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A survey on container stacking problems based on a conceptual classification scheme: limitations and future trends

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Abstract: Container stacking problem (CSP) is a challenging task in container terminal management. It consists in assigning containers to locations in a yard terminal. Numerous studies on CSP have been developed according to various objectives and constraints. Despite the widespread literature on this topic, efforts to review and analyse research on CSP are very limited and most of existing reviews treated specific issues, particularly related to stacking operations. For this reason, this survey paper proposes a new conceptual classification scheme, based on content analysis method, to classify and analyse existing literature based on a set of criteria. A special focus is devoted to the analysis of storage rules, which were not exhaustively covered in other surveys. More than 102 papers published on CSP studies within 2000–2020 are classified and analysed based on the suggested conceptual classification scheme. Finally, this paper discusses challenges and highlights research directions that are worth investigation.

Keywords: dynamic problems; container stacking strategies; decision support system; literature review; conceptual classification scheme; CCS.

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Biographical notes: Ines Rekik has obtained her PhD in Computer Science from the University of Sfax, Tunisia. Her research interests focus on the real-time decision making in logistics and transportation systems and the development of decision support systems for container storage management in seaport terminals. She uses some techniques issued from the artificial intelligence for the development of decentralised and intelligent decision making.

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1 Introduction

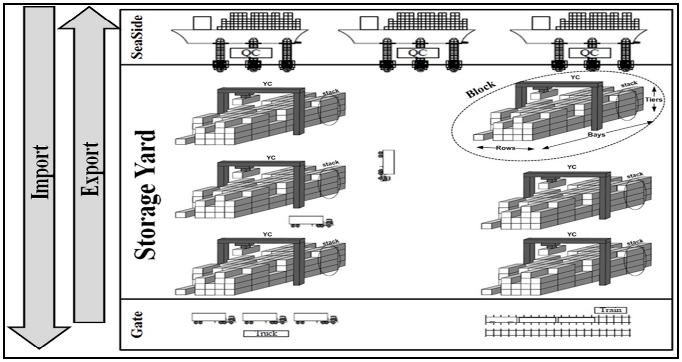
1.1 Background

Maritime transportation is one of the major means of international trade and represents an important part of global economy. With the increasing trends of globalisation and recent developments in container-based transportation, seaports have increasingly become an integral part of the international transport network. The growing popularity of maritime transportation has led to significant increases in container exchange flows between seaports, thus making the management of maritime traffic and seaport container terminals an increasingly complex task (Expósito-Izquierdo et al., 2012). In fact, seaport authorities are facing challenging problems that might affect their status within the strongly competitive maritime transportation industry. They need, for instance, to meet the growing requirements for larger and well-equipped facilities that can host large vessels and containers of different types (regular, refrigerated, …) and with adequate storage capacities. The maritime community is, therefore, facing increasingly challenging and complex tasks pertaining to the management of seaport container terminals. Several efforts have been made worldwide to improve seaport infrastructures (terminals, equipment, and storage areas) and technologies (automated material handling systems, automated monitoring and control systems, intelligent decision support systems, etc.). Port authorities need to maintain the performance of seaport terminals at a high level of quality of service in terms of storage area capacity and storage/retrieval time (Zhang et al., 2003).

In this way, the storage area, called also the storage yard, consists of a number of areas perpendicular or parallel to the berth called blocks. Each block is characterised by a number of bays, which represent the length of the block, a number of rows (or stacks), which represent its width, and a number of tiers, which represent its height (see Figure 1).

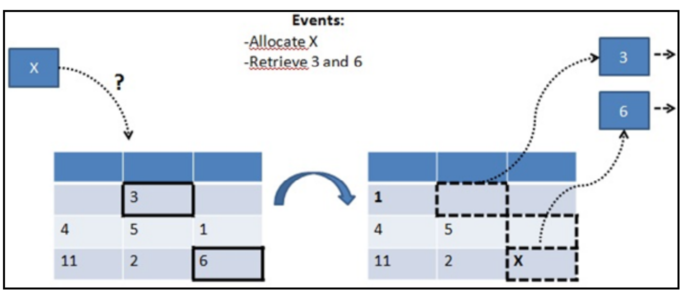
With the continuous development of seaports, various types of problems have emerged and attracted increasing attention in practice as well as in academic research. One of these problems is the container stacking problem (CSP), referred to also as Container Storage Problem, which consists in assigning a temporary storage location in a storage area (called yard) to containers on their arrival to the seaport. In other words, the CSPs include the process of storing or retrieving of containers in a stack so as to ensure the proper conduct of the rest of operations within the terminal. The effectiveness of this process depends on the occupancy rate of the storage area and on the strategies defined for the storage and of import/export containers (Gazdar et al., 2009).

Figure 1 A container terminal



To illustrate the problem, let us consider the example of a storage yard composed of 1 block containing 1 bay characterised by 3 stacks and 4 tiers (see Figure 2). In this example, we consider a request to stack a container X and a request to retrieve the containers 3 and 6. Hence, after the retrieval process, there are two storage positions that become free. So, before stacking the container X, the two containers 3 and 6 should be retrieved. The container 3 can be retrieved fluently. However, for retrieving container 6, container 1 should be first relocated as it is located above it. The issue here is to identify the best new position of container 1.

Figure 2 Container stacking example (see online version for colours)



The CSP has been reported to have critical effects on the performance of stacking systems and on the efficient operation of container terminals (Henesey et al., 2009). In the scientific literature, the CSP is widely treated considering both static and dynamic aspects:

- Static aspects: The problem is to determine, a-priori, a set of robust stacking positions that will undergo minor changes during their execution (Chenhao et al., 2020; Cifuentes and Riff, 2020; Oelschlägel and Knust, 2020; Zweers et al., 2020; Zhang et al., 2020; Feillet et al., 2019 ; Galle et al., 2017; Ji et al., 2015; Dayama et al., 2014). In example of Figure 2, if the order of arrival and retrieval of containers in the yard are well known in advance, then, their positions as well as the organisation of the yard blocks can be determined before the arrival of containers in the yard (that is to say before the allocation or retrieval requests). In this case, the position of a given container is well known before its entering to the yard side.

- Dynamic aspects: The problem consists in determining the stacking positions in real-time considering real-time changes in terminal environment (Rekik and Elkosantini, 2019; Rekik et al., 2018; Jin et al., 2014; Park et al., 2011). In Figure 2, if some unexpected events may occur during the stacking operation such as the breackdown of the yard crane related to block 1 or a fault on relocating the container 1 [as placing container 1 in the position (1, 1, 2, 3) in place of (1, 1, 1, 3)], then, the prescheduled positions of incoming containers should be revised taking into consideration new changes.

Different issues are also considered in the scientific literature including space allocation problems (SAPs) (Chenhao et al., 2020; Chen et al., 2004; Lee et al., 2012), container allocation problems (CAPs) (Oelschlägel and Knust, 2020; Rekik and Elkosantini, 2019; Rekik et al., 2018; Lee et al., 2011; Qiu et al., 2015; Chen and Lu, 2012) and container relocation problems (CRPs) (Cifuentes and Riff, 2020; Zweers et al., 2020; Zhang et al., 2020; Feillet et al., 2019; Galle et al., 2017; Lin et al., 2015; Jovanovic and Voß, 2014, Jin et al., 2014).

1.2 Objectives

Various literature surveys related to seaport terminals management have been developed to discuss different issues, such as operations in terminals (Steenken et al., 2004), material handling equipment (Vis and De Koster, 2003; Stahlbock and Voß, 2008), berth allocation and quay crane scheduling (Bierwirth and Meisel, 2010), and transport operations (Carlo et al., 2014b).

Despite the abundant literature on this topic, efforts on analysing the vast amount of CSP research are limited. Previous review papers focus on a specific approach with respect to limited considerations independently. For example, Bortfeldt and Wäscher (2013) have identified constraints that need to be considered in container loading. More recently, Lehnfeld and Knust (2014) developed a formal classification and proposed algorithms to solve different variants of CSP combining loading, unloading and pre-marshalling of containers in terminals. Carlo et al. (2014a) have discussed existing researches with respect to three issues: yard operations, yard design and equipment assignment.

