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Layout analysis affecting strategic decisions in artificial container terminals

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ABSTRACT

As a result of a major growth in world trade, importance of the container terminals, which are the exit gates of international maritime trade, has been emphasized and the competition between these terminals has increased. In recent years, increasing competition in shallow seas, which have low berth depth and intensive trade, has caused terminal managers to investigate how the strategic decisions affect the future development of terminal operations. Due to their low berth depth, container terminals in the feeder ports of shallow seas are built artificially near coastlines. The most common layouts found in these terminals are Π, L, π, or Ψ. In this paper, simulation models were developed for the container terminals to examine the effect of transporter dispatching rules and resource allocation strategies in terms of total annual handling amount. According to the results, terminal performance is significantly affected by terminal layout design under different transporter dispatching rules and allocation strategies.

1. Introduction

A significant share of world trade is conducted via ships and international maritime trade volume is increasing rapidly. In spite of the global economic crises over last two decades, world trade volume has increased in recent years and the share of containerized trade has grown accordingly. Due to innovations in the maritime industry, ships have increased speed and capacity to make transport operations more efficient. As such, intermodal freight transportation has become an important area of focus. Connecting land, sea and air transportation allows for gate to gate freight transportation which increasingly relies on container transportation. For these reasons, it is more important than ever to improve efficiencies in the global supply chain's container transport operations.

A review of scientific literature on the issue reveals that automation applications are generally conducted for large-scale seaport terminals. These large-scale seaports tend to be built on coasts where the sea is deep, named natural ports. Container terminals located on natural seaports generally have a single major berth running parallel to the coastline and storage yards are located horizontally or vertically to the major berth. Terminals in shallow seas are built artificially near the coastlines. These artificial terminals have more than one berth and low depth in comparison to natural ports. The most common layouts found in artificial container terminals are constructed in Π, L, π, or Ψ formats. Container terminals with more than one berth can have more than one storage yard for the terminal or cause to build storage yards that are perpendicular or parallel to the major berth.

In order to minimize waiting times of vessels in container terminals, speed is imperative, especially when transitioning containers among the berths, the internal transport areas, and the storage yards. Berth allocation, terminal equipment selection, vehicle routing, scheduling, and storage yard layout problems need to be solved in order to manage container terminal operations effectively. Today's challenging competitive environment requires more efficient management of terminal operations. In response to these challenges, terminal managers are increasingly depending on developing technology for automatic control technology based equipment, which is practical given the repetitive nature of terminal operations. Such technologies include automated guided vehicles (AGVs), automatic lifting vehicles (ALVs), and automated stacking cranes (ASCs).

In this paper, automated container terminals located in feeder ports are investigated to identify the most common layout formats. The effect of layout on terminal performance is analyzed using different simulation models. It also attempts to improve the performance of terminals by using different allocation strategies under the optimum dispatching rule. Total container handling amount per year in quay cranes is used as the major performance criterion.

The rest of this paper is organized as follows: in the next section, relevant literature is reviewed, followed by a detailed description of the container terminals and essential terminal operations in

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Section 3. Section 4 presents configuration of the designed container terminals and a detailed description of transporter dispatching rules and allocation strategies. The main features of the developed simulation models and the generation of input and output data are explained in Section 5 and the results of the simulation tests and statistical analysis are discussed in Section 6. The paper concludes with a summary of research conclusions and suggestions for further research.

2. Literature review

The planning and controlling of seaport container terminal operations has become a trendy subject in international academic research, evident by the many papers published on such topics as berth allocation, storage yard planning and routing, terminal equipment selection, scheduling, performance evaluation with simulation, and terminal layout. A comprehensive literature review covering a variety of decision problems related to container terminals was published by Vis and de Koster (2003). In this review, models used in solving decision problems were discussed. Steenken, Voß, and Stahlbock (2004) classified decision problems to manage terminal operations more efficiently and provided detailed descriptions of studies that reviewed all types of decision problems. Other comprehensive literature reviews about classifying operations and decision-making methods in container terminals were presented by Murty, Liu, Wan, and Linn (2005a), Murty et al. (2005b), Günther and Kim (2006) and Stahlbock and Voß (2008). In lights of these studies, the literature review section of this paper is limited to research that focuses on automated container terminals, terminal layout, and resource allocation.

