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# A case based heuristic for container stacking in seaport terminals

Ines Rekik[a], Sabeur Elkosantini[b,*], Habib Chabchoub[c]

[a] LOGIQ Research Unit, University of Sfax, Tunisia
[b] SMART Laboratory, High Institute of Management of Tunis, University of Tunis, Tunisia
[c] International School of Business, Tunisia

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ABSTRACT

In this paper, we suggest a Case Based heuristic for the online container stacking management system in seaport terminals. The main objectives of the system are to determine the exact position of each import container in the storage area and to control container allocation and react to unexpected events and disturbances in an intelligent, self-organizing and real-time manner. First, we propose learning mechanisms and knowledge models for a better management of knowledge related to disturbances and container environment. This system takes into account different types of containers especially the storage of dangerous containers. For assessment of the suggested system, real data are collected from King Abdul Aziz Dammam seaport terminal (Saudi Arabia). The performance of the developed heuristic is assessed with different scenarios and compared to three other stacking strategies studied in the scientific literature. The obtained results are promising and show that the developed CBR (Case Based Reasoning) based heuristic can be efficient or similar problems, i.e. online container staking.

## 1. Introduction

Maritime container terminals play an important role in the world. They are prone to challenges related to the increasing trends of globalization and the deployment of containerization. With the continuous development of seaports, many problems related to automation and containerization have emerged and attracted increasing attention in recent research. One of these problems concerns containers storage in seaport terminals. Storage-related problems, referred to as Container Stacking Problems (CSP), have been the subject of many research papers [43,15,20,45]. CSP consists in determining the containers' exact location in a terminal storage area. In general, the allocation position of an incoming container is determined so as to optimize some performance criteria (such as the weighted combination of certain criteria and the number of spaces allocated to containers).

Several Decision Support Systems (DSS) have been developed to assist port authorities in managing container storage operations. Such systems, referred to as Container Terminal Operating Systems (CTOS), use two types of storage strategies to determine the container locations: static and reactive stacking. In a static storage, the exact position of each inbound container, in the storage area, is determined before the arrival of vessels. The reactive stacking consists in determining the stacking positions in a real time manner; considering the real-time change in the terminal environment such as the occurrence of disturbances. The stacking system reactivity is defined as its ability to react in the time required to internal or external environment changes [6].

However, existing reactive CTOSs suffer limitations concerning knowledge management and to the effectiveness of used reactive stacking strategies particularly in presence of dangerous containers [30]. To the best of the authors' knowledge, only few works have exploited the online container stacking systems and most of existing CTOSs haven't considered the reactive aspect of the problem. Moreover, very few works have been interested in the management of dangerous containers [11].

To overcome the limitations of existing studies, particularly those related to knowledge capture, use and reuse for the online CSP, this article presents a new CBR based heuristic for the reactive CSP in a changing environment. The system integrates a set of knowledge models and Case Based Reasoning (CBR) based learning mechanisms in a heuristic. The proposed heuristic is able to select the most appropriate combination of storage rules to determine the most suitable container locations. The heuristic is able to reuse captured knowledge by learning from past encountered experience and adapt its decisions according to new situations.

In previous works [32,33], we have started the investigation of the use of CBR for the online CSP. However, these two works suffer from limitations related to computational time, the explicit representation of

* Corresponding author.
*E-mail address:* selkosantini@ksu.edu.sa (S. Elkosantini).

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cases and the integration of mechanisms allowing the reuse of captured knowledge in the past.

This article might be the first to suggest an explicit and generic knowledge model as well as a CBR learning mechanism for the reactive container stacking in seaport terminals.

The remainder of this paper is organized as follows: Section 2 presents a brief overview of the Container Stacking Problem (CSP) and the different approaches used to solve this problem. Section 3 introduces a set of knowledge models and learning mechanisms to allow the system to deal with a huge quantity of knowledge and to learn from past encountered experience. In Section 4, a CBR based heuristic is introduced using models and mechanisms of the 3rd section. Section 5 reports the achieved computational testing results of the proposed heuristic. Finally, a conclusion is drawn and some future research prospects are addressed.

## 2. Literature review

### 2.1. Container stacking problem (CSP)

Container terminals can be described as open systems of material flows. These flows include a set of container storage and handling operations in interaction with each other [2]. Incoming containers are stacked in a stacking area, named also the stacking yard or the yard-side. A storage yard consists of a certain number of blocks. Each block is made up of a number of bays which are composed of several stacks (called also rows) and each stack. Each Stack is characterized by a number of tiers representing the stack height. Thus, the objective of developed heuristics to solve CSP is to determine the exact location of an incoming container from the empty slots in the storage yard in order to guarantee the effectiveness of its loading onto a ship, truck or train and the safety of both the container and the entire terminal.