Consequently, the data currently available on CSPs generally remains disparate and disjoint sets of models and pieces of evidence exist. Therefore, there is a need for a systematic survey and critical review for the existing research to identify whether there has been any structured or integrative orientation towards the prevention or mitigation of CSPs, and to recognise potential gaps in the current literature. There is still a need for a more exhaustive classification framework that enables analysing existing works with respect to new aspects and emerging trends, rarely or not studied before, such as the type of the stacking rules and performance assessment. This article fills in these gaps by providing a new classification scheme that allows the analysis of existing works with respect to different considerations simultaneously including CSP's variants, stacking rules, online vs. offline fashion, resolution approaches and performance indicators (PIs). Table 1 summarises a comparative study between previous review papers and the presented paper.

The main objectives of this survey are:

- To provide a conceptual classification scheme (CCS) for reviewing CSP articles and identifying the key contents of the articles.
- To classify and summarise the research findings and to identify the research trends.
- To identify future trends in CSP based on the literature survey.

Table 1 Comparison between previous review papers and presented paper

Study	*Classification criteria*						
	Storage constraints	*Variants of CSP*	*Resolution approaches*	*All the yard issues*	*Type of existing rules*	*Online vs. offline CSP*	*Performance indicators*
Bortfeldt and Wäscher (2013)	×						
Lehnfeld and Knust (2014)		×					
Carlo et al. (2014a)				×			
Presented paper		×	×		×	×	×

1.3 Outline

The remainder of this paper is organised as follows: Section 2 presents the methodology for the selection and classification of the CSP research literature. Section 3 presents the proposed CCS. Section 4 classifies the articles with respect to year of publication, title of journal, last name of the author/co-author of the reviewed articles, and the proposed CCS. Section 5 discusses the results of the classification of reviewed articles, presents identified limitations and future research directions. Finally, Section 6 concludes with discussion of the major challenges in the field and highlighting further research directions related to the design and implementation of solutions for CSPs.

2 Research methodology

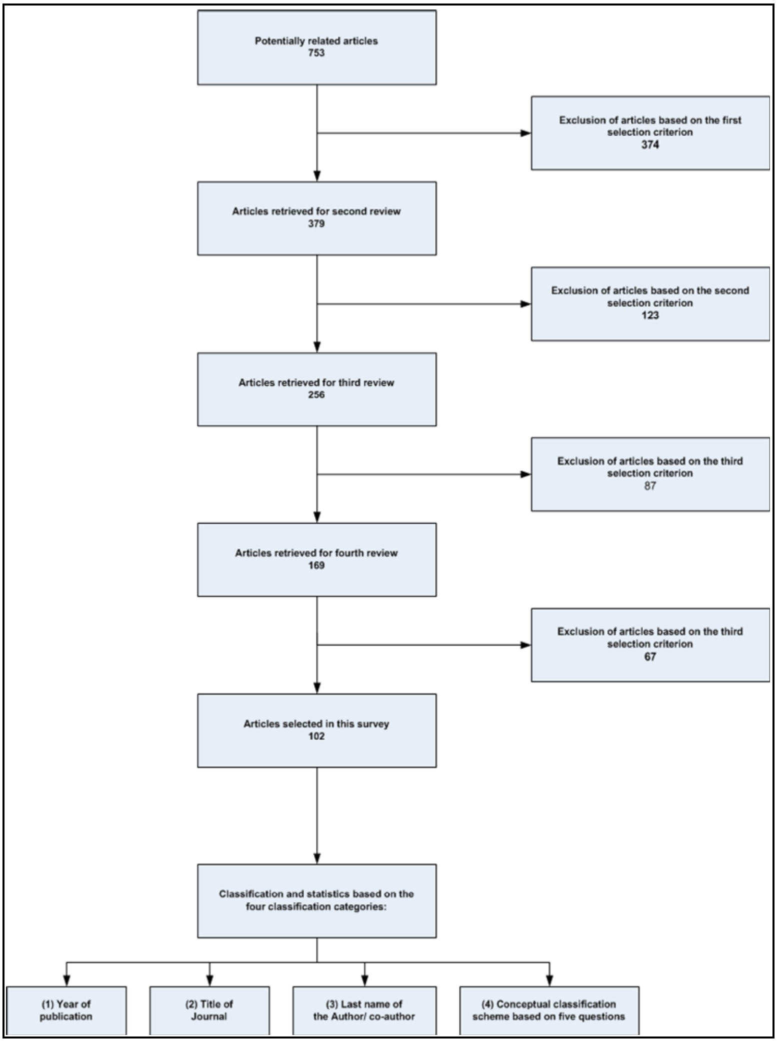
Conducting a literature review require a clear research methodology for a better analysis of papers in terms of their identification. In this context, Li and Cavusgil (1995) have identified three approaches for literature reviewing concerning a certain field or subject. The Delphi method is a forecasting method in which predictions are made by a group of experts. The meta-analysis method is defined by a statistical analysis of empirical scientific studies. Finally, the content analysis method, which is adopted in this literature review, is an observational research method that consists of a systematic, qualitative and quantitative evaluation of the content of literature related to CSP.

Content analysis is used to identify and classify key scientific contributions to a question and the results are then presented and discussed descriptively. This method is based on two major steps:

1. definition of procedures adopted for the search of articles to be analysed
2. definition of the classification method of the selected articles.

We have applied these two principles in the present survey of CSP literature.

Figure 3 The procedure for selecting the articles (see online version for colours)



2.1 Literature search procedure

The literature search was based on the following online journal databases: ScienceDirect, Inderscience, Wiley, Springer and IEEExplore. Moreover, the search is narrowed using the following descriptors: container, seaport terminal, system, storage or stacking, yard, algorithm, heuristic, and decision. Different selection criteria or filters are used to select articles related to the container stacking in seaport terminals. If the articles do not meet one of the following criteria, then they are eliminated. Selection criteria are described as follows:

- Filter 1: Only those articles that had been published in computer science, decision science and operation research related journals were selected.
- Filter 2: Only journal articles are considered. Other publication forms such as conference proceedings, unpublished working papers, master and doctoral dissertations, newspapers or books are not included.
- Filter 3: Only articles published since 2000 are considered.
- Filter 4: Articles addressing related problems such as yard layout design or material handling equipment are eliminated.

Authors are aware that relevant research works were published in other journals or before the year 2000. However, we have limited our research to these works to make our research methodology more relevant. Firstly, the literature search produced approximately 753 articles. After the application of these four filters (as shown in Figure 3), 102 articles are analysed according to the suggested CCS which is presented in Section 3. Each filter reduces the number of considered papers.

2.2 Classification categories

A final total of 102 articles are considered to be acceptable for the purposes of this survey. Each reviewed article is classified according to the following categories:

1. year of publication
2. title of journal
3. last name of the first author/co-author
4. CCS.

3 Proposed CCS

The objective of this section is to present the suggested CCS, referred to in this paper by CCS. It is based on different considerations as it will be detailed below. The proposed CCS was setup during the analysis of the 102 articles. Indeed, this survey uses this CCS for classifying the CSP related literature. As shown in Table 1, the proposed CCS is based on the following five questions:

1. What are the types of CSPs studied?
2. How the problem is addressed: online or offline CSP?
3. What are the adopted stacking rules?
4. What is the used approach for solving the CSP?
5. What are the adopted performance criteria?

Multiple possible responses to each of these questions are used for the classification of the reviewed articles into groups. The possible responses for each question are described in Table 2.

