (including planned and unplanned vessels) that must be accommodated in a berth of length L. T denotes the length of one planning cycle. An initial OFV can be obtained if the unplanned vessel(s) are not considered; this is denoted the basic cost *I*. When the unplanned vessels are considered, the OFV is different and is denoted by *B*, which is expected to be smaller or equal to *I*.

For $i = 1, \ldots, V,$ each vessel i (including planned and unplanned vessels) with vessel length l_i is assigned a lowest-cost berthing point, with the vessel's head or tail aligned at the berthing point b_i after it arrives at the coastal arrival time a_i, and the vessel's target departure time is d_i. The vessel is expected to berth for a maximum vessel operation period p_i. Each vessel i is arranged to berth at time x_i at a berthing point y_i and both these parameters are noted in the planning time period *T* and berthing line *L*, respectively. The berthing point is the mooring point at which the head or tail of a vessel is aligned using mooring ropes or lashings. The total berth length occupied by a vessel is equal to the vessel's length l_i. Vessel i may not be able to berth at its lowest-cost berthing point, which is indicated by b_i. Additionally, there is a tolerance for the length of time delay for each vessel i; this tolerance is denoted q_i and equals the maximum time after a vessel's coastal arrival for which no extra cost is incurred by the terminal in the form of a penalty given to the liner that operates the vessel. If the tolerance is exceeded, a penalty cost C_q^i is incurred for every unit of delayed or early arrival time over the tolerance q_i for vessel i. Similarly, for each vessel $i,$ there is a shifting tolerance k_i, which is the maximum amount the berthing position can be shifted from the ideal berthing point b_i without incurring any extra cost for the terminal due to a longer transfer distance between yard and quay areas. When the berthing position is shifted beyond this tolerance, a penalty cost D_k^i is incurred for every unit of shifting distance. Finally, a negative penalty cost item E_e^i is zero if vessel i is a planned vessel and nonzero if it is an unplanned vessel. E_e^i is a reward for the creation of a spare window in which an unplanned vessel can berth according to its ad hoc requirements. The ideal berthing time of vessel i is denoted t_i. The unplanned vessel will not berth if the tolerance time range is exceeded or else the unplanned vessel will create an extra cost instead of a benefit; this cost shall be paid by the terminal to overcome the difficulty in transferring the required loading containers outside of the preplanned time period because the transfer tractors are being used for other vessel and yard operations.

The decision variables are defined as follows:

x_i: berthing time of vessel i (unit: h), where $i = 1,\ldots, V$. The first time point is 1, the second time point is 2, and so on. The berthing time cannot be later than the last time point, which is the time at which the planned time period ends.

y_i: berthing point of vessel i (unit: bollard), where i = 1,…, V. The first bollard in the terminal is 1, the second bollard is 2, and so on. Bollards are separated by the standard interval distance, which is 10 m. The berthing point of a vessel cannot exceed a certain value that corresponds to the last physical berthing point. The berthing point is aligned with a vessel's head, and the total berth position occupied is from the vessel head (berthing point) to the vessel tail (berthing point + vessel length), including mooring and lashing.

f_{ij} :1 if vessel i is berthed at an x_i that is smaller than the x_j of vessel j; otherwise 0.

g_{ij} :1 if vessel i is located at a y_i that it is smaller than the y_j of vessel j; otherwise 0.

M: a very large positive number.

The MIP formulation is as follows:

Objective function:

$$\min \textstyle\sum_{i=1}^{V} \{ C_q^i \ (x_i - a_i) + \ D_k^i \ |y_i - b_i| + \ E_e^i \ (x_i - t_i)\} \tag{1}$$

Subject to:

$$x_i + p_i \leq T \ \ \forall \, i \tag{2}$$

$$y_i \ + \ l_i \leq L \ \ \forall \, i \tag{3}$$

$$x_i + p_i \leq x_j + M(1 - z_{ij}^u) \ \ \forall \, i \, , j . \ \ i \neq j \tag{4}$$

$$y_i + l_i \ \leq \ y_j + M\left(1 - z_{ij}^v\right) \ \ \forall \, i \, , j . \ \ i \neq j \tag{5}$$

$$f_{ij} + f_{ji} + g_{ij} + \ g_{ji} \geq 1 \ \ \forall \, i \, , j . \ \ i \neq j \tag{6}$$

$$x_i \geq a_i \ \ \forall \, i \tag{7}$$

$$\textstyle\sum_{i \in V} \{ C_q^i |x_i - a_i - q_i| + D_k^i |y_i - b_i - k_i| \} \leq B \tag{8}$$

$$f_{ij}, f_{ji} \, , g_{ij}, g_{ji,}, \sigma_{ij} \in \{ \, 0, 1 \, \} \ \ \forall \, i \, , j . \ \ i \neq j . \tag{9}$$

Objective function (1) represents the additional cost incurred by the terminal operator when vessels are berthed outside the vessel's requirements (i.e., the cost due to deviation from the planned berthing time and position) and the negative additional cost caused by the creation of spare windows. Constraint (2) ensures that all the vessels depart before or at the end of the planning cycle of length *T*. Constraint (3) ensures that the entire length of all vessels is berthed within the berth line. Constraints (4) and (5) ensure that no two vessels overlap; these two (sets of) constraints become effective only when f_{ij} or g_{ij} equals 1, and they ensure that the selected berthing times and berthing points are consistent with the definitions of x_i and y_i. Constraint (6) ensures that no vessels can overlap each other. Constraint (7) ensures that each vessel's berthing time does not occur earlier than the vessel arrives because this would be impossible. Constraint (8) ensures that the total budget does not exceed the difference between the original basic cost *I* (the cost when no unplanned vessels are permitted) and the given target OFV *B* when handling any unplanned vessel(s). Finally, constraint (9) defines the possible values of certain variables.