Automated container terminals are one of the important topics discussed in the literature. They were established in Western European countries where expensive labor has been managed through automatic control and information technologies and the efficiencies gained by equipment (AGVs, ALVs and ASCs). Kim, Won, Lim, and Takahashi (2004) developed an architectural design of control software and a simulation-based test-bed to test various control rules of the software used to control automated container terminals. Operation based problems were tested by an object-oriented simulation system using Java. Yang, Choi, and Ha (2004) compared AGVs with ALVs in container terminals using simulation. The conclusion of the study was that using fewer ALVs led to the same performance levels achieved using AGVs. ALVs work more efficiently than AGVs because ALVs do not wait for cranes in buffer stock areas. Grunow, Guenther, and Lehmann (2006) highlighted that multi-load AGVs can carry more than one container at a time. Henesey, Davidsson, and Persson (2009) focused on AGV systems in container terminals and compared the cassette-based AGV system with the traditional AGV system. They used a multi-agent simulation model and concluded that cassette-based AGVs are more efficient. Nguyen and Kim (2009) discussed how to dispatch ALVs by utilizing information about pickup and delivery locations and time in future delivery tasks. The problem was described as a scheduling problem and a mixed integer programming model was proposed. Significant improvements in the total travel time of ALVs, delays of quay cranes, and total waiting times of vessels at berth were derived in the study. Wong and Kozan (2010) analyzed the relation between the equipment in container terminals with a view to increase operations efficiency and to develop an analyzer tool for storage yards operation planning. Bae, Choe, and Park (2011) compared AGV and ALV systems. A simulation model that was able to find the shortest route and schedule with minimum traffic congestion was developed in the study.

Layout arrangements in container terminals are another topic extensively researched. Liu, Jula, Vukadinovic, and Ioannou (2004) considered the relation between automation, terminal layout, and terminal performance through simulation. It was concluded in the study that layout arrangements in storage yards affect the terminal performance and the number of AGVs. Han, Lee, Chew, and Tan (2008) examined yard management problems in a transshipment hub with intensive loading and unloading operations. In order to reduce vessel cycle time and potential traffic congestion, a mixed integer programming model was formulated and a tabu search based heuristic algorithm was used to solve the problem. Kim, Park, and Jin (2008) analyzed the expected travel distances and the expected numbers of re-handling occurrences according to the changing handling types for yard layout arrangements. As a result of the study, parallel placement was identified as having the lowest cost among other placement types. Petering and Murty (2009) developed simulation models to analyze the effects of block length on terminal performance. Block length that maximized the utilization rate of quay cranes was calculated using four different scenarios. Bazzazi, Safaei, and Javadian (2009) focused on storage space allocation problems in a container terminal. An efficient genetic algorithm was developed to solve real-sized instances. Petering (2009) analyzed the effects of block width on terminal performance via simulation. As a conclusion, it was found that the utilization rate of quay cranes were concave to block width when the other terminal equipment was assumed as fixed. Vis and Van Anholt (2010) compared the performance of traditional one-sided marginal berths with indented berths using simulation. They performed a sensitivity analysis that examined the relation between the selection of the indented berth, which enables quay cranes to unload and load the container from both sides of the vessel, and other design and control issues. Kemme (2012) developed a simulation model that was able to examine the effects of four types of ASC and yard block layouts on terminal performance. The results showed that triple crane systems had the best performance in different yard block layouts.

Another important subject in the literature is resource allocation in container terminals. Preston and Kozan (2001), Lee, Chew, Tan, and Han (2006) and Han et al. (2008) made important contributions to the field by applying yard allocation strategies in terminals. In these papers, yard allocations are implemented to minimize ship cycle time and traffic congestion. Another resource allocation strategy is vehicle allocation by which vehicles can be assigned to a berth or a crane. Contrary to this strategy, a pooled allocation concept allows every vehicle to serve every berth or quay crane (Kulak, Polat, Gujjula, & Günther, 2011). Bae and Kim (2000) compared these two strategies and concluded that the pooled allocation concept was superior to the vehicle allocation strategy. Kulak et al. (2011) investigated the possibility of increasing terminal performance in terms of container handling by exchanging the transportation system and extending the terminal equipment as well as applying resource allocation strategies.

The main contribution of this paper is to demonstrate how strategic decisions affect the future development of various terminal layouts in shallow seas. Terminal configuration and related logistics processes have been modeled in such a way that the simulation reflects real operations. In our simulation experiments, we investigate the possibilities of increasing terminal performance in terms of container handling for each layout format by applying transporter dispatching rules and resource allocation strategies. The simulation framework and the general experimental procedure are mainly relevant for artificial container terminals in feeder ports facing limited opportunities to improve overall performance.

3. Container terminals

Containers enter and leave the terminal by different means of transport, such as trucks, trains, and ships. Seaport container