Table 2 List of questions and of possible responses to the proposed CCS

1	What are the types of CSPs studied?		
	1.1	Space allocation problems (SAP)	
		1.1.1	Extended SAP
		1.1.2	Space requirement problem (SRP)
		1.1.3	Yard allocation problem (YAP)
	1.2	Container allocation problems (CAP)	
	1.3	Container relocation problems (CRP)	
		1.3.1	Block relocation problem (BRP)
		1.3.2	Container pre-marshalling problem (CPMP)
		1.3.3	Container re-marshalling problem (CRMP)
2	How the problem is addressed: online or offline CSP online or offline CSP?		
	2.1	Online CSP	
	2.2	Offline CSP	
3	What are the adopted stacking rules?		
	3.1	Block assignment rules	
		3.1.1	Dedicated areas
		3.1.2	Role separation of blocks
		3.1.3	Role separation of bays
	3.2	Bay assignment rules	
		3.2.1	Concentrated location
		3.2.2	Nearest location
	3.3	Stack assignment rules	
		3.3.1	Random stacking
		3.3.2	Levelling
		3.3.3	Segregation
		3.3.4	Maximum remaining stack height
		3.3.5	Closest position
4	What is the used approach for solving the CSP?		
	4.1	Optimisation approaches	
		4.1.1	Exact methods
		4.1.2	Heuristics
		4.1.3	Metaheuristics
	4.2	Artificial intelligence approaches	
	4.3	Simulation approaches	
5	What are the adopted performance criteria?		
	5.1	Storage space PIs	
		5.1.1	Stacking capacity
		5.1.2	Space reservation

Table 2 List of questions and of possible responses to the proposed CCS (continued)

5	What are the adopted performance criteria?		
	5.2	Allocation process PIs	
		5.2.1	Unproductive movements
		5.2.2	Container storage/retrieval time
		5.2.3	Handling time
		5.2.4	Ship's berthing time
		5.2.5	Cranes working time

3.1 Types of CSP

The stacking process is always accompanied by a number of constraints with different objectives. This has given rise to different variants of CSP. According to the nature of the considered problem, CSP can focus on optimising the temporary storage space or the allocation/retrieval process. In the suggested CCS, the variants of CSPs are classed into three main groups:

- SAP: These problems are related to the optimisation of the temporary allocation of incoming (or outgoing) containers from (or to) storage blocks by optimising the land utilisation (space reservations) (Bazzazi et al., 2009). In SAPs, storage space is assigned to a group of containers not to an individual container as for example assigning storage space to containers having the same destination vessels. Three types of SAPs are identified: extended SAP, space requirement problem (SRP) and yard allocation problem (YAP). In extended SAP, the type of containers is integrated in the SAP. In SRP, containers of the same group must be loaded in the same bay or in adjacent bays (Chenhao et al., 2020; Woo and Kim, 2011). The YAP is defined by the storage yard space allocation for container transshipment movements between mother and feeder vessels within a terminal as well as between terminals (Lee et al., 2012). In Figure 4 for example, a solution of a SAP consist on determining most appropriate blocks to quays 1 and 2, In this example, the solution is to dedicate blocks 1 and 4 to containers of quay 1 and blocks 2, 3, 5 and 6 to quay 2.

- CAP: named also container handling problem, consist in determining the exact storage slot in the yard-bay for each incoming container, which is usually defined by the crane operator during the transfer operation. In Figure 2, deciding the exact storage position (the block, bay, stack, and tier) of the incoming container to the yard is the focus of the CAP. In this example, the decided storage position of the incoming container X is (1, 1, 2, 3).

- CRPs: Consist in relocating stacked containers to pick up other ones or to facilitate the future retrieval process and so that the number of relocations is minimised during the retrieval process (Caserta et al., 2012). Relocation is then the movement of a container from a stack to another either in the same bay or in different bays. Three types of CRPs are studied in the literature: block relocation problem (BRP), container pre-marshalling problem (CPMP) and container re-marshalling problem (CRMP). The BRP consists in relocating containers within the same bay in order to retrieve other containers. In this type of problems there exist containers leaving the storage area and the order in which these containers are retrieved is defined. In CPMP, there are no items neither entering nor leaving the storage area (bay). In this case the relocation of containers is done according to the constraint of priority of ships departure in order to facilitate the future retrieving of the containers existing in this bay. In CRMPs, the same set of items is maintained, as in CPMP, but the marshalling process can be done not only in the same bay but also in different bays. In the CRMP, the storage yard is segregating into several zones according to the duration of stay (DOS) of containers (monthly storage stacks, daily storage stacks, …); and each container have to be removed according to its departure time to the next zone corresponding to the container's remaining DOS at that time (Shin and Kim, 2015). CRPs are illustrated in examples of Figure 5.

Figure 4 Space allocation problem

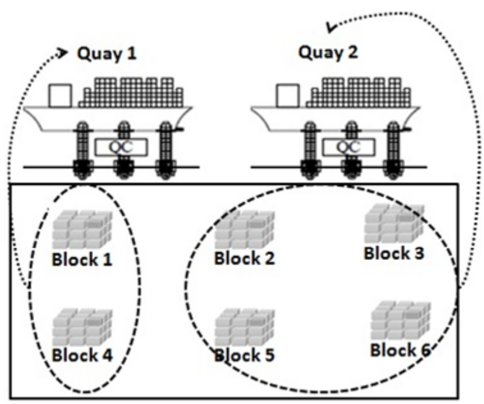
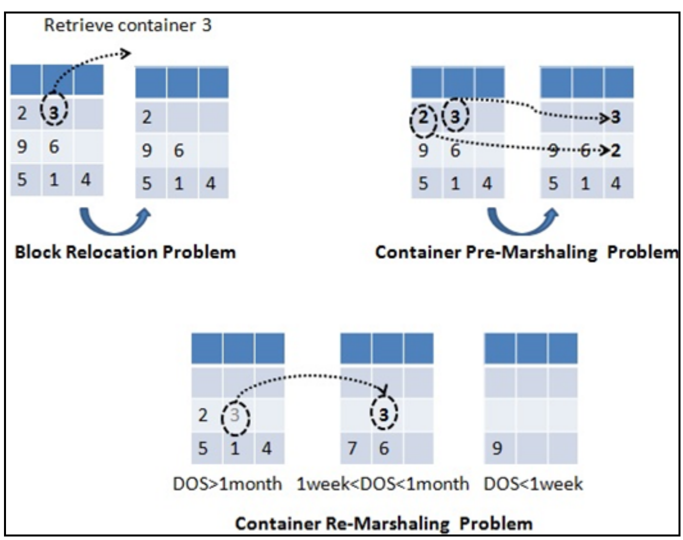


Figure 5 Container relocation problems (see online version for colours)



3.2 Online vs. offline CSP

In the scientific literature, CSP is widely treated considering both aspects (see Subsection 1.1):

- *Offline (static):* The problem is to design a set of robust stacking positions a-priori that will undergo minor changes during their execution. The stacking operations are planned before the arrival of containers to the storage yard, either before the arrival of the ship.
- *Online (dynamic):* The problem consists in determining the stacking positions in real-time considering the real-time change in terminal environments as those related to the stochastic arrival time of vessels or picking up of containers by their owners randomly. The dynamic nature of CSP makes it a complex, cyclic, and uncertain problem, where the interactions between the different components, such as containers, ships or handling equipment, are in perpetual evolution. For example, at a given time t, a ship is delayed or the yard crane related to a certain block is broken down. So, all the stacking planning must be changed and the storage positions of incoming containers have to be modified with respect to new unexpected events that have been occurred.

3.3 Stacking rules

Different stacking rules have been adopted in the literature to solve CSPs. The efficiency of each rule varies from terminal to terminal (Van Asperen et al., 2011). A stacking rule may be related to the selection of a block, a bay, or a stack. In this work, we categorise these rules into three main families: block assignment rules, bay assignment rules, and slot assignment rules. This paper is the first to classify the different stacking rules adopted for stacking incoming containers.

Block assignment rules consist in determining the 'appropriate' block for inbound and outbound containers. These rules include:

- *Dedicated areas* (*DA*) consists in reserving a specific area or block for specific types of containers as a block for imported containers or a block for some types of containers from a specific vessel. No DA means that there is no restriction on blocks for stacking containers. In some studies, containers with the same destination or with the same size (Chen and Lu, 2012; Zhang et al., 2003) are grouped and stored in the same block. However, this strategy can cause interference between yard cranes during the ship operation.
- *Role separation of blocks* (*RSBLOCK*) indicates that each block is assigned only to inbound or outbound containers. In a given block, inbound and outbound containers are not mixed (Chen and Lu, 2012).
- *Role separation of bays* (*RSBAY*) consists in partitioning the block into two sub-areas. One part of the bays of each block, which are near to the quay, is assigned to inbound containers, while the other part is assigned to outbound containers. In this rule, both inbound containers and outbound containers are allowed to be mixed up in one block.

