



CRITICAL FACTORS AFFECTING EFFICIENT YARD PLANNING IN A SEAPORT CONTAINER TERMINAL

YAPA MAHINDA BANDARA^{1*} AND CHAMARA PERERA²

¹Business School, Edinburgh Napier University, EH141DJ, Edinburgh, UK. ²University of Moratuwa, Katubedda, Sri Lanka.

*Corresponding author: Y.Bandara@napier.ac.uk

ARTICLE INFO	ABSTRACT
<p>Article History: Received: 11 June 2025 Revised: 11 August 2025 Accepted: 11 August 2025 Published: 25 August 2025</p> <hr/> <p>Keywords: Yard planning, critical factors, container terminal, Port of Colombo, Analytic Hierarchical Process, weight rated and ranking method.</p>	<p>Operations at a container yard within a port terminal represent one of the most complex aspects of terminal operations, as both inbound and outbound container flows must be handled simultaneously. Yard planning involves allocating appropriate storage locations for these containers in order to integrate all activities within the terminal area into a seamless operation. Consequently, yard planning directly influences port efficiency by addressing the storage allocation of inbound containers, the utilisation of yard equipment, and the retrieval sequence of outbound containers. Several factors determine the efficiency of the yard planning process. The main objective of this article is to explore and identify the factors affecting yard planning and its efficiency from the perspective of port terminal executives. A questionnaire survey was conducted with the participation of 30 port industry professionals representing the three port terminals operating at the Port of Colombo in Sri Lanka. The study employs the Analytic Hierarchy Process (AHP) method to identify the critical factors influencing yard planning efficiency and to determine the relative weight of each factor. The article further offers managerial and technical implications for improving yard planning in port terminal management.</p>

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Introduction

The maritime industry has been developing rapidly, providing inter-region and continental transportation and logistics for the manufactured output of many countries in the world in the past few decades. This growth provides financial and economic benefits for many countries' economic sectors, and one of its main domain is the shipping and port industries, which have proven to be the most important economy activity as they are essential contributors in facilitating trade (Shaiful *et al.*, 2016). Due to offshoring of manufacturing in Asia, especially by China, the container traffic has increased exponentially to cater the growing demand (Zhen, Xu, Wang, & Ding, 2016).

A key element in modern supply chain and logistics of any product is maritime transportation. In this mode of transportation,

the main method of transporting products is the containerised transportation by liner shipping between a pre-determined port network. Since their introduction in the 1960s, containers represent the standard unit load medium of package for international freight and ports have developed their layouts in port terminals and facilities to accommodate them. Containers are handled at every port along the liner shipping routes and the handling facilities and services are provided by a port terminal operator or a port authority. The transshipment of containers between different parties in a supply chain involves manufacturers producing goods for global use, freight forwarders, shipping lines, transfer facilities, and customers (Kim & Günther, 2007).

A seaport container terminal is a key part of supply chain in any product (Islama & Olsena, 2013). Container terminals play a fundamental role in intercontinental cargo transportation by serving as an intermodal interface between the sea and the land carriers. Typically, they receive cargos in containers from their origin, store them temporarily to account for the differences in arrival times of the sea and the land transport, and route them to their destinations (Chen, Hsu, & Huang, 2003). A container terminal has specific operations pertinent to container handling, which need to be planned prior to the vessels' arrival at the berth. Operation planning in a port terminal is performed for the efficient use of key resources during critical operations, which are those closely related to the key performance indicators of a container terminal. Some of the operation planning involves berth planning, quay crane (QC) scheduling, load/unload sequencing, and yard planning.

Some resources are classified as key resources because of their high cost and the consequent expense in increasing their capacity. Key resources may include berths, quay cranes, and storage spaces in most container terminals (Lee, Chung-Lee; Meng, 2014). However, containerisation brings not only opportunities, but also restrictions to the maritime industry, mostly applicable to container terminals (Bandeira, Becker, & Borenstein, 2009). The increasing number of containers and the mounting dimensions of vessels are adding stress to seaports to increase the capacity of container terminals. Because of that the bottleneck of port operations has started in the yard side (Lu Zhen, 2013). Ports are bound to respond with new terminals and added infrastructure facilities (Islam & Olsen, 2011).

In addition, efficient port operations that maximise the port throughput are essential to increase the ports' profits. To do so most port operators increase the efficiency of the quay side to shorten the processing time to turn around the vessel (Zhen *et al.*, 2016). As a result, the capacity bottleneck of terminal operations has resulted in the yard side where containers are stacked and stored, either for transshipment

purposes or for internal trade. Further, because of the increase in the container traffic, the ship manufacturers began to manufacture ships with larger capacities to cater to the increase in the container cargo demand. As a result, efficient port operations that maximise the port throughput are essential to increase the ports' profits and to attract shipping lines. As a consequence of this capacity bottleneck, the main problem that arises at most ports is the lack of space at the container port storage areas. Most of the ports around the world are now facing capacity shortages and finding storage space is becoming a huge burden on container port operators.

To meet this growing demand for space, the port authorities in many countries have invested in capacity expansion projects at key port terminals. However, capacity expansion alone is not sufficient to raise terminal efficiency. In order to build an efficient container terminal, yard planning is essential. There are many factors that affect the efficiency of yard planning process.

The main aim of this article is to investigate and identify the critical factors that port operators need to consider when implementing an efficient yard planning process. The article is organised as follows: First, a literature review on yard planning is presented to identify the technical and operational factors affecting yard planning in a port terminal. Section 3 presents the methodology and data collection process. The data analysis, results, and discussion are provided in Section 4, and Section 5 concludes the article.

