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The storage location assignment problem: A literature review

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A B S T R A C T

The storage of goods plays a crucial role in warehouse management systems. Although this operation is often considered simple, it is in fact complex, due to the volume of products, the uncertainty in demands, and the rapid customer service response that the market requires. Moreover, the optimization of logistical resources to maintain an efficient operational flow, such as the allocation of storage spaces, often requires complex decisions. In this paper, we analyze academic contributions on the storage location assignment problem published between 2005 and 2017. The literature is classified according to the solution methods, objectives, and related considerations. Suggestions are also provided for future research.

1. Introduction

In supply chain management, storage is defined as a buffer of accumulated products to guarantee the quantities demanded in the shortest possible time. Frazelle et al. (2007) identify the main challenges for storage: small transactions, more articles, complex and perishable products, international orders and returns, value-added services, less margin of error, and less time to satisfy the customer. Warehouse operations systems are configured through the following sequential processes: reception, storage, order-picking, and dispatch. These processes imply resource allocation decisions that affect system performance. Fig. 1 shows the main operational decisions affecting storage systems (Gu et al., 2007).

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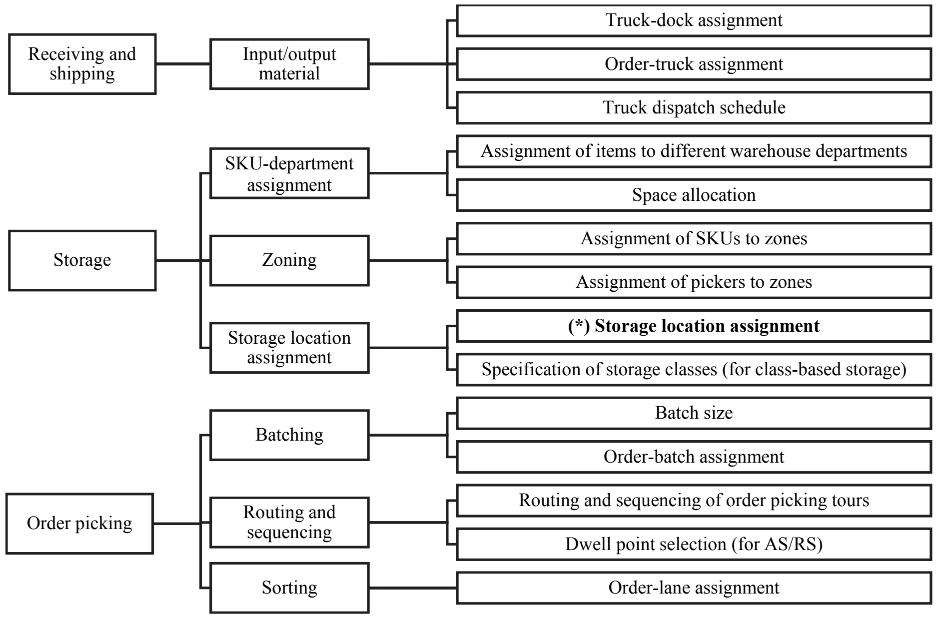

Fig. 1. Operational decisions in storage management. Source: Adapted from (Gu et al., 2007)

In this paper, we develop a systematic literature review of the storage location assignment problem *(SLAP)*. The *SLAP* is an operational decision associated with the accommodation and picking process, influencing batch definition, classification, routing, and order sequencing. In the following sub-sections, we provide a more complete definition of the *SLAP*, the motivation for our work, and the structure of the paper.

1.1. Storage Location Assignment Problem (SLAP)

The *SLAP* concerns the allocation of products into a storage space and optimization of the material handling costs or storage space utilization. The problem depends on parameters such as storage area design, storage space availability, warehouse storage capacity, physical characteristics of the products, arrival times, and demand behavior. The main optimization approaches concern warehouse space utilization and the cycle time for order preparation and picking operations, considering restrictions such as available storage capacity, order-picking resource capacities, and dispatching policies (Gu et al., 2007). In terms of complexity, Frazelle (1989) classifies the *SLAP* as *NP-Hard*, due to variations caused by the number of products and warehouse storage characteristics. When the number of products is equal to the number of storage spaces, the problem is defined as a quadratic allocation problem *(QAP)* (Kofler, 2015). Moreover, if the number of products is greater than the number of storage spaces and each storage space can store several products, it becomes a knapsack problem *(KP)* (Gu et al., 2010).