After assigning containers to blocks by using one or more of the blocks assignment rules presented above, bays where containers must be located are determined based on several strategies including:

- *Concentrated location* (*CL*) rule consists in assigning containers to non-empty bays even if they are from different groups. According to the concentration principle for the storage locations of outbound containers, some area of the storage space is reserved in advance for a specific group of containers to minimise relocations of containers. Then, containers of different groups must not be mixed in the same stack. The two most popular reservation units adopted in practice are 'stack unit' and 'bay unit'. In the stack unit, all the slots in a stack are reserved for containers of the same group. Otherwise, in the bay unit, all the slots in the same bay are reserved for containers of the same group (Woo and Kim, 2011).
- *Nearest location* (*NL*) rule consists in assigning the nearest bay to berth for inbound containers (Woo and Kim, 2011).

Stack assignment (SA) rules include strategies adopted to determine the exact storage location in the assigned bays of the assigned block. Some of these rules are defined as follows:

- *Random stacking* (*RS*) rule does not need data about containers or load plan for selecting stacks. A random stack from the selected bay is selected if its maximum height is not reached.
- *Levelling* (*LEV*) rule does not 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. In other words, this rule consists on assigning the incoming container to the lowest stack in the yard which means filling up all empty stacks and then levelling the height of stacks layer by layer.
- *Segregation (Seg and non-segregation N-Seg) rules:* The principle of segregation is that the stacking of inbound containers on top of containers that are already stacked is not allowed. However, this rule is not quite obvious since sometimes a new container arrives but must be placed above the old containers considering that its departure time comes earlier than the stored ones.
- *Maximum remaining stack height* (*MRSH*) rule consists in placing the container in stacks having the highest tiers (Ji et al., 2015).
- *Closest position* (*CP*) rule consists in choosing the closest to gate stack in case of import containers (closest to the berth in case of export containers).
- *Priority order rule:* In this rule, containers with higher priority must not be placed under containers with lower priority.

If we take the example of an incoming container X to the yard (of destination d), the best storage position of this container should be determined in order to minimise the travelled distance of arriving trucks. To achieve this objective, the manager decides to reserve the block number 1 to containers of destination d, the bay number 2 of this block to containers that will be transported by the truck t and the nearest stack to the gate (of the bay 2). In other words, he has selected and then applied the following stacking rules for the selection of the most appropriate block, bay and stack respectively to allocate the container X: DA, CL and CP.

3.4 Approaches to solve CSP

Several approaches are used to solve the different types of CSP. These approaches can be categorised into three main families: optimisation approaches (exact approaches, heuristics and metaheuristics), intelligent approaches (artificial intelligence approaches and multi-agent systems) and simulation-based approaches. According to our study, intelligent approaches as well as simulation approaches are not widely used for the resolution of CSPs compared to optimisation approaches. We can note also that most of CSPs and especially CRPs require to heuristics as resolution approaches. This is explained by the lack of consideration of the dynamic aspect of the CSP that consider both intelligent (or reactive) approaches based on artificial intelligence or simulation approaches.

3.5 Adopted performance criteria

In order to evaluate and validate the performance of the CSP's approaches and methods, several PI have been developed in the literature. These PIs can be categorised into two main families: storage space PIs and allocation process PIs. The storage space PIs, as the stacking capacity and the space reservation, are used to evaluate the capability of port management systems to optimise the storage space under a limited available space. The allocation process PIs are suggested to evaluate the allocation process with regard to the process time or handling operations. Some of these allocation process PIs are defined as follows:

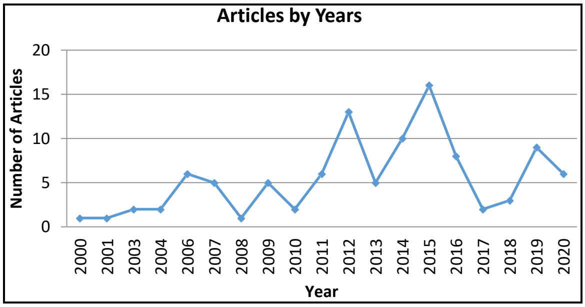
- Unproductive movements: Such indicator is used to evaluate the loading and unloading operations at a terminal for the relocation of a container from a stack to another one in order to allow access to other containers (Chen and Lu, 2012).
- The storage/retrieval time.
- The handling time.
- The ship's berthing time.
- The cranes working time.

4 Results

4.1 Classification of articles according to the year of publication

As indicated in Figure 2, the number of papers published in each year since 2000 ranges from 1 to 16. The average of published articles per year dealing with CSP is six. As expected, the number of papers published per year demonstrates a progressive increasing trend.

Figure 6 Distribution of articles by years (see online version for colours)



4.2 Classification of articles according to the title of the journal

The classification of reviewed articles according to the journal's title is presented in Table 2. The reviewed articles are published by 41 journals. In this table, only journals publishing more than one article dealing with CSP are identified.

Table 3 Distribution of reviewed articles according to the journal title

Journal	*Total*	*Percentage*
European Journal of Operational Research	23	22.55
Transportation Research Part E	11	10.78
Computers & Operations Research	10	9.80
Computers & Industrial Engineering	8	7.84
OR Spectrum	8	7.84
Flexible Services Manufacturing Journal	5	4.90
Expert Systems with Applications	4	3.93
Transportation Research Part B	4	3.93
Journal of Intelligent Manufacturing	3	2.94
International Journal of Production Economics	3	2.94
Journal of the Operational Research Society	2	1.96
IEEE Transactions on Automation Science and Engineering	2	1.96
Transportation Research Part C	2	1.96
Naval Research Logistics	2	1.96
Others	15	14.71
Total	*102*	*100*

We have noted that the largest numbers of articles were published in *European Journal of Operational Research* and *Transportation Research Part E* which account for 22.55% and 10.78% of the 102 reviewed articles, respectively. They are followed by *Computers & Industrial Engineering*, *OR Spectrum*, *Computers & Operations Research*, *Flexible Services Manufacturing Journal*, *Expert Systems with Applications*, and *Transportation Research Part B*, which together account for 38.24% of the reviewed articles. We can note that there are 14 journals that published at least two articles, while 15 other journals have published each with only one article. Finally, this classification shows the interest of many journals to the CSP problem.

4.3 Classification of articles according to the author/co-author

Table 3 presents the number and percentage of reviewed articles according to the last name of the authors/co-authors. It identifies only authors that have published two or more articles related to CSP. Indeed, Kap Hwan Kim, Andrew Lim, Loo-Hay Lee and Stefan Voß published the largest number of articles, which represented 7.84%, 6.86%, 6.86% and 5.88% of the 102 reviewed articles respectively. Together, they have published 33.7% of reviewed articles.

Table 4 Distribution of reviewed articles according to the author/co-author

Authors	*Affiliation/country*	*Total*	*Percentage*
Kap Hwan Kim	Department of Industrial Engineering, Pusan National University	8	7.84
Andrew Lim	Department of Industrial Engineering and Engineering Management, Hong Kong University of Science and Technology	7	6.86
Loo-Hay Lee	Department of Industrial and Systems Engineering, National University of Singapore	7	6.86
Stefan Voß	Institute of Information Systems, University of Hamburg, Von-Melle-Park 5, 20146 Hamburg, Germany	6	5.88
Bo Jin	Institute of Future Networks, Southern University of Science and Technology, Shenzhen, China	4	3.93
Yusin Lee	Department of Civil Engineering, National Cheng Kung University, Tainan 701, Taiwan	4	3.93
Dominique Feillet	Ecole des Mines de Saint-Etienne and LIMOS UMR CNRS 6158, CMP Georges Charpak, Gardanne, F-13541 France	3	2.94
Rommert Dekker	Econometric Institute, Erasmus University Rotterdam, Burg. Oudlaan 50, 3062 PA Rotterdam, The Netherlands	3	2.94
Erhan Kozan	Queensland University of Technology	2	1.96
Taejin Park	Department of Computer Engineering, Pusan National University, Geumjeong-gu, Busan 609-735, Republic of Korea	2	1.96
Florian Forster	Department of Information Systems, University of Hagen, Profilstr. 8, D-58084 Hagen, Germany	2	1.96

Table 4 Distribution of reviewed articles according to the author/co-author (continued)