Literature Review

There are various performance indices that look at the efficiency of a container terminal from different perspectives, but ultimately, terminal performance is measured by its service level to customers. Port operators typically pursue two main objectives: (a) to minimise the average vessel turnaround time, which reflects the terminal's service level to its customers—namely, the shipping companies—and (b) to maximise the average throughput of the terminal (often reflected by the quay crane rates), which

serve as a measure of terminal productivity (Zhang *et al.*, 2003). To achieve a satisfactory level of performance, several operational-level decisions must be made to manage activities and all these decisions influence one another. Moreover, the involvement of multiple stakeholders and the complex interactions among various service processes further complicate terminal operation management (Holguín-Veras & Jara-Díaz, 1998). Therefore, it is evident that arriving at an optimal decision that supports the overall objectives of a port is a challenging endeavour to say the least. A logical approach to resolving this issue is to apply hierarchical decomposition, breaking down the original complex problem into simpler sub-problems (Psaraftis, 1998). However, before reasonably and effectively decomposing the problem into smaller sequential tasks, it is necessary to examine container terminal workflows in detail in order to gain a complete understanding of the problem. These sub-problems (or processes) are commonly identified as berth allocation, stowage planning, yard planning, and logistics planning, each with different target time horizons.

The sequential order of these processes was identified, and among them, yard planning involves allocating appropriate storage locations for inbound containers to integrate all activities within the terminal area into a seamless process. Operations in the storage yard represent the most complex part of port terminal activities, as both inbound and outbound container flows are handled simultaneously in this area (Chen *et al.*, 2003). Yard planning refers to the pre-planning of space for temporarily storing containers discharged from vessels, as well as for outbound containers arriving through the gate. A yard management system supports efficient yard operations by coordinating handling equipment, monitoring yard space usage, and enabling quick identification of container inventory levels (Lee, Chung-Lee, & Meng, 2014).

A distinctive feature of terminal management is the significant difference in planning horizon lengths, for example, yard planning is performed on a time scale of weeks, whereas loading and unloading lists are prepared

only minutes in advance or in most cases, in real time. As a combined outcome of these decision-making tasks, loading and unloading lists for individual vessels are adjusted according to real-time situations. Of all terminal processes, the planning of yard operations plays a crucial role in efficient port management, particularly given the limited space and high throughput in many terminals (Chen *et al.*, 2003). In container terminal operations, the storage yard is regarded as the most critical area, as the most complex operations occur when both import and export flows are handled concurrently (Zhang *et al.*, 2003).

To efficiently perform container handling operations, storage yard management primarily reflects three types of yard resources, namely transport vehicles, yard cranes, and storage space (Lu Zhen, 2013). The configuration of a yard block depends on the type of yard cranes used for container stacking. The basic unit of storage space is the slot, which accommodates one 20-foot equivalent unit (TEU). Since container stacking is carried out by yard cranes, the specific configuration and layout of yard blocks are determined by the type and arrangement of cranes. The delivery of containers within the terminal is handled by transport vehicles (Zhen, 2013). Majority of the container yard is allocated to general cargo (dry cargo) containers. However, in the maritime industry, there are also reefer containers, hazardous cargo, and empty containers, each of which is assigned to designated areas within the yard. Reefer containers are stored in areas equipped with power-supply racks, while hazardous cargo containers are stored in segregated zones in accordance with the International Maritime Dangerous Goods (IMDG) segregation rules. Empty containers are usually stored in separate areas and handled with reach stackers or top handlers (Lee, Chung-Lee, & Meng, 2014).

Decision Making in Yard Management

A yard management system is used to ensure the efficient operation of handling equipment in the yard, monitor yard space utilisation, and quickly identify container inventory levels (Lee,

Chung-Lee & Meng, 2014). Since container stacking is performed by yard cranes, the specific configuration and layout of yard blocks depend on the types and arrangement of these cranes. The transportation of containers within the terminal is handled by transport vehicles

(Lu Zhen, 2013). Based on these resources, storage yard management can be divided into three decision levels: The “strategic level”, the “planning level”, and the “operational level”, as shown in Figure 1.

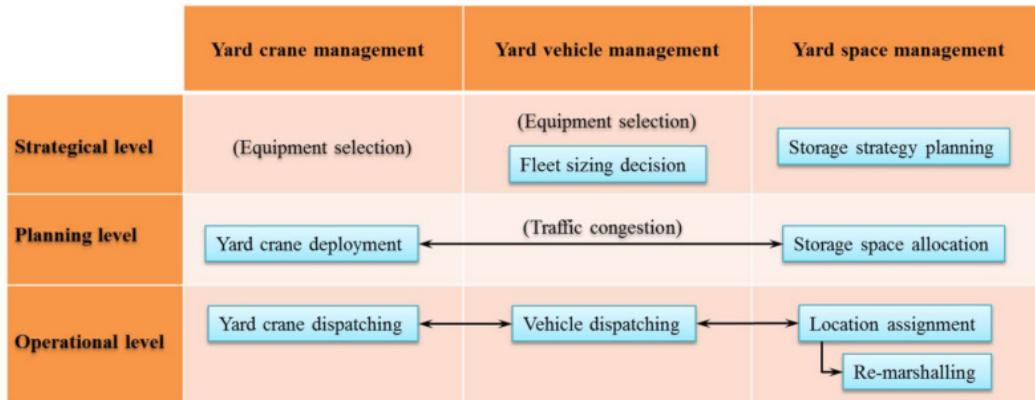


Figure 1: Major research areas on storage yard management

Source: Lu Zhen (2013)

The strategic level is considered during the construction or initial phase of the storage yard. Decisions at this level primarily involve determining the storage strategy and the equipment mix, including the types and number of yard cranes and transport vehicles to be deployed in the yard. The planning level focuses on allocating storage space for

incoming containers and deploying yard cranes for container handling. At the operational level, decisions concerning all yard resources are specified down to the level of individual containers. At this stage, the interactions between yard cranes, transport vehicles, and the storage location of each container must be carefully considered to maximise operational efficiency (Lu Zhen, 2013).