Solution Procedure: Heuristics

To efficiently allocate both planned and unplanned vessels, three different heuristics are proposed for three different business cases. The first business case is defined as when the penalty cost for delayed berthing is much higher than the penalty cost for an undesirable berthing point. The second business case is the reverse of the first case: the penalty cost for an undesirable berthing point is much higher than the penalty cost for delayed berthing. The third business case is when the penalty costs for both berthing time and berthing point are equally high. For all three cases, the unplanned vessels can be arranged to berth at any berthing point providing that they are berthed at the required berthing time. There is a penalty cost incurred if the unplanned vessels are not arranged to berth at their target berthing times. Depending on the ratio of the number of planned to unplanned vessels, the impact of penalty costs due to unplanned vessels can vary. For all three cases, each of the vessels in the vessel set, consisting of both planned and unplanned vessels, is assigned a unique priority in terms of the berthing arrangement sequence. In the terminal industry, earlier vessels always have higher priority than vessels arriving during the later stages because such vessels may be delayed or omit the terminal unexpectedly. The same principle is followed for all business cases.

Business case 1: high penalty cost incurred by a delayed berthing time but not an undesirable berthing point

i. Each vessel is arranged to berth at the top or bottom of the available berthing length at its ideal checking time, which is set by default to be equal to the vessel's target berthing time.

ii. The sum of the available berthing segments (or continuous berth length) is determined for the vessel's target berthing time.

iii. If the sum is bigger or equal to the vessel length, the subsequent berthing time required for the vessel's entire port stay is checked.

iv. If an affirmative result is obtained, the vessel is arranged to berth and the time–space unit area is marked as used in a two-dimensional array, with the total number of rows equal to the berth length in 10 m units and total number of columns equal to the total berth time period in hours.

v. If the vessel cannot be berthed at the top, it is checked for the bottom using similar logic.

vi. If both the top and bottom are available for berthing, the one closer to the target berthing point is selected, or else either is selected according to the assignment sequence.

vii. The process repeats until the vessel is berthed successfully at the target berthing time or all berthing points at the target berthing time have been considered but a location for the vessel cannot be found. Unsuccessful cases are due to remaining berth segments being too short or too scattered, meaning that the vessel is not small enough to berth.

viii. The time check is increased by 1 time unit (1 h), and steps (i) to (vii) are repeated until the vessel can be berthed or marked as "impossible to arrange" if the time check is equal to the last time point of the overall planning time period.

ix. Steps (i) to (viii) are repeated until all the vessels have been considered and are allocated, if possible.

x. The initial OFV is calculated for the set of vessels when unplanned vessels have been allocated the same as the planned vessels without variation.

xi. The alternative OFV is further calculated for the same set of vessels, with alternative berthing points for the unplanned vessels considered. The berthing point should slide along the available berthing line, if available.

xii. The minimum OFV obtained is the most favorable result out of the best berthing arrangement for the set of vessels, after all the combinations have been calculated and compared.

Business case 2: high penalty cost incurred by an undesirable berthing point but not delayed berthing time

i. Each vessel is arranged to berth at its ideal berthing point at its ideal checking time, which is set by default to be equal to the vessel’s target berthing time.

ii. The sum of the available berthing segments (or continuous berth length) is determined for the vessel’s target berthing time.

iii. If the sum is bigger or equal to the vessel length, the subsequent berthing time required for the vessel’s entire port stay is also checked.

iv. If an affirmative result is obtained, the vessel is arranged to berth and the time–space unit area is marked as used in a two-dimensional array, with the total number of rows equal to the berth length in 10 m units and total number of columns equal to the total berth time period in hours.

v. If the vessel cannot be berthed at the time check point, it is checked for both the up and down directions concurrently using similar logic.

vi. The process repeats until the vessel is berthed successfully in either the up or down direction. The distances from the ideal berthing point are then compared, and the shorter distance is employed to berth the vessel. The process is complete when all the berthing points in the up or down direction have been considered. In this case, remaining berth segments that are too short or too scattered in both directions mean that the vessel is not small enough to berth.

vii. The time check is increased by 1 time unit, and steps (i) to (vi) are repeated until the vessel can be berthed or marked as “impossible to arrange” if the time check is equal to the last time point of the overall planning time period.

viii. Steps (i) to (vii) are repeated until all the vessels have been considered and are allocated, if possible.

ix. The initial OFV is calculated for the set of vessels.

x. The alternative OFV is also calculated for the same set of vessels, with alternative berthing points for the unplanned vessels considered. The berthing point should slide along the available berthing line, if available.

xi. The minimum OFV obtained is the most favorable result out of the best berthing arrangement for the set of vessels, after all the combinations have been calculated and compared.

