



Optimal space for storage yard considering yard inventory forecasts and terminal performance



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ABSTRACT

This paper presents a method for forecasting the yard inventory of container terminals over an extended period, and addresses an integrated yard planning problem for determining the optimal storage space utilization by considering the yard congestion effect on terminal performance. A formulation based on random variables and probabilistic functions was developed, which allows prediction of the storage space requirement without requiring fully-integrated simulation models. Then, an integrated cost objective function was defined. Numerical experiments were performed to illustrate how the forecasting model works and to support decision-making on yard planning and design for both inbound and outbound/transshipment areas.

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1. Introduction

The storage yard is considered the most complex element of container terminals. Storage operations require the use of various resources, such as quay cranes (QCs), yard cranes (YCs), transport vehicles, storage space, and driving lanes. Thus, the efficiency of yard operations is sometimes considered a measure of the terminal's competitive strength because it affects the rest of the terminal's performance (Chen et al., 2003).

The design and layout of the storage yard is a factor that affects handling operations and productivity, which are in turn affected by previous decisions regarding the terminal's capacity and the type of equipment used for stacking operations (Wiese et al., 2011). However the size and capacity of the storage yard are determined during the initial planning stages, when the available information and detail are lacking. In addition, as containerhips are still increasing in size, levels of demand for freight maritime transport are unpredictable, and container terminals must cope with unprecedented container volumes; hence, new challenges must be met in order to improve the efficiency of port operations (Zhen, 2014).

For yard-planning and design, planners also need to consider the annual workflow and deal explicitly with stochastic effects regarding the seasonal variations, peak factors and dwell time, which usually contains a degree of uncertainty. Once the capacity of the main resources has been defined, the availability of the resources needs to be checked in advance so that they can be allocated efficiently (Won et al., 2012). With this in mind, forecasting the yard inventory and its fluctuations over a given period would be decisive to assuring the efficient use of the main yard and terminal resources.

Many authors have analyzed the terminal planning process (Stahlbock and Voss, 2008; Carlo et al., 2014); most have used advanced simulation models, while others have developed analytical formula to estimate storage capacity. For example, to

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calculate yard capacity, [Boll \(2004\)](#) developed a simulation tool for determining the capacity of the quay and container stacking area, while [Sgouridis et al. \(2003\)](#) developed a simulation model to optimize yard parameters. [Brinkmann \(2005\)](#) approximated the required storage capacity for each type of equipment by considering the annual container turnover, mean dwell time, and peak factor. Similarly, [Chu and Huang \(2005\)](#) derived a general equation to calculate the total number of container ground slots for different yard sizes with different handling systems, a straddle carrier (SC), a rail-mounted gantry crane (RMGc), and an overhead bridge crane (OHBC) based on the respective equipment dimensions, transshipment ratios, and average container dwell times.

Other studies that have sought to calculate the space requirement for planning include [Taleb-Ibrahimi et al. \(1993\)](#), who determined the aggregate space requirements for two storage strategies for export containers, deriving a formulation for calculating the container accumulation as well as the number of container slots that must be reserved for storing future container arrivals as a function of time. [Roux \(1996\)](#) derived analytical formula to estimate the minimum import storage capacity for a given throughput requirement under the constraint of infrequent congestion. [Kim and Kim \(1998\)](#) determined the best combination of space and number of yard cranes under a minimization cost model. [Murty et al. \(2005\)](#) developed a decision-support system for the capacity planning of container terminals. [Kim and Kim \(2002\)](#) determined the optimal size of the storage space and number of transfer cranes to serve outside trucks for import containers. They considered the number of slots to be allocated for import containers to remain constant (storage capacity) and the required number of slots to depend on the inventory profile of the inventory containers.