Current Situation in Yard Planning

Since the 1990s, global container traffic has grown at rates up to three times faster than the global gross domestic product (GDP), primarily due to the offshoring of manufacturing to Asia, especially China. Port throughputs have expanded even more swiftly as container transshipment volumes increase (Lu Zhen, 2013). Container throughput has risen steadily year by year, with volumes climbing from 102 million metric tonnes in 1970 to 1,578 million metric tonnes in 2013 (Shaiful *et al.*, 2016). This trend has continued into recent years, driven by persistent growth in international trade and supply chain complexity. With this development and growth of international trade, container

terminals in the world play major role in the world maritime transportation. Limitation of the land and the arrival of the mega container ships pose a great challenge to provide services efficiently, especially for transshipment ports.

In the terminal operators pay much more attention to increase the efficiency of quayside to shorten the processing time to turn around the vessel. Container terminals are critical nodes in global maritime logistics; however, increased vessel sizes (mega-container ships) and limited terminals land create significant challenges for efficient operations, particularly at transshipment hubs (Jiang *et al.*, 2012).

Terminal strategies have focused heavily on improving quayside operations — such as enhancing crane productivity and berth efficiency — but studies indicate that these gains alone are insufficient to boost overall terminal throughput without concurrent improvements in yard operations (Lu Zhen, 2013). The bottleneck in terminal operations has increasingly shifted away from the quay side to the container yard due to spatial constraints and complexities in container handling (Lu Zhen, 2013). In the context of this rapid development of container transportation, container terminals were concerned to be discontinuity because of lagging of the development of shipping.

The development of new container ships with larger capacity, modern technology and the automation at container terminals through their specialisation are considered to be the basic features of modern container transport trends (Park & Dragović, 2009). A sea port as one of the key parts in the global supply chain, due to proliferation of container cargo, many seaports of the world are currently facing the problem of capacity shortage in terminals. As a result of that seaport authorities are under pressure to keep up to date with ways in which to solve it (Islama & Olsena, 2013). The logistical challenge for container terminals arises when there might be several moored vessels, some of which are being unloaded and others loaded. A combination of container demand increase and storage yard capacity scarcity creates complex operational challenges for storage yard managers (Carlo, Vis, & Roodbergen, 2014). Container terminals around the world must be planned to satisfy the prompt accommodation of ships with minimum turnaround time and maximum throughput of the berth facilities. With achieving these contradicting objectives, each container port must reach a compromise, the number of berths which will achieve the most economical transfer of cargo between ships and shore (Park & Dragović, 2009).

Efficient yard planning is therefore recognised as a crucial factor affecting terminal capacity, throughput, and vessel turnaround

times. Yard planning challenges include container stacking strategies, space allocation, and the management of container flows to minimise reshuffles and crane idle times (Christensen & Ellis, 2022; Hakim *et al.*, 2025). Modern trends, such as the digitalisation of yard operations and the application of automation, have gained traction as solutions to yard inefficiencies. For instance, digital twin technologies that create virtual replicas of container yards allow real-time monitoring, simulation, and optimisation of stacking and handling operations, reducing non-productive movements and increasing productivity (Hakim *et al.*, 2025).

Additionally, flexible yard space allocation — including flexible stacking layers and dynamic container assignment — has been identified as effective for minimising handling times and energy consumption (Tomazic *et al.*, 2025). Container terminals also face capacity shortages due to surging container volumes and spatial limitations. The increasing arrival frequency of large vessels poses logistical challenges requiring coordinated scheduling of quay cranes, trucks, and yard cranes for efficient container transfer (Zhou *et al.*, 2025). Research emphasises the importance of integrated scheduling and truck dispatch optimisation to minimise vessel turnaround and maximise yard crane use (Zhou *et al.*, 2025).

Studies also focus on yard layout optimisation tailored for automated container terminals (ACTs), employing mathematical models to improve cycle times and yard space usage (Liu *et al.*, 2025). These models help terminal operators plan container stacking strategies, equipment deployment, and internal transport routes to improve overall yard efficiency.

Beyond technological solutions, strategic decisions such as container yard ownership models, intermediate storage configurations, and hybrid inbound flow management are emerging topics. For example, industrial case studies illustrate how container yards can serve as complementary warehousing solutions, balancing operational expenditure and capacity

needs outside congested warehouse facilities (Christensen & Ellis, 2022).

Past Research on Yard Planning

Regarding yard planning, there is a substantial body of research; however, most studies have primarily focused on introducing simulation models, templates, and technical modules for yard planning processes, with relatively few studies having survey reviews. Table 2 summarises the research identified, which was reviewed to determine the factors affecting efficient yard planning. Maloni and Jackson (2005) showed that ports retain influence only on gate capacity and terminal yard space and as a result ports are primarily focusing on increasing their capacity by enhancing productivity of existing facilities, labour, and technology than on physical expansion.