Business case 3: similar penalty costs incurred by delayed berthing time and undesirable berthing point

i. Each vessel is arranged to berth at its ideal berthing point at and ideal checking time, which is set by default to be equal to the vessel’s target berthing time.

ii. The sum of the available berthing segments (or continuous berth length) is determined for the vessel’s target berthing time.

iii. If the sum is bigger or equal to the vessel length, the subsequent berthing time required for the vessel’s entire port stay is checked.

iv. If an affirmative result is obtained, the vessel is arranged to berth and the time–space unit area is marked as used in a two-dimensional array, with the total number of rows equal to the berth length in 10 m units and total number of columns equal to the total berth time period in hours.

v. If the vessel cannot be berthed at the time check point, it is checked for both the up and down directions concurrently using similar logic.

vi. The process repeats until the vessel is berthed successfully in either the up or down direction. The distances from the ideal berthing point are then compared, and the shorter distance is employed to berth the vessel temporarily.

vii. The process exits when all the berthing points in the up and down directions have been considered. In this case, remaining berth segments that are too short or too scattered in both directions mean that the vessel is not small enough to berth.

viii. The time check is increased by 1 time unit, and steps (i) to (vii) are repeated until the vessel can be temporarily berthed at a less desirable berthing point or marked as “impossible to arrange” if the time check is equal to the last time point of the overall planning time period.

ix. The short distance is used as a distance interval to check for the possibility of berthing the vessel at its ideal berthing point. The process identifies a berthing arrangement with a short delay. If such as berthing position is found, the vessel is arranged to berth a bit later but close to its ideal berthing position, or else the previous berthing arrangement is taken as permanent.

x. Steps (i) to (ix) are repeated until all the vessels have been considered and are allocated, if possible.

xi. The initial OFV is calculated for the set of vessels.

xii. The alternative OFV is also calculated for the same set of vessels, with alternative berthing points for the unplanned vessels considered. The berthing point should slide along the available berthing line, if available.

xiii. The minimum OFV obtained is the most favorable result out of the best berthing arrangement for the set of vessels, after all the combinations have been calculated and compared.

Feasibility Check

The effect of unplanned vessels on the OFV is the main concern in this problem, whereas their effect on cycle time is a secondary concern. To ensure that it is possible to serve one or multiple unplanned vessels, the idling area in the berth–time diagram that does not include unplanned vessels is calculated. If the idling area is equal to or bigger than the total area required by one or more unplanned vessels, it is possible to handle all or some of these unplanned vessels.

Otherwise, no unplanned vessel can be included. The nonoperation of planned vessels is not considered in this study or in practice; thus, the terminal is said to be saturated with its original set of planned vessels such that it cannot handle any extra vessels on an ad hoc basis. However, whether the terminal can handle unplanned vessels is dependent on their size. Therefore, the consideration is different for different sets of unplanned vessels, whereas the planned vessels must remain unchanged.

Spare Window Distribution

An even distribution is employed (Figure 4.5) for the generation of an initial set of unplanned vessel arrival times and results in spare windows 1, 4, 5, and 6 (denoted SW1, SW4, SW5, and SW6, respectively). Arranging unplanned vessels to berth at different berth segments is highly preferred to decrease the pressure on the corresponding yard block area, if possible. The size of the unplanned vessels is standardized. The probability of an unplanned megavessel being released from its home terminal is lower than that for a normally sized vessel, because its home terminal wants to avoid a chaotic situation in terms of a large volume of transshipment containers before and afterwards. In summary, unplanned vessels represent ad hoc vessel demand during the berth allocation process. The resulting OFV is reviewed using different test cases and with variation in the total vessel number, number of unplanned vessels, and berthing time requirements of unplanned vessels.

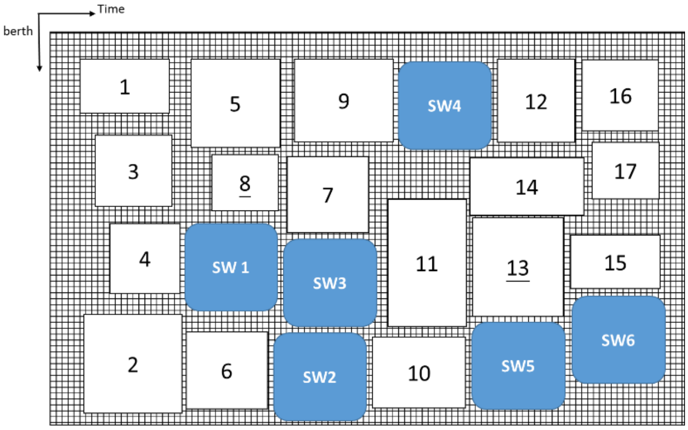


Figure 4.5 Spare vessel windows cluster without spare window at the cycle starting time.