Authors	*Affiliation/country*	*Total*	*Percentage*
Christopher Expósito-Izquierdo	Universidad de La Laguna, Dpto. de Estadística, IO y Computación, 38271 La Laguna, Spain	4	3.93
Matthew E.H. Petering	University of Wisconsin-Milwaukee, Department of Industrial and Manufacturing Engineering, P.O. Box 784, Milwaukee, WI 53201, USA	2	1.96
Rui Jorge Rei	INESC Porto and Faculdade de Ciências, Universidade do Porto, Rua do Campo Alegre, 4169-007 Porto, Portugal	2	1.96
Patrick Jaillet	Operations Research Center, MIT, 77 Massachusetts Ave, Cambridge, MA 02139, USA	2	1.96
Amir Gharehgozli	David Nazarian College of Business and Economics, California State University, Northridge, CA, USA	2	1.96
Yugang Yu	School of Management, University of Science and Technology of China, Hefei, China	3	2.94
René de Koster	Rotterdam School of Management, Erasmus University, Rotterdam, the Netherlands	3	2.94
André Hottung	Decision and Operation Technologies Group, Bielefeld University, 33615 Bielefeld, Germany	2	1.96
Shunji Tanaka	Institute for Liberal Arts and Sciences and Department of Electrical Engineering, Kyoto University, Kyotodaigaku-Katsura, Nishikyo-ku, Kyoto City, 615–8510 Kyoto, Japan	2	1.96
Kevin Tierney	Decision and Operation Technologies Group, Bielefeld University, 33615 Bielefeld, Germany	2	1.96
Others		30	29.41
Total		*102*	*100*

4.4 Classification of articles according to the developed CCS

Table A1 presents a classification of reviewed articles according to the proposed CCS detailed in Section 3. As listed in the table, the cross indicates that the article of the associated row belongs to the group (as defined in the proposed CCS) of the associated column. The distribution of reviewed articles according to the classification scheme is shown in Table 4.

A discussion of the survey contributions within each of the classified groups defined in the proposed CCS is presented in the next section.

Table 5 Distribution of reviewed articles according to the classification scheme

Classification criteria			*Number*	*Percentage*
1	What are the types of CSPs studied?			
	1.1	Space allocation problems (SAP)		21.36
	1.1.1	Extended SAP	3	2.91
	1.1.2	Space requirement problem (SRP)	10	9.71
	1.1.3	Yard allocation problem (YAP)	9	8.74
	1.2	Container allocation problems (CAP)	28	27.18
	1.3	Container relocation problems (CRP)		51.46
	1.3.1	Block relocation problem (BRP)	31	30.1
	1.3.2	Container pre-marshalling problem (CPMP)	19	18.45
	1.3.3	Container re-marshalling problem (CRMP)	3	2.91
2	Online or offline CSP?			
	2.1	Offline CSP	79	76.7
	2.2	Online CSP	23	23.3
3	What are the stacking rules adopted?			
	3.1	Block assignment rules		
	3.1.1	Dedicated areas	29	24.58
	3.1.2	Role separation of blocks	3	2.54
	3.1.3	Role separation of bays	3	2.54
	3.2	Bay assignment rules		
	3.2.1	Concentrated location	5	4.24
	3.2.2	Nearest location	4	3.39
	3.3	Stack assignment rules		
	3.3.1	Random stacking	7	5.93
	3.3.2	Levelling	3	2.54
	3.3.3	Segregation	4	3.39
	3.3.4	Maximum remaining stack height (MRSH)	2	2.02
	3.3.5	Closest position	6	5.08
	3.3.6	Weight	7	5.93
	3.3.7	Priority order	45	38.13
4	What is the used approach for solving the CSP?			
	4.1	Optimisation approaches		
	4.1.1	Exact methods	24	20.17
	4.1.2	Heuristics	65	54.62
	4.1.3	Metaheuristics	20	16.81
	4.2	Other artificial intelligence approaches	6	5.04
	4.3	Simulation approaches	4	3.36

Table 5 Distribution of reviewed articles according to the classification scheme (continued)

Classification criteria			Number	Percentage
5	What are the adopted performance criteria?			
	5.1	Storage space PIs		
	5.1.1	Stacking capacity	10	9.17
	5.1.2	Space reservation	4	3.67
	5.2	Allocation process PIs		
	5.2.1	Relocations	64	58.72
	5.2.2	Container storage/retrieval time	6	5.5
	5.2.3	Handling time	13	11.93
	5.2.4	Ship's berthing time	4	3.67
	5.2.5	Cranes working time	8	7.34

5 Discussion and research directions

This section presents a discussion of the currently available works based on each of the classified groups defined in the proposed CCS.

5.1 Types of CSP

According to our CCS, selected papers can be classified into three major categories:

1 SAPs such as extended SAP, SRP, YAP

2 CAPs

3 CRPs.

Based on our analysis, it seems that CRPs are widely studied in the literature (about 53 from 102 articles, i.e., 51.46%). From this category of CSP, the BRP is still the most treated variant (about 31 from 102 articles, i.e., 30.1%). The percentage of research studies in CAPs has reached 27.18% (i.e., 28 articles). The CPMP is also widely treated in the literature. The percentage of reviewed articles falling in the CPMP has reached 18.45% between 2000 and 2021.

As shown in Figure 3, we can note that some variants are not well studied such as CRMP and the extended SAP with both 5.82% of reviewed papers. Much effort should be dedicated to them.

5.2 Online vs. offline CSP

As shown in Subsection 3.2, CSP can be treated as an online or offline problem. Based on analysis, the offline CSP is still the most addressed in the literature. It is interesting to find that more than 76.7% of published papers dealing with CSP (i.e., 79 articles) between 2000 and 2020 focused on the offline CSP. The dynamic behaviour of the seaport terminal requires more investigation for a better consideration of unexpected events to adopt the problem in a more realistic fashion characterised by a high degree of uncertainty and dynamism face to the diverse containers and handling cranes flows and also the disturbances that may occur at any time. However, despite its importance, only 23.3% of reviewed papers (i.e., 23 articles) have addressed the online, referred to in some papers as real-time, CSP. The distribution of articles according to the offline vs. online considerations is detailed in Table 4 and summarised in Figure 4.

Figure 7 Distribution of articles according to the type of CSP searched (see online version for colours)

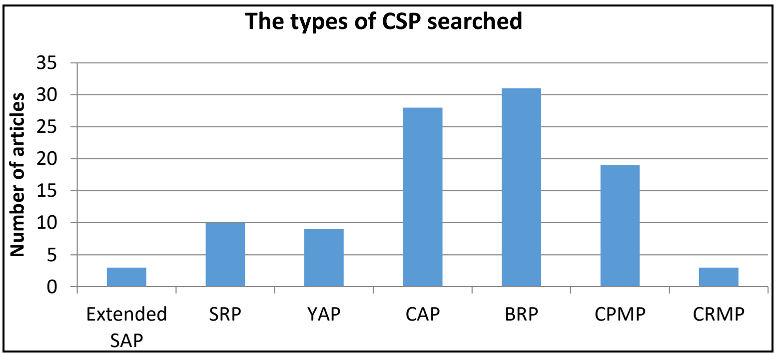
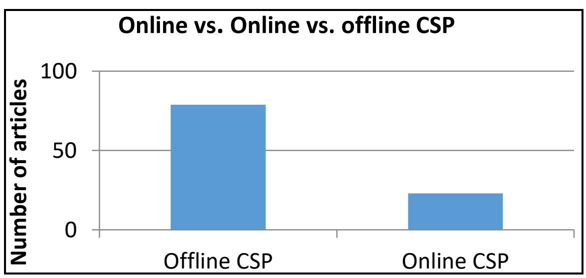


Figure 8 Distribution of articles according to the online/offline considerations (see online version for colours)



Regarding papers dealing with offline CSP, we noted that only three papers have developed an offline approach to solve an extended SAP (Bazzazi et al., 2009; Fu et al., 2007) and only three papers have developed an offline approach to solve a CRMP (Choe et al., 2011; Yu and Qi, 2013; Shin and Kim, 2015). From another side, many papers were published suggesting offline approaches for CAP (26 papers), BRP (29 papers) and CPMP (18 papers).