Ortiz *et al.* (2007) viewed yard delays including loading and unloading delays that occur when a particular shipment is held up for

any arbitrary reason such as random scanning are as intermittent constraints that delay or disrupt the movement of freight during transport. Islam and Olsen (2011) described that over all capacity of a port is impacted by a series of connected capacity components determined by many stakeholders such as rail lines, transport operators, terminal operators, stevedoring companies, gate operators and shipping lines, and a delay at any of those points affects overall capacity of the port. Shaiful *et al.* (2016) viewed overcoming the lack of container yard space is vital for terminal efficiency and introduced a new innovative means of container stacking/storage strategy that leads to increase efficiency and effectiveness in handling containers, and the profit margin of ports. The limitations of the container yard area, the high volume of containers and high volume of vessels that are entering the port at the same time have led to capacity issues in the port.

Table 1: Past literature

Research Type	Research
Simulation Models/ Templates	(Yun & Choi, 1999), (Chen <i>et al.</i> , 2003), (Park & Dragović, 2009), (Bandeira <i>et al.</i> , 2009), (Jiang <i>et al.</i> , 2012), (Islama & Olsena, 2013), (Zhen, 2014), (Jin, Lee, & Hu, 2015), (Tang, Jiang, Liu, & Dong, 2015), (L Zhen <i>et al.</i> , 2016), (Cho <i>et al.</i> , 2020)
Literature Reviews	(Psaraftis, 1998), (Steenken, Voß, & Stahlbock, 2004), (Kim & Günther, 2007), (Stahlbock & Voß, 2008), (Boile, Theofanis, & Golias, 2009), (Park & Dragović, 2009), (Stopford, 2009), (Bierwirth & Meisel, 2010), (Böse, 2011), Zhen, 2013), (Carlo <i>et al.</i> , 2014), (Lee, Chung-Lee; Meng, 2014), (Christian Bierwirth & Meisel, 2015), (van Twiller <i>et al.</i> , 2023), (Ningrum <i>et al.</i> , 2024), (Weerasinghe <i>et al.</i> , 2024)
Factors	(Robinson, 2003), (Maloni & Jackson, 2005), (Ortiz <i>et al.</i> , 2007), (Islam & Olsen, 2011), (Maloni & Jackson, 2014), (Shaiful <i>et al.</i> , 2016)
Other	(Holguín-Veras & Jara-Díaz, 1998), (Hwan Kim & Bae Kim, 1999), (Steenken, Winter, & Zimmermann, 2001), (Zhang <i>et al.</i> , 2003),

There is extant research regarding yard planning in areas such as introducing new simulation plans, yard templates, container reshuffling and stacking, and literature reviews. All of these studies were carried out with regard to capacity issues - space limitations in container yards at seaports which is the most significant factor regarding yard planning, however there

are more significant factors that should be considered when implementing yard planning. Therefore, a study on identifying critical factors in yard planning in the perspective of Sri Lanka was identified as the focus on the research. Gap identification led to the origination of the research problem and ultimately this article contributes to add new knowledge to the

existing literature in identifying factors affecting yard planning in the Sri Lanka context as well as new factors to be considered in future studies in other port settings.

Overview of Port of Colombo

The Port of Colombo is the largest and busiest port in Sri Lanka and South Asia. Located in Colombo on the southwestern shores of the Kelani River, it serves as a significant terminal in Asia due to its strategic location in the Indian Ocean. The port underwent rapid modernisation in the 1980s, including the installation of cranes, gantries, and other modern terminal infrastructure. Currently, with a capacity of 4.1 million TEUs and a dredged depth of up to 18 metres (49 ft), Colombo Harbour ranks as one of the busiest ports in the world, and was ranked 30th globally in 2014, handling a volume of 4.91 million TEUs. It is also one of the largest artificial harbours in the world, responsible for most of the country's foreign trade, with an annual cargo tonnage of 30.9 million tonnes.

The Port of Colombo has three major container terminals: Jaya Container Terminal (JCT), South Asia Gateway Terminals (SAGT), and Colombo International Container Terminal (CICT). JCT began operations when the port was upgraded to handle containerised cargo in the early 1980s, becoming the country's first and only container terminal until SAGT was opened in 1998, followed by CICT in 2013, which has an annual capacity of 2.4 million TEUs. Due to these developments and its strategic position along major trade routes, the port has become more attractive to mainline shipping than any other port in the region.

For vessels at JCT and SAGT, there are two entrances to the terminal: The Western Entrance (230 m x 15.0 m) and the Northern Entrance (190 m x 13.0 m). There are three breakwaters: South-West (1,570 m), North-West (810 m), and North-East (330 m), with a dredged depth ranging between 12.0 m and 15.0 m. JCT has four main container berths and two feeder berths, with a quay wall of 1,292 m plus a 350 m feeder berth quay wall, along with 20 quay cranes (Panamax

& Super Post Panamax). SAGT offers a total quay length of 940 m with three berths.

CICT differs from the others, as it was built with more modern equipment. The berth depth is 18 m, with a total breakwater length of 6,830 m and an access channel 20 m deep, allowing for two-lane traffic access. It is equipped with 12 quay cranes featuring twin-lifting capability, capable of handling vessels with up to 23 rows across.

Methodology and Data

In this article, a qualitative and quantitative methodology incorporating both questionnaires and interview sessions was employed. First, the factors contributing to the lack of space in port terminals were identified based on a literature review, resulting in an initial list of 13 factors. In the first questionnaire, three experts were asked to rate each factor on a scale of 0–10 according to its impact on yard planning in port terminals. The experts were also invited to suggest any additional factors they considered important.