OFVs

Once two OFVs have been calculated, the lowest is selected. If the alternative OFV (with unplanned vessels) is higher than the original OFV (without unplanned vessels), the final decision may be to refuse the ad hoc unplanned vessel berthing requirements for a certain number or all of the unplanned vessels. This happens when the terminal is saturated with planned vessels. Conversely, if the alternative OFV is lower than the original OFV, a lower cost is incurred if the unplanned vessels are handled; thus, the unplanned vessels are contributive and served. In practice, no spare windows are assigned that have the same arrival time as another vessel to avoid congestion within the same short time period of container transfer between terminals. However, two consecutive spare windows can overlap in time, as shown by SW2 and SW3 in Figure 4.5. An excessive number of new or ad hoc vessels to be handled at the same time will negatively affect the yard operation productivity and the operation of planned vessels. Exact overlapping is not suggested and taken as a minor case.

4.5 Computational Results and Discussion

To illustrate the high importance and wide application of the model proposed in Section 4, this paper uses the model to perform the berth allocation of a standard four-berth terminal with a berth length of 160 m and a cycle time of approximately 7 days (168 h). The first business case considers that berthing time is more crucial than berthing point, and this case has the widest application in the terminal community. In the industry, the penalty cost for a delayed berthing is much higher than the penalty cost incurred by an undesirable berthing point; at least 10 times higher. It is unreasonable for a terminal to refuse the berthing of a vessel when a suitable berthing length is available at or close to the target berthing time. To reduce the adverse impact of the longer distance between berthing point and the predefined container storage location of loading containers, terminals usually arrange more tractors to maintain high crane productivity. The cost of extra tractors is relatively small compared with the two types of penalty cost. Before a computation is begun, a feasibility check is performed to ensure that all the unplanned vessels can be handled within the expected planning time period. For a higher number of unplanned vessels, the computation time required is longer. The extreme case, in which the total time required to serve all vessels is longer than the planning time period, is also demonstrated to show the limit to the number of planned vessels in each unplanned vessel case. In theory, a longer cycle time period is highly undesirable because it affects the next planning cycle. In practice, however, the next planning cycle is sometimes short of demand in the earlier part of the time period. Therefore, these extreme cases are also included as a reference. A sample vessel data set for the case of 51 planned vessels with a 5% spare window area available for unplanned vessels, which results in accommodation of three unplanned vessels, is presented in Table 4.1. The table displays the arrival time, length, and operation time period for each vessel, planned and unplanned. For unplanned vessels, the lowest-cost berthing point is input as zero because such vessels' containers for loading are yet to arrive at the terminal. When they arrive, the resulting berthing point shall be available for the corresponding yard operations, and the loading containers are sent to the best position.

Vessel number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Arrival time	1	2	3	4	6	8	13	15	16	18	20	22	24	25	28	28	30	32	36	36	38	38	42	45	48
Vessel Length (per 10 m)	30	32	30	28	32	28	32	32	38	32	32	28	38	28	36	32	38	32	38	28	28	33	38	36	35
Vessel operations time period	12	12	12	12	14	10	14	12	16	12	12	11	14	10	12	12	14	12	12	12	14	10	14	14	11

Lowest cost berthing point	1	128	31	100	61	1	128	29	90	1	33	132	0	65	96	1	0	33	122	65	94	1	0	124	35
planned or unplanned vessel (1 or 0)	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	0	1	1
Vessel number	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Arrival time	48	50	52	56	68	70	76	82	84	88	98	100	102	104	106	110	115	118	125	132	136	140	142	144	144
Vessel Length (per 10 m)	32	36	35	32	32	32	32	35	32	32	35	32	33	28	32	35	36	32	38	35	34	32	33	35	30
Vessel operations time period	14	14	14	12	12	12	12	14	14	13	14	12	12	12	14	14	14	10	15	12	12	12	12	12	12
Lowest cost berthing point	1	88	33	128	1	96	33	125	65	1	33	92	127	1	94	29	92	128	1	39	126	94	39	1	130
planned or unplanned vessel (1 or 0)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Vessel number	51	52	53	54																					
Arrival time	145	152	154	158																					
Vessel Length (per 10 m)	32	32	34	35																					
Vessel operations time period	12	12	12	12																					
Lowest cost berthing point	98	37	1	125																					
planned or unplanned vessel (1 or 0)	1	1	1	1																					

Table 4.1 Sample berth allocation data set for a four-berth terminal with 51 planned vessels.

In our computation, five levels of berth–time utilization by planned vessels—denoted V30, V34, V39, V45, and V51—are tested using a set of unplanned vessels with normal distributed arrival times, where the distribution is defined by the optimal mean and standard derivation times—36 and 6 h for example, respectively—as indicated in Table 4.2. The numbers of planned vessels employed are 30, 34, 39, 45, and 51, describing a range of situations with respect to the maximum number of vessels, which is 56 for a continuous time period of 7 days. Assuming each vessel is berthed for an average of 12 h and each occupies the full length of each berth (40 m), it is possible to operate 7 × 2 × 4 = 56 vessels at a four-berth terminal. In real operations, however, this is impossible as vessel berthing and unberthing require waiting time with uncertainty.