Regarding papers dealing with the online CSP, we have noted that there is no research works that have been conducted investigating the online CSP considering CPMP and CRMP. Moreover, we noted that extended SAP, SRP and YAP are not well investigated with only article for the first (Kim and Park, 2003), two articles for the second (Chen et al., 2004; Ku et al., 2012) and one paper for the third (Qiu et al., 2015). We noted also that 43.48% of papers dealing with online CSP have considered BRP. Therefore, more focus should be given for the offline assignment of containers for SAP, SRP and YAP.

Although the number of conducted research dealing with the online CSP, the dynamic consideration is limited to the dynamic arrival of containers or the dynamic change in the storage space. There is a need for approaches that consider the different unexpected events that may occur during the stacking process, such as accidents, especially those related to the handling of dangerous containers, fault in a container placing, yard crane breakdown. Moreover, it important to outline that in the 23 reviewed papers dealing with the online container assignment, there are no generic approaches dealing simultaneously with a variety of disturbances, such as the arrival of damaged containers, a technical problem is a crane. Most of the studies so far performed have treated a restricted number of disturbances but did not take into account the interaction between the different containers stacked in the yard and all disturbances which may occur. Therefore, further studies that take unexpected events and uncertain environments into consideration through suitable reactive assignment strategies remain a relevant global research direction.

5.3 Stacking rules

Table 5 presents the distribution of articles according to the stacking rules with a specific focus on the relation between the rule and online/offline specification. According to this table, we note that most of the stacking rules adopted in the literature (45 from 102 articles, i.e., about 38.1%) are based on the priority order of incoming/outgoing containers. However, the use of MRSH strategy is still limited despite its importance (about 2.02%). There are only two articles adopting the MRSH stacking rule (Ji et al., 2015; Dayama et al., 2014). Moreover, many rules were not investigated for the development of approaches for the online container allocation. Rules such as RS block, RS bay, CL or Seg are not yet assessed. Regarding the offline assignment of containers, most of rules were used and some of them were widely studied and they have demonstrated a good performance such as DA (Kim and Kim, 2007; Bazzazi et al., 2009; Zhen, 2014; Tao and Lee, 2015) or priority order (Lee and Lee, 2010; Caserta et al., 2012; Zhang et al., 2015; Wang et al., 2016). Only Lev rule (levelling) is not yet tested.

In addition, many papers have combined different rules for the identification of locations of containers. For example, Chen and Lu (2012) have suggested an approach combining different rules related to the block (DA and RS block), bay (CL and NL) and stack allocation (RS) of incoming containers for the CAP. In the block allocation rule, containers with the same size are grouped and stored in the same block (DA) and each block is assigned either to inbound or to outbound containers (RSBlock). In the bay allocation rule, containers of different destination groups must not be mixed in the same bay and are also assigned to the nearest bay to berth (NL). In the stack allocation rule, a random stack (RS) is selected for the allocation of the incoming container. Moussi et al. (2015) have also combined the DA (inbound and outbound containers are not mixed in the same block) and priority order (the order of departure time) rules for the CAP. Saurí and Martín (2011) have treated the SRP by combining DA, RS block and segregation rules. In other words, import containers (DA), containers from different ships are not mixed (RS block) in the same block and new containers can be stacked on top of old containers (non-segregation).

Table 6 Distribution of articles according to the stacking rules

Rules	*Num. of papers dealing with*		*Total*
	Offline CSP	*Online CSP*	
DA	22	6	28
RS block	3	0	3
RS bay	2	0	2
CL	5	0	5
NL	3	0	3
RS	4	3	7
Lev	0	2	2
Seg	4	0	4
MRSH	2	2	2
CP	4	2	6
Weight	2	3	5
Priority order	34	15	49

Table 7 Stacking rules vs. type of CSP

Rules	*Extended SAP*	*SRP*	*YAP*	*CAP*	*BRP*	*CPMP*	*CRMP*
DA	3	10	6	8	1	0	0
RS block	0	2	0	1	0	0	0
RS bay	0	2	0	0	0	0	0
CL	0	1	1	3	0	0	0
NL	0	1	1	1	0	0	0
RS	0	0	0	7	0	0	0
Lev	0	0	0	2	0	0	0
Seg	0	1	0	1	0	1	1
MRSH	0	0	0	5	0	1	0
CP	0	0	0	2	1	1	1
Weight	0	0	0	3	1	0	1
Priority order	0	0	0	5	27	14	1

Table 6 provides another overview about the result of this classification as it provides the number of conducted researches for each rule and for each variant of CSP. In general, we can observe that DA rule is frequently used in papers focusing on variants of SAPs (extended SAP, SRP or YAP) such as Bazzazi et al. (2009), Ku et al. (2012), Sharif and Huynh (2013), Liang et al. (2015), Zhen (2014) and Tao and Lee (2015) or on CAPs such as Kim and Kim (2007), Güven and Eliiyi (2014), Park et al. (2011) and Moussi et al. (2015). RA rule is also used in many papers dealing with CAPs such as Dekker et al. (2006), Van Asperen et al. (2011) and Luo and Wu (2015). We can note also that the majority of CRPs considers the priority order rule (Caserta et al., 2012; Rei and Pedroso, 2013; Zehendner et al., 2015; Ku and Arthanari, 2016). This table show clearly that more efforts are required to assess the performance of some rules, such as CL or NL, to solve some variants of CSP, such as BRP or CPMP respectively.

5.4 Approaches to solve CSP

The approaches used to solve CSPs can be categorised into three main families: optimisation approaches (including exact methods, heuristics and metaheuristics), artificial intelligence approaches and simulation approaches.

Conventionally, optimisation approaches serve as a very useful and standard metrics for solving CSPs. The distribution of the reviewed articles according to the adopted resolution approaches, which is detailed in Table 4 and summarised in Figure 6, indicates that 91.6% of reviewed papers used or developed optimisation methods. There are 20 reviewed articles using metaheuristics in CSPs, such as Tabu search (Casey and Kozan, 2012; Chen et al., 2004; Fu et al., 2007; Han et al., 2008; Jiang et al., 2013); simulated annealing (Casey and Kozan, 2012; Chen et al., 2004; Fu et al., 2007; Kang et al., 2006; Zhen, 2014); genetic algorithms (GAs) (Bazzazi et al., 2009; Casey and Kozan, 2012; Fu et al., 2007; Ji et al., 2015; Yang and Kim, 2006); critical-shaking neighbourhood search (Lim and Xu, 2006). Among these optimisation approaches, the GAs seems to become quite popular in solving CSPs. The GA has demonstrated a better performance compared with other approaches such as branch and bound (Ji et al., 2015), simulated annealing (Chen et al., 2004) or Tabu search (Fu et al., 2007). Hybrid approaches have been also developed combining different approaches and have demonstrated good results such as the heuristic developed by Moussi et al. (2015) combining ant colony and simulated annealing. Authors have obtained good results comparing with branch and bound and ant colony optimisation.

Although the number of papers assessing the performance of developed approaches, we noted that there is still a lack for an in-depth performance assessment and comparison of different optimisation approaches. The comparison is still limited to most famous approaches such as GA or Tabu search. Moreover, we noted also that there no benchmarking platforms allowing the assessment and comparison of conducted research. Only some simulation software are used.

Moreover, few research studies have addressed simulation solving approaches for based CSPs such as optimisation simulation (only 3.36% of reviewed papers). For example, Borgman et al. (2010) suggested the use of a discrete-event simulation for the online containers stacking considering imperfect or imprecise departure time information. The authors have investigated two concepts. The first concept is to use knowledge about container departure times to minimise the number of reshuffles. The second concept is the trade-off between stacking further away in the terminal versus stacking close to the exit points and accepting more reshuffles. A simulation study of different stacking rules in an automated stacking system was also proposed by Dekker et al. (2006) in order to discuss the advantages and limitations of each stacking strategy.

The use of artificial intelligence techniques such as multi-agent systems for solving CSPs is also not widely investigated since 2000. Indeed, only e papers were identified (Kefi et al., 2009; Moussi et al., 2015; Rekik et al., 2018; Rekik and Elkosantini, 2019; Hottung et al., 2020; Zhang et al., 2020). For example, Kefi et al. (2009) developed a distributed a multi-agent-based system, denoted as container stacking via multi-agent approach and heuristic (COSAH) method to solve the online CAP. This approach seeks to simulate, solve and optimise the amount of storage space for handling container departures and arrivals within a fluvial or maritime port. Kefi et al. (2009) compared the performance of multi-agent approach to branch and bound algorithm and with the decision rule heuristic proposed by Kim and Hong (2006) and founded better results.