Different problems related to container stacking in seaport terminals are studied: storage space allocation, container allocation and container relocation. In storage space allocation, the purpose is to assign a group of containers to storage blocks. The container allocation consists in determining the exact storage slot in the yard-bay for each incoming container [19]. Finally, in container relocation, stacked containers are relocated in order to pick up other ones or to facilitate the future retrieval process, with the aim of minimizing the number of relocations [37].

For the development of container stacking systems, several stacking rules (strategies) have been developed in the literature in order to decide where allocate newly arrived containers. Container stacking strategies are solution algorithms used to determine the exact storage position of each incoming container, considering several constraints. The effectiveness of each rule is related to the configuration of terminals [1]. In [30], stacking rules are categorized into three main families (block stacking rules, bay stacking rules and stack stacking rules) as follows:

- Block Stacking Rules (BlSR): are responsible for the selection of the "appropriate" block of imported/incoming containers. Several block stacking rules have been studied in the literature, such as: Role Separation of Blocks, dedicated areas, Different Priorities on Blocks for Different Berths, Role Separation of Bays, the Maximum Number of Internal Trucks and Road Trucks in a Block and No Restriction. The Role Separation of Blocks strategy, for example, indicates that each block is assigned only to inbound or outbound containers. In a given block, inbound and outbound containers are not mixed [4].
- Bay Stacking Rules (BSR): consist on determining a bay from the pre-selected block. Such rules dealing with bay selection include Concentrated Location Principle and Sequence rule. The Concentrated Location (CL) rule consists in assigning containers to non-empty bays even if they are from different groups. The yard cranes travelled distance can be reduced [4,22]. The Sequence (Seq) rule consists in selecting an empty bay for inbound containers.
- Slot Stacking Rules (SSR): are responsible for determining the exact storage location in the preselected bay of the preselected block. Many SSR were developed such include the Leveling rule, Random rule, Maximum Remaining Stack Height rule, Closest Position rule. The Leveling (LEV) rule, for example, doesn't also make use of available data about containers for selecting stacks. The stack is filled layer by layer. All empty ground positions are filled with containers first, before containers are stacked upon others [8]. The main idea of the Closest Position (CP) rule here consists in choosing the stack having the closest position among candidate stacks. The Maximum Remaining Stack Height (MRSH) rule needs information about the type and the departure time of a container. In fact, open top containers are placed in stacks having the highest tiers [14].

### 2.2. Disturbances management capabilities of CTOS

In a storage yard, the determination of the exact storage locations in the storage area of incoming containers can't be planned in advance due to the unexpected disturbances and events that may occur. Thus, the allocation positions of incoming containers are determined in a real time manner.

In this article, a disturbance is introduced as a change in the allocation plan and that can lead to deadlock or failure situations [44]. Examples of disturbances are breakage of materials (yard cranes), a fault in a container placing and equipment breakdown. Such other unexpected events include retrieval events since the retrieval requests are issued in a random order by randomly arriving road trucks.

To overcome these undesirable situations that can affect the overall performance of the allocation process, disruptive events are recognized and the allocation decisions are essentially made in response to these events [17]. The purpose here is to enable the storage system to respond to these deviations in order to minimize their bad impact, thus to avoid the need of re-planning.

In the scientific literature, there are a lot of studies that suggested approaches for the planning and scheduling of containers in a terminal yard, but disturbances management is still a problem to be solved. Unfortunately, there are no generic approaches dealing simultaneously with a variety of disturbances, such as the arrival of dangerous containers, a technical problem related to a crane breakdown… Most of existing studies have treated a restricted number of disturbances (especially retrieval events) but haven't taken into account the interaction between the different containers stacked in the yard and all disturbances that may occur [23,38]. Moreover, very few works gave attention to disturbances related to dangerous containers. Rodriguez-Molins et al. [35] have developed a heuristic to solve a Static Container Relocation Problem (SCRP) wherein dangerous containers must be allocated separately by maintaining a minimum distance. However, the integration of dangerous container management for the reactive container stacking hasn't been studied in the literature.

Moreover, few researchers were interested in the online CSP (called also reactive CSP). Indeed, it is difficult to quickly adjust stacking policy using the classical offline approaches. Russel and Norvig [36] stressed that the online search is a good option in dynamic settings where there is no sufficient time for computation before taking actions.

Zhen [46] has proposed a real-time CTOS for the yard space allocation to cope with uncertain environment as the unexpected changes of loading/unloading time of vessels and workloads in each time shift. Ngai et al. [27] have presented an intelligent context-aware decision support system (ICADSS) for the control of container terminal operations. This system has been applied to the Hong Kong container terminal and has been effective, but hasn't taken into consideration the real-time stacking process. Rekik et al. [31] have proposed a Multi-Agent architecture for the real-time monitoring of container stacking. The suggested system is based on a set of knowledge models (based on If…Then rule based systems) and on the memorization and the reuse of