The numbers of vessels employed are thus 55%, 60%, 70%, 80%, and 90% (30, 34, 39, 45, and 51 planned vessels, respectively) of the maximum capacity. Utilizations from 50% to 90% are the most commonly found situations faced by terminal management and are suitable for spare window possibility. An approximate 10% efficiency loss is expected for all levels of utilization in practice; therefore, 90% is selected as the upper limit. Each unplanned vessel is defined as having a vessel operation time equal to or less than 14 h, with unplanned vessels' length equal to or less than 38 m. A Matlab program is developed for computation and to enable trend and pattern analysis in terms of the different values and combinations of the input parameters. The Matlab program is the 2014 version and is run on a computer with an Intel i8 core and 55000U 2.40 GHz CPU.

Virtual vessel optimal arrival time	Probability of virtual vessel occuring (%)		
	within +/- 1 std (68%)	within +/- 2 std (27%)	within +/- 3 std (4%)
N(36,6)	**(30,42)**	**(24, 48)**	**(18,54)**
N(24,4)	(20,28)	(16,32)	(12,36)
N(48,8)	(40,56)	(32,64)	(24,72)

Table 4.2 Unplanned vessel arrival time definition.

In general, the computational results demonstrate, through the resulting OFVs and cycle time (CT), that lower utilization promotes the creation of spare windows compared with higher utilization. Spare window insertion does not increase the CT when utilization is low, such as for case V30 (utilization of 50% to 70%), when a low OFV is obtained. This proves that a strong incentive exists for terminals with low utilization to arrange spare windows for unplanned vessels.

In high utilization cases, however, spare windows are not beneficial to the terminal. For a middle level of utilization, such as V39, the decision to arrange spare windows depends on the actual distribution of planned vessels. If the utilization around the optimal time is lower than average, spare window arrangement is still beneficial. The OFVs and CTs for unplanned vessels that are distributed N(36,6) and where the planned number of vessels is 30 to 51 within each planning time period are respectively summarized in Tables 4.3 and 4.4 and Figures 4.6 and 4.7. All computation is completed within 10 min, with a lower computer processing runtime when the number of planned vessels is higher because of the fewer choices available for unplanned vessels; this also limits the resulting combinations, as indicated in Table 4.5.

Planned vessel count	No. of unplanned vessel and % of area occupied in berth-time diagram						
	0	3	6	8	12	15	17
	0%	5%	10%	15%	20%	25%	30%
30	4,500	-49,700	-127,900	-119,600	-150,500	-109,600	-109,600
34	18,000	-63,500	-157,300	-180,800	-150,600	-80,400	-28,400
39	36,800	-55,300	-91,400	-71,500	50,800	107,700	182,600
45	75,900	84,500	46,300	190,600	262,700	350,500	452,700
51	216,600	357,000	513,100	554,900	715,200	822,500	963,900

Table 4.3 OFVs for different combinations of planned and unplanned vessels.

Planned vessel count	No. of unplanned vessel and % of area occupied in berth-time diagram						
	0	3	6	8	12	15	17
	0%	5%	10%	15%	20%	25%	30%
30	167	167	167	167	167	167	168
34	165	165	165	165	165	169	182
39	170	170	170	170	170	188	199
45	172	172	206	206	206	206	211
51	199	199	205	214	236	237	244

Table 4.4 CTs for different combinations of planned and unplanned vessels.

	No. of unplanned vessel and % of area occupied in berth-time diagram

Planned vessel count	0	3	6	8	12	15	17
	0%	5%	10%	15%	20%	25%	30%
30	1.12	9.57	9.12	8.78	8.51	8.16	8.15
34	1.25	8.76	8.70	8.14	8.02	7.87	8.25
39	1.41	8.55	8.62	8.45	8.42	8.27	8.29
45	1.65	7.87	7.85	8.25	7.89	7.78	7.56
51	1.70	7.28	7.45	7.10	7.24	7.17	6.89

Table 4.5 Computation time (min) for different combinations of planned and unplanned vessels.

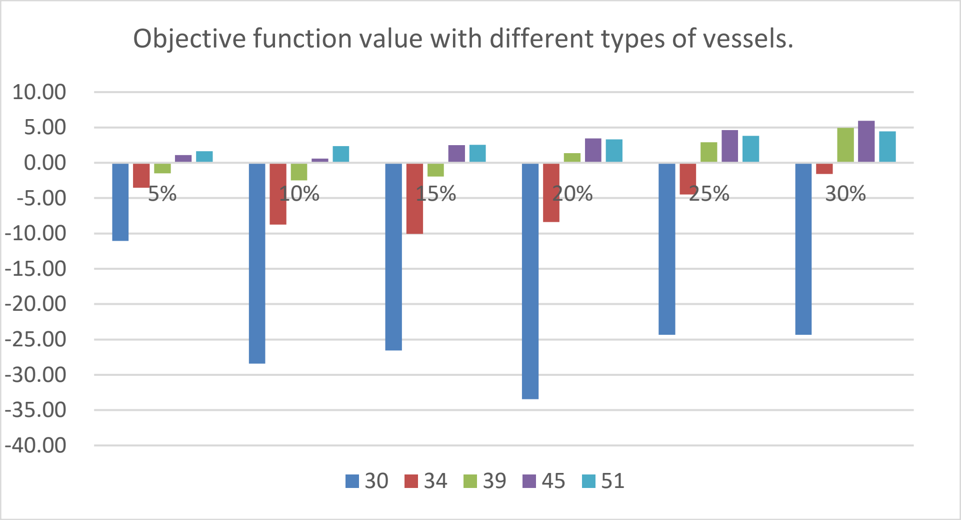


Figure 4.6 OFV variation for planned and unplanned vessels at a four-berth terminal.