Figure 9 Distribution of articles according to the resolution approaches of CSP (see online version for colours)

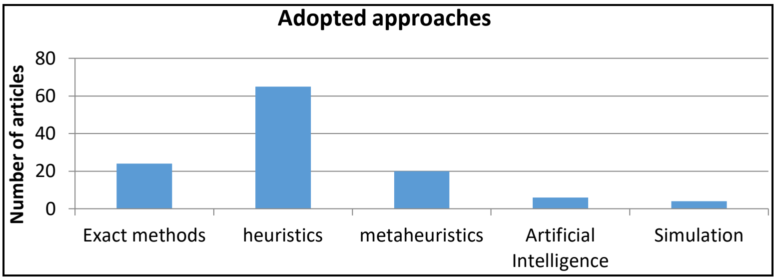


Table 7 presents the number of papers per type of approaches and per the type of addressed problem (online or offline). We note that most of developed optimisation techniques have developed for the offline container assignment while simulation and artificial intelligence-based approaches have been developed for the online assignment. It is clearly shown in the table that the selection of the appropriate approach is closely related to way in which the problem is addressed, i.e., online or offline. Many approaches should be investigated for the online container assignment such rule-based systems such as fuzzy logic, neural network or knowledge-based approaches such as case-based reasoning (CBR). Regarding the offline assignment, we noted that most of paper used is heuristics but some metaheuristics such as bees algorithms and immune inspired approaches are not well investigated.

From our analysis, we can note that artificial intelligence approaches as well as simulation approaches are not widely used for the resolution of CSPs compared to optimisation approaches. Few works have exploited distributed CSP management systems. Such works used multi-agent systems for managing all port operations (Yin et al., 2011) but did not deal specifically with container stacking operations. However, due to the complexity of the CSP, the distributed nature of the CSP and diversity of different constraints in stacking operations, multi-agent systems seem to be an appropriate approach to solve the CSP. Moreover, knowledge-based approaches such as CBR are not well investigated.

Table 8 Approaches vs. online/offline CSP

Approaches	*Number of papers*	
	Offline	*Online*
Exact methods	20	4
Heuristics	51	14
Metaheuristics	17	3
Artificial intelligence	0	6
Simulation	1	3

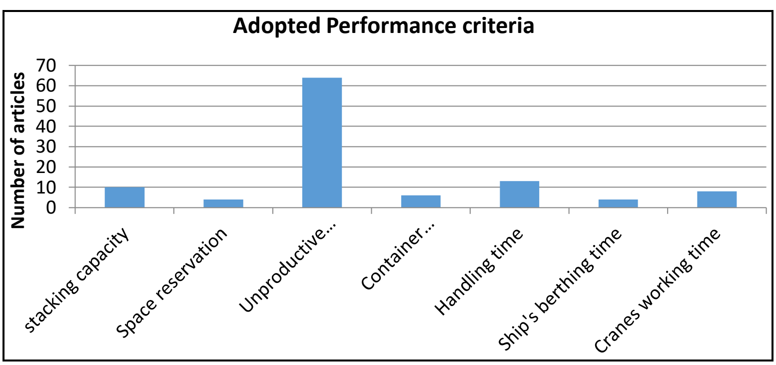
5.5 Adopted performance criteria

To evaluate the performance of developed algorithms for the different variants of CSP, several PIs have been used, including the number of spaces allocated to containers (Lim and Xu, 2006) and the average cycle time (Kefi et al., 2009). In the suggested CCS, these PIs are categorised into two main families: storage space PIs and allocation process PIs (see Section 3). To the best of the authors' knowledge, this review is the first adopting this classification of the different PIs related to the storage of containers.

The distribution of reviewed articles according to the adopted performance criteria is detailed in Table 4 and summarised in Figure 6. Storage space PIs have been used in 14 articles (i.e., about 12.84%) of the total of the reviewed articles while 87.16% of reviewed papers (95 papers) have adopted the allocation process PIs.

As indicated in Figure 6, most of the allocation process PIs used for assessment the performance of the CSP are those related to the number unproductive movements. It is important to note that there is still a need to assess the performance of developed algorithms in the literature with regards to other PIs. For example, container storage/retrieval time or space reservation PIs have been only used by Kim and Kim (2007), Bazzazi et al. (2009), Ünlüyurt and Aydın (2012), Güven and Eliiyi (2014), Woo and Kim (2011), Jiang et al. (2014) and Zhen (2014) respectively. Finally, we have noted that many papers have combined different PIs such as Zhen (2014), Petering et al. (2016), Park et al. (2011) and Chen and Lu (2012).

Figure 10 Distribution of articles according to the adopted PIs (see online version for colours)



6 Conclusions

This paper aims to provide a comprehensive survey on recent research dealing with CSPs. It is based on a large number of recent references within 2000–2020, representative of the major lines of thought in the field. The content analysis research methodology is used with a new CCS. 109 articles published in leading scientific journals are analysed and classified. Although those authors are aware that some interesting research woks were published in conference proceedings or in other academic and professional journals.

The review and analysis of currently available works reveals that CSP continue to be an interesting and open area of research. Several observations were discussed in Section 5 and many limitations and future research directions were identified and which are classified based on the suggested CCS. In spite of the considerable efforts spent since 2000, some research trends and directions can be investigated. Without claiming to be exhaustive, five issues are identified for immediate attention:

- *Investigation of some variants of CSP:* As discussed in Section 5, many variants of CSP are not well addressed in the literature. Indeed, new approaches or decision support systems are required for container staking for some problems such as extended SAP, SRP or CRMP.
- *Development of new assignment rules:* Although the number of developed assignment rules (for selection of blocks, bays or stacks), only few of them were assessed in different variants such as the rule DA. More efforts are required to assess the performance of some rules, such as CL or NL, to solve some variants of CSP, such as BRP or CPMP respectively. In addition, some other assignment rules can be inspired from other problems such as the workers' assignment problem (Zhao et al., 2021), integration of worker skills in assignment operations (Abdullah and Süer, 2019).
- *Development of new approaches for the online allocation of containers:* A very limited number of paper have addressed the online assignment of containers. In spite of the limited number of papers using multi-agent systems, for CSP (Kefi et al., 2009) or connected problems such as Berth allocation (Yin et al., 2011), more efforts are required to develop distributed decision support systems. Other approaches are not yet investigated. To the best of authors' knowledge, approaches such as those inspired by immune systems or knowledge-based approaches such as CBR and regression analysis learning mechanism (Kambara, 2020) are not yet used. Such approaches should be able to capture knowledge on management processes, store it, and then exploit it, either simply by documentation, archiving and retrieval for decision makers when needed, or in combination with more sophisticated algorithms capable of reusing and adapting it to handle new situations.
- *Safety issues and dangerous container management:* Management of dangerous containers is a particular aspect of disturbance management. Very few works gave attention to the integration of dangerous containers as constraints. Recently, Rodriguez-Molins et al. (2012) have developed a heuristic to solve a CRP wherein dangerous containers must be allocated separately by maintaining a minimum distance. However, the integration of dangerous container management in dynamic CSP has not been studied in the literature. More generally, there is a need for approaches that consider safety issues, such as safety distances, emergency management, and major industrial risks (floods, fire, etc.). In addition, combining container allocation and green container transport and routing is another issue related to the integration of environmental factors in dangerous containers movement flows to guarantee sustainable development (Moalla et al., 2021; Takanokura et al., 2019).

- *Assessment of approaches:* The assessment of developed approaches requires an in-depth performance analysis. Indeed, the performance of developed approaches should be compared considering identical experimentation framework including same seaport terminal configuration, same scenarios and same PIs. Unfortunately, papers used different experimentations. Although the existence of dedicated simulation software, the development of an open-source benchmarking system for the assessment of decision support systems for CSP seems to be promising. Similar benchmarking platforms were developed in other field such as manufacturing systems (Trentesaux et al., 2013) or transportation systems (Gheriani et al., 2016).