Once the main decisions about storage capacity and equipment choice have been made, the next step for planners involves the terminal and block layout. Several studies on container terminal design have been conducted but few have compared parallel and perpendicular yard layouts using simulations. One exception is [Liu et al. \(2004\)](#), who concluded that a perpendicular layout is better in terms of QC mobility and the amount of horizontal transport equipment required. However, [Petering \(2008\)](#) analyzed both layouts for a transshipment terminal and found that the parallel layout was preferable to the perpendicular layout, even though the perpendicular layout's QC rate sometimes outperformed the other's. [Wiess et al. \(2009\)](#) reported that a parallel layout with transfer lanes was used in about 90% of cases where rail-tired gantry cranes (RTGs) were used for stacking and that a perpendicular layout was used in 85% of the cases with automated RMG systems.

Simulation and analytical techniques have also been used to test the impact of the yard and block layout on the performance measures in container terminals. For example, [Chen et al. \(2003\)](#) sought better ways to utilize the storage space within a port's dynamic environment. [Lim and Xu \(2006\)](#) addressed the yard allocation problem faced by the Port of Singapore Authority by proposing an effective meta-heuristic procedure, and [Kempe \(2012\)](#) examined the design of four strategic RMG crane systems and 385 yard block layouts and their effects on yard and terminal performance.

Other simulation studies on container terminal design include [Duinkerken et al. \(2006\)](#), [Nam and Ha \(2001\)](#), and [Yang et al. \(2004\)](#). The most comprehensive models take the gross crane productivity and average turnaround time as performance measures, and most track several performance measures, such as yard utilization and truck productivity, to show the different values for the type of handling equipment, vehicle fleet size, or terminal layout. However, most studies have simulated only one day's activity and considered only a single berth facility.

By contrast, [Petering \(2009\)](#) and [Petering and Murty \(2009\)](#) proposed the terminal designs of a multiple-berth transshipment container terminal over an extended period of time by developing a fully integrated simulation model. They analyzed the influence of the width and length (number of bays) on terminal performance (long-run average quay crane rate) for a parallel layout. In both studies, a simulation model was used in the analysis of a transshipment container terminal. The results showed that the optimal block width ranged from six to 12 rows and the block length from 56 to 72 because these values guaranteed the highest quay crane work rate and yard crane mobility.

[Kim et al. \(2008\)](#) also analyzed the optimal layout of container yards and presented a method of designing it. Their results showed that a parallel layout allowed for shorter expected travel distances and lower costs than a perpendicular layout. [Lee and Kim \(2010a\)](#) attempted to determine the optimal size of a single block by considering the throughput requirements of YCs and the block storage requirements. They also provided detailed formulae for the expected cycle times and variances of all YC operations, which depended on the block layout. On the other hand, [Lee and Kim \(2010b\)](#) provided more detail on the expression of expectancies of the YC cycle time for parallel and perpendicular layouts with different block layouts, useful for estimating the YC operating costs. [Lee and Kim \(2013\)](#) later determined the optimal layout of an entire container yard, as specified by the dimensions of a block and the number of aisles. Their results showed that the parallel layout performed better than the perpendicular layout in terms of the total cost and that, for both layouts, the block width had to be increased for better performance and lower total cost.

A few studies have examined port operations under uncertain environments. [Han et al. \(2010\)](#) addressed the berth and quay crane scheduling problems simultaneously with the uncertainties of the vessel arrival time and container handling time. [Zhen et al. \(2011\)](#) studied the berth allocation problem by considering the uncertain arrival time and operation time of vessels. [Zhen \(2014\)](#) focused on the yard template planning problem under uncertainty. Unlike the abovementioned papers, these studies considered the number of containers loaded (and unloaded) onto (and from) each vessel within a cycle time as a stochastic parameter.

Thus, many authors have addressed the yard planning and design problem through simulation or optimization models, but none has attempted to analytically determine storage space requirements by considering the stochastic properties of the storage yard. The first approach, by [Taleb-Ibrahimi et al. \(1993\)](#), was based on deterministic functions and for export containers only. No study has attempted to determine how much space should be provided individually for the storage area

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