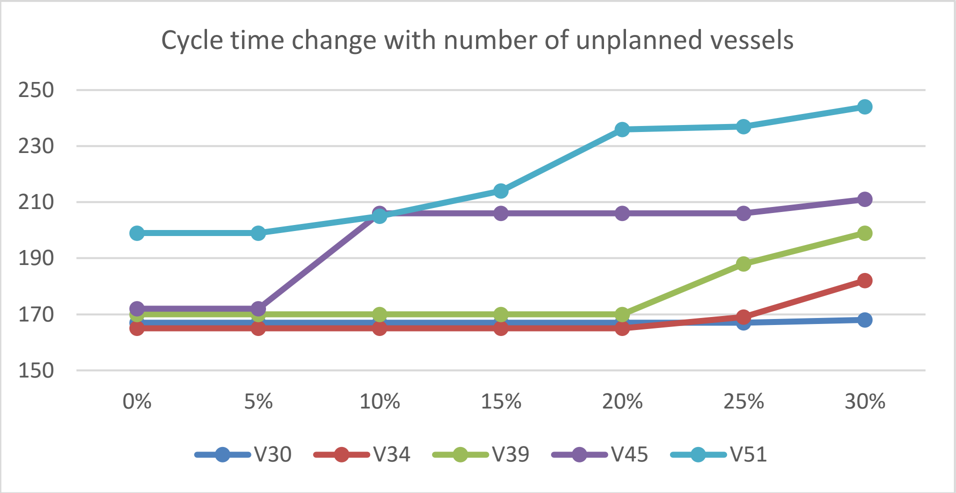


Figure 4.7 CT variation for planned and unplanned vessels at a four-berth terminal.

The experimental results reveal a clear decrease in the OFV, which is composed of three components: penalty cost for variation in arrival time, penalty cost for variation in berthing point, and negative penalty cost (reward) for the creation of a spare window. To create a spare window, the penalty costs in the first and second components are forced to increase by the minimum possible amount, as shown in Table 4.6. Table 4.6 indicates the minimum required business returns if the terminal is to break even. These returns serve as a basic revenue target for commercial effort when the addition of extra vessels to the existing planned vessel set is suggested. Because extra unplanned vessels may vary in vessel length and operation time period, there is a minimum revenue requirement for each spare window in each test case, as shown in Table 4.7.

For example, for a berth allocation with 30 planned vessels (occupying approximately 45% of the total berth–time area in the berth–time diagram), if 5% of the idling area is used for spare windows, the minimum required business return needed to break even is HKD100,300. This implies that each of the three extra vessels must contribute at least HKD33,433 in business gain to cover the increased penalty costs, and that the target number of extra vessels (unplanned vessels) should be six instead of three for a lower unit cost per spare window.

For another berth allocation case with 34 planned vessels (occupying about 50% of the total berth–time area in the berth–time diagram), the unit cost of arranging six spare windows is lower than that for the case of 30 planned vessels. This result indicates that a lowest value exists for each case that is dependent on the actual number of unplanned vessels to be included in each vessel set. The higher the number of planned vessels in each case—for example, V45 and V51, occupying 70% and 77% of the total berth–time diagram area—the higher the unit cost of spare windows. This indicates a critical level above which the long-term agreement with customers regarding existing planned vessel arrival and/or operation time period should be arranged to create more room for extra vessels. In this case, the unit cost of an additional three spare windows is more than twice that in the case of 51 planned vessels (HKD169,000) when compared with the case of 45 planned vessels (HKD78,167).

The impact on CT is summarized in Tables 4.8 and 4.9, revealing the possible effect on the next cycle when an excessive number of vessels is added to the original planned vessel set. The data in the tables are plotted in Figures 4.8 and 4.9, respectively. To summarize, when unplanned vessels can be handled with the highest flexibility, or scattered or few vessels are found in the optimal unplanned vessel arrival period, the maximum number of unplanned vessels can be served. However, this also corresponds to the situation wherein there are few planned vessels, which is not preferred by terminals. In realistic tactical and operational berth allocation planning, terminals search for additional vessels when a basic planned vessel set is available, but not in the reverse situation. Therefore, breaking even when incurring increased penalty costs and extra business profit is critical, or else serving any extra vessels may not be justified. Terminals select the strategies that suit their customer service strategy. For example, a terminal with a small number of existing vessels—30 or 34, for example—is aggressive about obtaining ad hoc vessels, whereas a terminal with numerous existing vessels—45 or 51, for example—is more conservative when obtaining more ad hoc vessels because the ideal CT can be exceeded.

Planned vessel count	No. of unplanned vessel and % of area occupied in berth-time diagram						
	0	3	6	8	12	15	17
	0%	5%	10%	15%	20%	25%	30%
30	4,500	100,300	172,100	280,400	449,500	640,400	740,400

34	18,000	86,500	142,700	219,200	449,400	669,600	821,600
39	36,800	94,700	208,600	328,500	650,800	857,700	1,032,600
45	75,900	234,500	346,300	590,600	862,700	1,100,500	1,302,700
51	216,600	507,000	813,100	954,900	1,315,200	1,572,500	1,813,900

Table 4.6. Penalty costs (HKD) for spare window arrangement for accepting unplanned vessels.