Following several omissions and additions, a total of 18 factors were identified as significant for consideration in container terminal yard planning. These factors are space in the container yard area, annual volume of containers (TEUs), equipment (RTG/GC/QC), technological applications (IT/Terminal Management Systems), spatial planning/design, quality standards (yard surface/numbering/road traffic network), number of vessels entering the terminal, ship size, port management (top management investment), environmental issues affecting direct operations (wind/rain), environmental concerns (CFP/pollution/emissions/green port), gates (number/design/location), labour (performance/skills), empty consignee returns, frequency of vessel calls, number of berthing slots, reworks, and on-carrier changes.

A second questionnaire, developed based on the factors identified above was sent to 30 industry experts representing the three container terminals operating at the Port of Colombo. The Port of Colombo comprises of Colombo

International Container Terminal (CICT), Jaya Container Terminal (JCT) operated by the Sri Lanka Ports Authority (SLPA), and South Asia Gateway Terminal (SAGT). Using the scores provided by the respondents, the factors were ranked via Multiple Weighted Score Analysis.

A third questionnaire was then developed, structured in line with the Analytic Hierarchical Process (AHP) methodology, focusing on the five highest-ranked factors from the second survey. The purpose of this questionnaire was to conduct pairwise comparisons of the selected

factors and to determine the relationship between expert evaluations and these factors.

If the number of significant factors selected from 2nd stage questionnaire analysis is n , then number of pairwise comparisons need to be considered was determined as $\frac{n(n-1)}{2}$. At the second stage, five factors were considered as significant factors. Then n is equal to 5 and it consists of 10 pairwise comparisons among 5 significant factors. The point scale denoting 1, 3, 5, 7, and 9 proposed by Saaty (1987) was adopted for pairwise comparison.

Table 2: Point scale for pairwise comparison

Scale	Meaning	Explanation
1	Equally important	Both criteria are equally important
3	Slightly important	Judgement call slightly favours one element
5	Important	One element is more important than all the others
7	Very important	One element is very important when compared to the others
9	Extremely important	One element is extremely important when compared to others

Source: Saaty (1987)

As strategies for controlling non-response errors and measurement errors, a cover letter was attached to the questionnaire, and surveys were conducted either in person or over the phone to increase the response rate. In addition, clear guidelines on how to complete the questionnaire were provided using simple wording, explanations of the factors, a pairwise comparison scale, and a smaller number of questions to minimise measurement errors.

Multiple Weight Score Analysis is the main data analysis method that was used to achieve the second objective Hashim *et al.* (2007). This method is basically used for ranking purposes.

In this article, Multiple Weight Score Analysis was used to obtain the total score denoting the perceived importance for each factor- i the scores for all the factors were calculated using the following equation.

$$TI_i = \sum_{j=1}^{n_i} I_{ij} \tag{1}$$

where:

TI_i = total score of perceived importance of critical factor i

I_{ij} = j th score of perceived importance of critical factor i

n_i = number of scores of critical factor- i ($n_i = 30$)

i = 1, 2... m

j = 1, 2... n_i

From the total score, the mean score for each critical factor was obtained. This was to eliminate the effect on the inequality of the

number of scores for all critical factors, but in this study, the number of scores for all the factors were equal.

$$\overline{TI}_i = \frac{\sum_{j=1}^{n_i} I_{ij}}{n_i} \tag{2}$$

With the mean score of perceived importance for the *i*th factor, then the total score of mean

could be calculated from the following equation.

$$T(\overline{TI}_i) = \sum_{i=1}^m \overline{TI}_i \tag{3}$$

where, *m* = number of critical factor (*m* = 18)

If we use *WI_i* to represent the weight of perceived importance of *i*th factor, then weights could be determined by calculating the mean score for factor *i* and then dividing it by the total

mean score of all factors. For all weight values, from perceived importance scores, the critical factors could be rated in descending order. The weight mean could be used to indicate the ranking of importance for the critical factors.

$$WI_i = \frac{\overline{TI}_i}{T(\overline{TI}_i)} \tag{4}$$

All the critical factors could be rated to determine which ones were perceived as being of higher importance. The identification process can be carried out using measures of central tendency or quartiles, depending on the distribution of the weights. In this study, the factors rated above the third quartile were considered the most significant of the 18 identified critical factors.

in the pairwise comparisons was consistent. The CR is calculated as follows (Saaty, 1987):

$$CR = \frac{CI}{RI}$$

$$CI = \frac{(\lambda_{max} - n)}{(n - 1)}$$

where:

- CI = Consistency Index
- n = Size of matrix/Number of factors
- CR = Consistency Ratio
- RI = Random Consistency Index

For the purpose of calculating the weights of these significant factors, the AHP, developed by Thomas L. Saaty in the 1970s was used. AHP was selected as the data analysis method because it is one of the most widely used analytical tools in international research settings and enabled respondents to assess the importance of factors in an accurate and structured manner.

To calculate the λ_{max} , the matrix multiplication of the Eigen vector of normalised matrix and the column sum of the consolidated matrix are taken. RI denotes the mean CI of a randomly generated comparison matrix from a ratio scale of 1 to 9. Table 3 shows consistency index for random judgements (Saaty, 1987).

The consistency of responses was measured using the Consistency Ratio (CR), which helped to verify whether the respondents' judgements

Table 3: Consistency index for random judgements

(n)	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

When calculating the CR, first calculate the total of priority weight of each factor and the column total in the comparison matrix to obtain λ_{\max} . Then, calculate CI and after that CR can be calculated. On account of the fact that human decision-making on factor evaluation is not consistent, a tolerance level of less than 10% is acceptable as CR (Saaty, 1987).