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Appendix

Table A1 Classification of reviewed articles according to the proposed CCS

Article	*1*							*2*		*3*												*4*					*5*						
	1			*2*	*3*					*1*			*2*		*3*							*1*			*2*	*3*	*1*		*2*				
	1	*2*	*3*		*1*	*2*	*3*	*1*	*2*	*1*	*2*	*3*	*1*	*2*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*1*	*2*	*3*			*1*	*2*	*1*	*2*	*3*	*4*	*5*
Van Asperen et al. (2011)				×					×						×	×										×			×				
Akyüz and Lee (2014)					×				×												×		×						×				
Bazzazi et al. (2009)	×							×		×														×						×			
Borgman et al. (2010)				×					×						×	×										×			×				
Bortfeldt and Forster (2012)					×			×													×		×						×				
Caserta et al. (2011)					×				×												×	×		×					×				
Caserta et al. (2012)					×			×													×		×						×				
Casey and Kozan (2012)					×				×												×		×	×					×				
Chen et al. (2004)		×							×	×														×			×						
Chen and Lu (2012)				×				×		×	×		×	×	×								×						×		×		
Chenhao et al. (2020)		×							×	×												×				×			×				
Choe et al. (2011)							×	×												×	×			×					×				
Cifuentes and Riff (2020)					×				×												×		×										×
Clausen and Kaffka (2015)				×				×													×					×					×		
Cordeau et al. (2007)			×					×		×				×									×								×		
Dayama et al. (2014)						×		×										×				×							×				
Dekker et al. (2006)				×					×						×											×			×				×
Expósito-Izquierdo et al. (2012)						×		×													×		×						×				
Expósito-Izquierdo et al. (2015a)					×				×												×		×						×				

Table A1 Classification of reviewed articles according to the proposed CCS (continued)

Article	*1*							*2*		*3*												*4*					*5*						
	1			*2*	*3*			*1*	*2*	*1*			*2*		*3*							*1*			*2*	*3*	*1*		*2*				
	1	*2*	*3*		*1*	*2*	*3*			*1*	*2*	*3*	*1*	*2*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*1*	*2*	*3*			*1*	*2*	*1*	*2*	*3*	*4*	*5*
Expósito-Izquierdo et al. (2015b)					×			×													×	×							×				
Feillet et al. (2019)					×			×													×		×						×				
Feng et al. (2020)					×			×													×		×						×				
Forster and Bortfeldt (2012)					×			×													×		×						×				
Fu et al. (2007)	×							×		×													×	×			×						
Galle et al. (2017)					×			×													×	×							×				
Gharehgozli and Zaerpour (2017)				×				×									×			×			×							×			
Gharehgozli et al. (2019)				×	×			×											×			×	×								×		
Güven and Eliiyi (2014)				×				×		×									×				×							×			
Han et al. (2008)		×						×		×														×					×				
Hottung and Tierney (2016)						×		×													×			×					×				
Hottung et al. (2020)						×		×													×				×				×				
Huang and Lin (2012)						×		×															×						×				
Jovanovic et al. (2015)						×		×													×		×						×				
Ji et al. (2015)				×				×										×						×					×				
Jiang et al. (2012)			×					×		×																		×					
Jiang et al. (2013)				×				×		×												×	×				×						
Jiang et al. (2014)				×				×		×												×	×				×						
Jin (2019)					×			×													×	×							×				
Jin et al. (2014)					×				×												×		×						×				

Table A1 Classification of reviewed articles according to the proposed CCS (continued)

Article	1							2		3												4					5						
	1			2	3			1	2	1			2		3							1			2	3	1		2				
	1	2	3		1	2	3			1	2	3	1	2	1	2	3	4	5	6	7	1	2	3			1	2	1	2	3	4	5
Jin et al. (2015)			×					×		×													×				×						
Jovanovic and Voß (2014)					×			×															×						×				
Kang et al. (2006)				×				×					×											×					×				
Kefi et al. (2009)					×				×	×													×		×				×				
Kim et al. (2000)				×				×		×			×		×							×	×						×				
Kim and Park (2003)	×								×	×													×				×						
Kim and Hong (2006)					×			×												×		×	×						×				
Kim and Kim (2007)				×				×		×												×								×			
Kim et al. (2004)				×				×												×		×									×		
Kim et al. (2016)					×				×												×		×						×				×
Ku and Arthanari (2016)					×			×													×		×						×				
Ku et al. (2012)		×							×	×													×										×
Lam et al. (2007)				×					×													×							×				
Lee et al. (2006)		×						×		×		×											×						×				
Lee and Hsu (2007)						×		×									×				×	×							×				
Lee and Chao (2009)						×		×													×		×						×				
Lee and Lee (2010)					×			×													×		×						×				×
Lee et al. (2012)			×					×															×								×		
Liang et al. (2015)		×						×		×														×			×						×
Lim and Xu (2006)			×					×					×											×			×						

Table A1 Classification of reviewed articles according to the proposed CCS (continued)

Article	*1*							*2*		*3*												*4*					*5*						
	1			*2*	*3*			*1*	*2*	*1*			*2*		*3*							*1*			*2*	*3*	*1*		*2*				
	1	*2*	*3*		*1*	*2*	*3*			*1*	*2*	*3*	*1*	*2*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*1*	*2*	*3*			*1*	*2*	*1*	*2*	*3*	*4*	*5*
Lin et al. (2015)					×			×											×				×						×				
Luo and Wu (2015)				×				×							×								×	×								×	
Luo et al. (2016)				×				×							×									×								×	
Maldonado et al. (2019)				×				×													×	×	×						×				
de Melo da Silva et al. (2018)					×	×		×													×	×							×				
Moussi et al. (2015)				×				×		×											×			×								×	
Nishimura et al. (2009)			×					×		×													×								×		
Oelschlägel and Knust (2020)				×				×														×	×					×					
Park et al. (2011)				×					×	×									×				×				×		×				
Petering and Hussein (2013)					×			×													×		×						×				
Petering et al. (2016)				×					×											×			×									×	×
Preston and Kozan (2001)					×			×																×							×		
Qiu et al. (2015)			×					×	×												×	×					×						
Rei and Pedroso (2012)						×		×													×		×						×				
Rei and Pedroso (2013)						×		×													×		×						×				
Rekik et al. (2018)				×					×									×	×	×	×				×					×	×		
Rekik et al. (2019)				×					×									×	×	×	×				×					×	×		
Rodriguez-Molins et al. (2012)						×			×										×				×		×				×				
Saurí and Martín (2011)		×						×		×	×						×												×				
Sharif and Huynh (2013)		×						×		×														×							×		
Shin and Kim (2015)							×	×											×				×						×				

Table A1 Classification of reviewed articles according to the proposed CCS (continued)

Article	*1*							*2*		*3*													*4*					*5*						
	1			*2*	*3*					*1*			*2*		*3*								*1*			*2*	*3*	*1*		*2*				
	1	*2*	*3*		*1*	*2*	*3*	*1*	*2*	*1*	*2*	*3*	*1*	*2*	*1*	*2*	*3*	*4*	*5*	*6*	*7*		*1*	*2*	*3*			*1*	*2*	*1*	*2*	*3*	*4*	*5*
Tanaka and Takii (2015)					×			×													×		×							×				
Tanaka et al. (2019)						×		×													×		×							×				
Tao and Lee (2015)			×					×		×													×	×										×
Tierney et al. (2016)						×		×													×			×						×				
Ünlüyurt and Aydın (2012)						×		×													×		×								×			
Wan et al. (2009)					×			×													×			×						×				
Wang et al. (2014)						×		×													×			×						×				
Wang et al. (2016)						×		×													×			×						×				
Woo and Kim (2011)		×						×		×	×		×	×										×					×					
Yang and Kim (2006)				×				×									×						×	×	×					×				
Yu and Qi (2013)							×	×									×							×						×				
Zehendner et al. (2016)					×				×												×			×						×				
Zehendner et al. (2015)					×				×												×		×							×				
Zhang et al. (2003)		×						×		×		×											×	×								×		
Zhang et al. (2014)				×				×												×				×						×				
Zhang et al. (2015)					×			×													×			×						×				
Zhang et al. (2020)					×			×													×		×			×				×				
Zhen (2014)			×					×		×															×				×			×		
Zhu et al. (2020)				×				×										×			×		×	×						×				
Zweers et al. (2020)					×			×													×		×	×						×				
Zweers et al. (2019)					×				×												×		×	×						×				