Planned vessel count	**No. of unplanned vessel and % of area occupied in berth-time diagram**						
	0	**3**	**6**	**8**	**12**	**15**	**17**
	0%	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**
30	N/A	33,433	28,683	35,050	37,458	42,693	43,553
34	N/A	28,833	23,783	27,400	37,450	44,640	48,329
39	N/A	31,567	34,767	41,063	54,233	57,180	60,741
45	N/A	78,167	57,717	73,825	71,892	73,367	76,629
51	N/A	169,000	135,517	119,363	109,600	104,833	106,700

Table 4.7. Minimum revenue requirement (HKD) for spare window arrangement for accepting unplanned vessels.

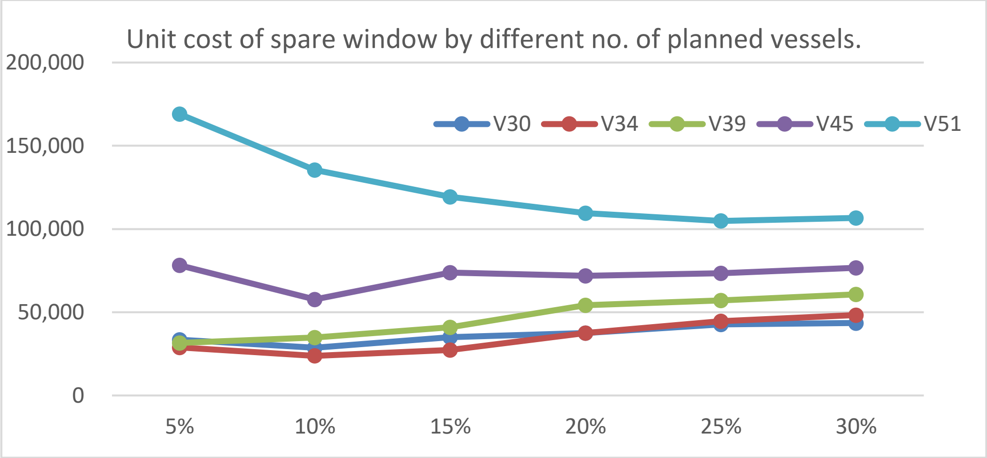


Figure 4.8 Unit cost of a spare window (HKD) for different numbers of planned vessels.

Real vessel count	No. of virtual vessel and % of area occupied in berth-time diagram						
	0	3	6	8	12	15	17
	0%	5%	10%	15%	20%	25%	30%
30	167	167	167	167	167	167	168
34	165	165	165	165	165	169	182
39	170	170	170	170	170	188	199
45	172	172	206	206	206	206	211
51	199	199	205	214	236	237	244

Table 4.8 CT (h) for different combinations of planned and unplanned vessels.

Real vessel count	No. of virtual vessel and % of area occupied in berth-time diagram						
	0	3	6	8	12	15	17
	0%	5%	10%	15%	20%	25%	30%
30	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.60%
34	100.00%	100.00%	100.00%	100.00%	100.00%	102.42%	110.30%
39	100.00%	100.00%	100.00%	100.00%	100.00%	110.59%	117.06%
45	100.00%	100.00%	119.77%	119.77%	119.77%	119.77%	122.67%
51	100.00%	100.00%	103.02%	107.54%	118.59%	119.10%	122.61%

Table 4.9 Percentage of CT for different combinations of planned and unplanned vessels.

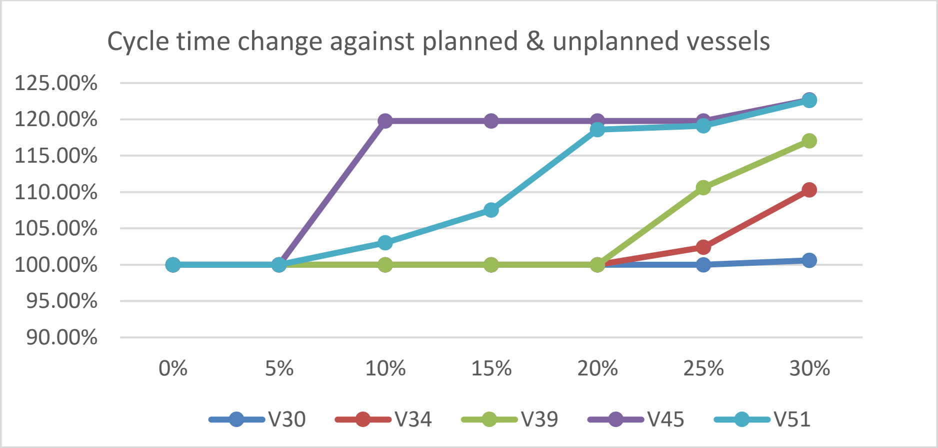


Figure 4.9 CT variation for different combinations of planned and unplanned vessels.