Data Analysis and Results

Identification Significant Factors

With the questionnaire 2 scores for each factor were given by 30 industry professionals surveyed. To identify significant factors from the above factors, Multiple Weighted Score Analysis was conducted. Table 4 presents how the factors ranked according to the score given.

Table 4: Multiple weight score analysis

Q. No.	Factor	Total of Importance	Mean TI	Weight of Importance	Rank
1	Space in the container yard area	279	9.30	0.0823	1
2	Annual Volume of containers (TEUs)	246	8.20	0.0725	2
3	Equipment (RTG/GC/QC)	242	8.07	0.0713	3
16	Number of Berthing Slots	238	7.93	0.0702	4
15	Frequency of Calling	225	7.50	0.0663	5
5	Spatial Planning/Design	221	7.37	0.0652	6
10	Environmental issues that affect direct operations (wind/rain)	204	6.80	0.0601	7
4	Technological Applications (IT/ Terminal Management Systems)	195	6.50	0.0575	8
7	Number of vessels entering the terminal	183	6.10	0.0540	9
6	Quality Standards (Yard Surface/Numbering/ Road Traffic Network)	175	5.83	0.0516	10
13	Labour (performance/Skills)	170	5.67	0.0501	11
18	On-Carrier Changes	168	5.60	0.0495	12
12	Gates (Number of gates/ Designs/ Location)	153	5.10	0.0451	13
9	Port management (Top Management Investment)	150	5.00	0.0442	14
8	Ship size	146	4.87	0.0430	15
14	Empty Consignee Returns	143	4.77	0.0422	16
17	Reworks	132	4.40	0.0389	17
11	Environment concerns (CFP/Pollution/ Emission/Green Port)	122	4.07	0.0360	18
Total		3392	113.07	1.0000	

To assess whether the scores given by the respondents were normally distributed, the Anderson–Darling test was conducted (Figure 2). The Anderson–Darling statistic measures how well the data follow a specified distribution; the better the fit, the smaller the statistic. The hypotheses for the Anderson-

Darling test are: H_0 : The data follow a specified distribution and H_1 : The data does not follow a specified distribution pattern. For this analysis the specified distribution is the normal distribution. In here the test was carried out for the weights that were calculated for each score.

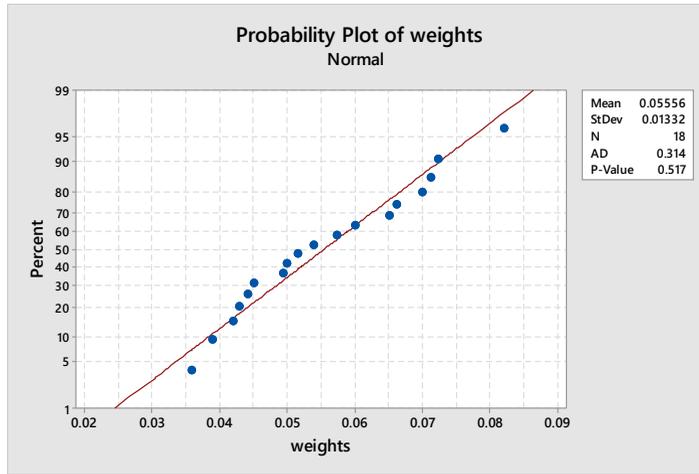


Figure 2: Anderson-Darling test results for weights

From the result of Anderson-Darling normality tests, this study found that the weight distributions of importance of the factors are normally distributed with significance value of 0.517, which are greater than α value, 0.05.

Selection of Most Significant Factors

For the scores obtained in Table 4, the following descriptive statistics was calculated to select the most significant factors (Table 5).

Table 5: Statistical values for multiple weighted score analysis

	Total of Importance	Mean TI	Weight of Importance
Minimum	122	4.07	0.0360
Maximum	279	9.30	0.0823
Mean	188.44	6.28	0.0556
Standard Deviation	45.17	1.51	0.0133
Q1	150.75	5.03	0.0444
Q3	224.00	7.47	0.0660

Descriptive statistics was used to determine the most significant factors that should be selected for questionnaire 3 – the AHP questionnaire. Above mean value and the Q1 there are 8 and 14 factors respectively and only 5 factors above Q3. If higher numbers were selected the number

of comparisons will be high and according to Saaty, (1987) it is difficult for the human mind to compare that number of comparisons. Therefore, the factors ranked above Q3 were selected as the most significant factors and used for pair-wise comparisons. They are:

- F1 = Space in the container yard area
- F2 = Annual volume of containers (TEUs)
- F3 = Equipment (RTG/GC/QC)
- F4 = Number of Berthing slots
- F5 = Frequency of calling

In the pair-wise comparison survey, the following responses were received from each of the respondents. Table 6 presents respondent 1's response.

Table 6: Comparisons of respondent 1

Factor	F1	F2	F3	F4	F5
F1	1	7	5	5	1
F2	1/7	1	1/7	1/5	1/7
F3	1/5	7	1	3	1/7
F4	1/5	5	1/3	1	1/7
F5	1	7	7	7	1

By taking natural logarithmic value for each response such as Table 7 below, the average natural log value matrix was calculated for summing each response (Table 8).