4.6 Conclusion

The determination of spare windows for unplanned vessels in the BAP gives a clear picture of “what’s next” instead of focusing on existing planned vessels only. When there are no unplanned vessels, the original cost serves as a basic cost. When the number of unplanned vessels increases, the OFV decreases because the increasing penalty costs due to existing vessels are overcompensated for by the rewards from unplanned vessels. Ideally, the alternative OFV should be lower than the original OFV that is obtained for no unplanned vessels. If numerous unplanned vessels are considered, the OFV increases again because the penalty costs become so high that serving the set of unplanned vessels is not justified in terms of overall terminal performance and an undesirable elongated CT. Therefore, the proposed model can be used as a critical tool for evaluating new business opportunities. In addition to aiding berth allocation planning within a terminal, it allows a fair comparison between two terminals of similar size, number of planned vessels, and total handling volume. Comparisons can be performed regarding the business potential in terms of berth allocation and throughput volume, instead of throughput volume solely. To conclude, this paper shares how idling times or resources can be used to service unplanned demand when full information is not available. Clear breakeven targets are calculated for consideration of additional business volume. Any extra costs are reviewed carefully, and it is analyzed and applied as a means of indirect investment to attract future customers without expensive investment in additional terminal capacity. Further research efforts on multiple sizes of spare windows with different optimal proposal times are suggested.

CHAPTER 5 SUMMARY AND LIMITATIONS

This thesis provides a comprehensive overview on container terminal efficiency and discovers two hidden influences on efficiency. Four key factors affecting efficiency are uncovered, and how they are linked is determined. A review at the port level further illustrates their vital links and effects. The two hidden influences are applicable at terminals worldwide, regardless of each terminal’s economic and shipping demand. Study of the two hidden influences provides an effective means to improve terminal efficiency without additional investment in capital or staffing. Terminal efficiency is adversely affected by these two influences, yet no tools are available to effectively solve the problems they pose. We provide effective and efficient solutions to these problems, enabling an increase in the efficiency of a container terminal without altering the input resources or customer base. However, there are some limitations to the proposed solutions. Regarding the first influence, prolonged vessel berthing periods due to vessel workload waiting time are discussed. Liners are assumed to be willing to arrange for vessels to temporarily depart terminals if the required workloads are not yet available, but some liners may have old-fashioned ideas and dislike rehandling even if it is proven to have a lower cost. Even if they are aware that a temporary departure is justified and promotes higher vessel carrying volume for the same berthing, they may not be willing to arrange for the vessel to leave. Liners may worry about a potential delay when the time comes for their vessel to reberth. Additionally, they may choose to rearrange all loading containers, which can decrease the vessel waiting time considerably. Therefore, the model and conclusions are applicable to terminals and liners that have good working relationships, but not terminal–liner pairs without mutual trust. Applying the conclusions in terminal–liner pairs with worsening business volume and a negative cargo forecast for outbound cargo is also difficult. If a terminal’s business volume is decreasing, liners will not agree to temporarily depart because the total port stay period (including time for the discharge and loading of containers from/to the vessel) may be much shorter than before. The temporary departure period may be too long compared with the vessel’s total port stay period. Additionally, our method is not perfectly applicable when the outboard cargo volume is decreasing and inbound cargo is dominant. In such cases, vessels do not have similar discharge and loading periods and splitting the discharge operation is not preferred by liners. This is due to discharge operations always being possible without any precedence related consideration. Conversely, if the inbound container volume is much smaller than the outbound container volume, our method is again not perfectly applicable because outbound container volumes should be handled within a definite time period without splitting by volume. Therefore, our proposed model and solution are applicable to terminals with vessels that have similar inbound (discharging) and outbound (loading) volumes. The method is especially useful when the penalty cost of transshipment replanning is high, as confirmed by liners. Regarding the second efficiency influence, unplanned vessels and service demands are discussed. Unplanned vessels are assumed to be able to wait instead of berthing directly at their preferred berthing time. This assumption may not be applicable if an extra service charge is paid by an unplanned vessel in exchange for immediate berthing upon arrival. In critical situations, such as when a fatality or accident is possible, liners are usually willing to pay a premium to reduce the risk to lower levels in order to avoid substantial business loss and claim reimbursements that can affect the company in the long term. Therefore, the terminal that serves such unplanned vessels must complete vessel operations at a higher than normal productivity rate at a higher cost level to serve the immediately arriving unplanned vessel. Luckily, cases of this type occur infrequently, and liners are generally willing to wait for a short period once they have been informed of the much shorter vessel waiting time arrangement due to an overflow decision. This study also assumes that handling unplanned vessels is technically possible once such vessels have been accepted by the terminal that has idling time. In reality, the serving terminal is sometimes busy and its idling time period is extremely small. The unplanned vessels may thus be operated with decreased productivity or become a source of container transfer traffic during the busy operation periods of earlier vessels. We do not consider the level of yard-side activity and assume that a certain amount of storage space is available for storing the loading containers that are urgently transferred from an unplanned vessel's original terminal. We also assume that there are sufficient yard cranes for these arrangements. In reality, container transfer may be postponed until the last moment to avoid adverse effects on the productivities or performances of other vessels, which may belong to other liners.

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