Table 7: Natural log values for response 1

Factor	F1	F2	F3	F4	F5
F1	0.0000	1.9459	1.6094	1.6094	0.0000
F2	-1.9459	0.0000	-1.9459	-1.6094	-1.9459
F3	-1.6094	1.9459	0.0000	1.0986	-1.9459
F4	-1.6094	1.6094	-1.0986	0.0000	-1.9459
F5	0.0000	1.9459	1.9459	1.9459	0.0000

Table 8: Average natural log matrix

Factor	F1	F2	F3	F4	F5
F1	0.0000	0.4784	0.7068	1.0730	0.1703
F2	-0.4784	0.0000	-0.3662	0.5365	0.2540
F3	-0.7068	0.3662	0.0000	0.3662	-0.7608
F4	-1.0730	-0.5365	-0.3662	0.0000	-1.5513
F5	-0.1703	-0.2540	0.7608	1.5513	0.0000

By taking the power of each value from the average natural log matrix, the consolidated matrix was obtained (Table 9).

Table 9: Consolidated matrix

Factor	F1	F2	F3	F4	F5
F1	1.0000	1.6134	2.0274	2.9240	1.1856
F2	0.6198	1.0000	0.6934	1.7100	1.2892
F3	0.4932	1.4422	1.0000	1.4422	0.4673
F4	0.3420	0.5848	0.6934	1.0000	0.2120
F5	0.8434	0.7757	2.1400	4.7177	1.0000
Sum	3.2985	5.4161	6.5541	11.7939	4.1541

After dividing each value from the sum of the respective column sum the normalised matrix was obtained (Table 10).

Table 10: Normalised matrix

Factor	F1	F2	F3	F4	F5	Normalisation
F1	0.3032	0.2979	0.3093	0.2479	0.2854	0.2887
F2	0.1879	0.1846	0.1058	0.1450	0.3103	0.1867
F3	0.1495	0.2663	0.1526	0.1223	0.1125	0.1606
F4	0.1037	0.1080	0.1058	0.0848	0.0510	0.0907
F5	0.2557	0.1432	0.3265	0.4000	0.2407	0.2732

This derives the relative weights for each factor which is the average per row value in normalised matrix (Table 11).

Table 11: Relative weights for factors

Notation	Factor	Weights
F1	Space in the container yard area	0.2887
F2	Annual Volume of containers (TEUs)	0.1867
F3	Equipment (RTG/GC/QC)	0.1606
F4	Number of Berthing Slots	0.0907
F5	Frequency of Calling	0.2732

After calculating the relative weights, the most significant hierarchical factors are the space in the container yard area, frequency of calling, annual volume of containers (TEUs), equipment (RTG/GC/QC), and number of berthing slots respectively. To measure the consistency of responses in pairwise comparison, the consistency ratio for the factors was calculated based on RI is equal to 1.12 (Table 12).

Table 12: Consistency analysis

λ max	5.2208	
CI, when no. of factors, n is equal to 5	$CI = \frac{(5.2208 - 5)}{(5 - 1)}$	0.0552
CR	$CR = \frac{0.0552}{1.12}$	0.0493

In the responses received, the inconsistency is 4.93% and according to Saaty (1987) any inconsistency below 10% is accepted. Therefore, the respondents' subjective evaluation about their preference is consistent.

Efficient yard planning in container terminals is critically influenced by several interrelated factors, with empirical studies and analytical hierarchy process (AHP) surveys consistently ranking the available space in the container yard as the most significant determinant of operational performance (Lee & Kim, 2013; Zhang *et al.*, 2020). The physical capacity and layout of the yard directly affects stacking strategies, container accessibility, and the frequency of rehandling moves, with research showing that optimised space allocation can reduce rehandling by up to 30% (Wang *et al.*, 2022). Further, optimised yard space facilitates effective stacking, minimises unnecessary container movements, and reduces handling time, thereby enhancing productivity and reducing congestion (Liu, 2010; Ali *et al.*, 2022). Insufficient yard capacity often leads to bottlenecks, adversely affecting overall port performance (Danladi *et al.*, 2024), hence adequate yard space is vital for efficient container handling in a port terminal. The frequency of vessel calls is the next most critical factor.

The frequency of calling, or how often vessels arrive, significantly impacts the scheduling and yard management operations, as higher ship call rates intensify yard congestion and require more agile planning to synchronise yard operations with vessel schedules, thereby minimising truck waiting times and equipment idle periods (Chen *et al.*, 2013). High call frequencies require efficient berth allocation and resource planning to avoid terminal congestion and vessel queuing, which can delay cargo handling and increase turnaround times (Danladi *et al.*, 2024; Liu, 2010). The annual volume of containers (TEUs) directly indicates the workload and throughput requirements of the terminal. Annual container throughput, typically measured in TEUs, is a key scalability driver; terminals with higher TEU volumes need to adopt advanced yard management

systems and equipment, such as automated rail-mounted gantry cranes, to maintain efficiency and accommodate peak loads (Steenken, Voß, & Stahlbock, 2004).

Growth in container volume necessitates scalable infrastructure and operational adaptations to maintain efficiency (Ali *et al.*, 2022). Without adequate capacity, rising volumes lead to increased dwell times and reduced service quality. Equipment availability, including rubber-tyred gantries (RTG), yard cranes (GC), and quay cranes (QC), is critical for efficient container handling. The type and availability of handling equipment, including RTGs, GCs, and QCs, further shape yard efficiency, as equipment productivity and flexibility directly influence container movement rates and the ability to respond to dynamic operational demands (Bazzazi, Safaei, & Javadian, 2009). Modern, well-maintained equipment improves lifting capacity, reduces berth times, and supports rapid container movement between ship and yard, key factors in enhancing terminal productivity (Hsu *et al.*, 2023; Liu, 2010).

While the number of berthing slots is somewhat less influential, it remains an important factor; insufficient berthing capacity can lead to vessel delays and increased yard congestion, as containers accumulate while awaiting loading or discharge (Imai *et al.*, 2006). Further, the number of berthing slots affects the port's ability to accommodate multiple vessels simultaneously, reducing anchorage delays and improving overall turnaround rates (Danladi *et al.*, 2024). A limited number of berths restricts throughput capacity and can cause vessel congestion, negatively impacting terminal efficiency and shipping schedules. AHP-based studies confirm this hierarchy of factors, with yard space typically assigned the highest weight, followed by vessel call frequency, TEU volume, equipment, and berthing slots (Zhang *et al.*, 2020; Wang *et al.*, 2022). This evidence emphasises the need for integrated yard planning approaches that prioritise spatial optimisation and equipment adaptability, while aligning operational strategies with vessel schedules and throughput variability.

Conclusion and Implications for Research and Policy

Yard planning is one of the major decision-making processes in container terminal operations. Because the maritime industry is developing rapidly, the yard planning process has become increasingly difficult and complex. There are numerous factors that must be considered to implement this process efficiently. This study focuses on identifying these factors, determining which have the greatest impact, and establishing which should be prioritised when implementing an efficient yard planning process.

Based on the results of an AHP-based questionnaire, and after calculating the relative weights, the significant hierarchy of factors was determined as follows: space in the container yard area, frequency of calling, annual volume of containers (TEUs), equipment (RTG/GC/QC), and number of berthing slots.

The analysis results showed that space in the container yard area was the most significant factor. This issue is a major challenge for many seaport container terminals worldwide. With maritime trade increasing exponentially, the number of container exchanges is high, which in turn causes storage yard space to become scarce. As a result, many ports seek to expand their yard storage areas or construct new terminals as solutions. However, expansion is often constrained by port location—particularly as major ports are typically situated in a country's economic capital—and, apart from land reclamation from the sea, increasing the yard storage area is often not feasible. Consequently, many hub ports have invested heavily in new terminal developments to accommodate increasing cargo flows.

Frequency of calling was identified as the second most significant factor affecting yard planning. A higher frequency of ship calls increases the number of containers moving through the yard storage area. When more ships arrive, import and export activity rises, and consequently, container volumes passing through the yard also increase. This higher level

of movement can enhance port throughput and profitability, but it also demands more efficient yard planning to maintain smooth operations and avoid congestion. Efficient planning at this stage benefits both customers and shipowners, while supporting the port's financial performance.

The annual volume of containers (TEUs) was the third most significant factor influencing efficient yard planning in a seaport container terminal. A terminal can only handle container volumes that correspond to its available slots. Annual volume data is crucial for forecasting container capacity requirements, and yard planners use this forecast to determine the allocation of yard storage slots. Higher annual volumes necessitate more slots and greater yard space. Currently, such forecasting is formally conducted only at CICT (Colombo International Container Terminal) in the Port of Colombo.

Equipment availability and capability also influence yard capacity. Equipment such as Rubber-Tyred Gantry cranes (RTGs) and Gantry Cranes (GCs) are among the next most significant factors affecting the efficiency of the yard planning process. These cranes are essential for storing containers in their designated slots within the storage yard. The movement of RTGs and GCs must be carefully synchronised with the movement of containers throughout the yard; otherwise, yard planning becomes inefficient, leading to bottlenecks that can negatively impact both vessel turnaround time and overall container throughput at the port. Containers in the yard are often stored using multi-level stacking methods, and RTGs/GCs are designed according to the intended number of stacking levels. If the equipment does not allow for higher stacking, yard capacity is reduced, thereby directly affecting the yard planning process.

Another significant factor influencing efficient yard planning in a seaport container terminal is the number of berthing slots. A higher number of slots allows more ships to

berth simultaneously, which increases container movements both within the terminal and in the yard. This heightened activity requires efficient yard planning; otherwise, congestion and bottlenecks can occur, slowing down terminal operations. For instance, in the Port of Colombo, the Jaya Container Terminal (JCT) and the South Asia Gateway Terminal (SAGT) each have four and three berthing slots respectively, whereas the Colombo International Container Terminal (CICT) has a variable configuration. CICT is the only terminal capable of accommodating mega-vessels such as Maersk's Triple-E class ships, with only two such large vessels able to berth at the same time. However, a greater number of smaller vessels can be berthed at CICT simultaneously, which also increases yard activity and requires precise yard planning to avoid operational bottlenecks.

The growth of international seaborne trade is reflected in the increase in container ships, container throughput, and container terminals. As containerisation continues to expand, it is essential to develop strategies to accommodate the rising demand. With existing port space becoming increasingly inadequate to handle the annual growth in container throughput, this study has identified the key factors contributing to inefficient yard planning in seaport container terminals. The findings reveal that limitations in the available container yard space present the most critical challenge. Other significant factors include the annual volume of containers arriving at ports, the level of technological application, and the number of berthing slots available. Most of the studies carried out in this area are rather operation research based and introduce simulation models, yard templates for optimising yard space of container terminals and mostly limited to the yard storage capacity optimisation. This article identifies several other factors that should be considered in planning and implementing efficient yard planning process that future research can consider in their numerical and simulation-based research.

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Conflict of Interest Statement

The authors declare that they have no conflicts of interest related to this work.

Author Contributions Statement

The authors confirm contribution to the article as follows: Study conception and design: Yapa Mahinda Bandara, Chamara Perera; data collection: Chamara Perera; analysis and interpretation of results: Chamara Perera, Yapa Mahinda Bandara; draft manuscript preparation: Yapa Mahinda Bandara, Chamara Perera. All authors reviewed the results and approved the final version of the manuscript.

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