Hausman et al. (1976) observe that there are various storage space allocation policies, among which the most representative are random storage, dedicated storage, and class-based storage. In addition, Gómez et al. (2008) introduced storage policies that depend on the closest free space and inventory rotation. In short, the random policy uses any location for storage products, while the closest free space policy prioritizes storage locations available at shorter distances from the reception or dispatching areas. In the dedicated storage policy, each product is placed in a pre-assigned location, according to its classification. For the inventory rotation policy, products with higher sales indices are stored as close as possible to the reception or dispatching areas. Finally, the class-based storage policy classifies the products and assigns them to a pre-established location, depending on their classification criteria.

1.2. Motivation for a Review of Research Papers on SLAP

The *SLAP* occurs in various logistical scenarios in which a set of entities must temporarily occupy a warehouse storage area, *e.g.,* raw materials warehouses, distribution centers, hospitals, or parking lots. This gives the present study a practical relevance in its consideration of methods for solving the storage allocation problem and its variations.

Gu et al. (2007) note that the *SLAP* is one of the problems that has received the most attention from the research community; however, as far as we know, there has been no comprehensive literature review addressing the *SLAP*, despite its practical and theoretical applications. In this paper, our objective was to present a synthesis and exhaustive analysis of the existing literature on this topic and, more specifically, on the solution methods.

The present paper is organized as follows: Section 2 introduces the review methodology; Section 3 describes the results; Section 4 presents the discussion of the research trends and future research; finally, Section 5 provides some conclusions.

2. Review Methodology

For this work, a systematic literature review *(SLR)* of the *SLAP* was carried out. The SLR approach was selected because it allowed us to identify and answer a specific research question, contextualize the subject, construct and understand specific theoretical concepts, obtain the information needed to construct a set of relevant bibliographical references, and analyze the results at a quantitative and qualitative level, as well as suggest future research directions on the subject (Seuring et al., 2005; Rowley & Slack, 2004). The overall research question guiding this work was: *How has the SLAP been addressed?* Additionally, the following specific research questions were proposed:

(1) *How do authors refer to the SLAP?*
(2) *What kind of methods have been used to solve the SLAP?*
(3) *What kind of performance measures have been optimized?*
(4) *What considerations or constraints have been defined for the proposed solutions?*

To answer the research question(s), we took the following sequential steps, based on the works of Seuring and Gold (2012) and Seuring et al. (2005):

(1) *Material collection.*
(2) *Descriptive analysis.*
(3) *Category selection.*
(4) *Material evaluation.*

2.1. Material Collection

The scope of this literature review was limited to papers published in academic journals of high impact and academic relevance, as well as high levels of accessibility and search facility. Specifically, the *Scopus* and *Web of Science* databases were used. We excluded books, conference proceedings, project reports, and professional journals (although such resources could be considered in future research). The present review only considered literature published between 2005 and 2017, as Gu et al. (2007) have presented a review of progress on the *SLAP* up to 2004. One critical issue in conducting this review was that the SLAP had been referred to different terminology. For this reason, segregated keywords were used in subsets related to: nouns that indicated *solution methods*, nouns focused on referencing elements of *location*, active verbs that suggest *location*, and also nouns that considered a *classification* within the investigative context of the *SLAP*. To facilitate this process, a search string was used in which truncated forms and a proximity of a maximum of four words were permitted to elements of the inclusive keyword subsets. The logical structure of the search string is presented as follows:

(warehous) AND (system* OR model* OR method* OR procedure* OR solution* OR solv*) AND ((storag* OR space* OR product* OR good* OR slot* OR reserv* OR stock*) NEAR/4 (locat* OR allocat* OR assign*) NEAR/4 (function* OR process* OR decision* OR problem* OR rule* OR polic*))*

2.2. Descriptive Analysis

In this section, the main results derived from the analysis of the selected publications are addressed, subdivided according to the following factors:

(1) *Distribution of publications per year.*
(2) *Main journals in which the selected articles were published.*
(3) *Specific research methodologies used in the articles analyzed.*

2.3. Category Selection

Fig. 2 presents the classification structure used to answer the present study's research questions.

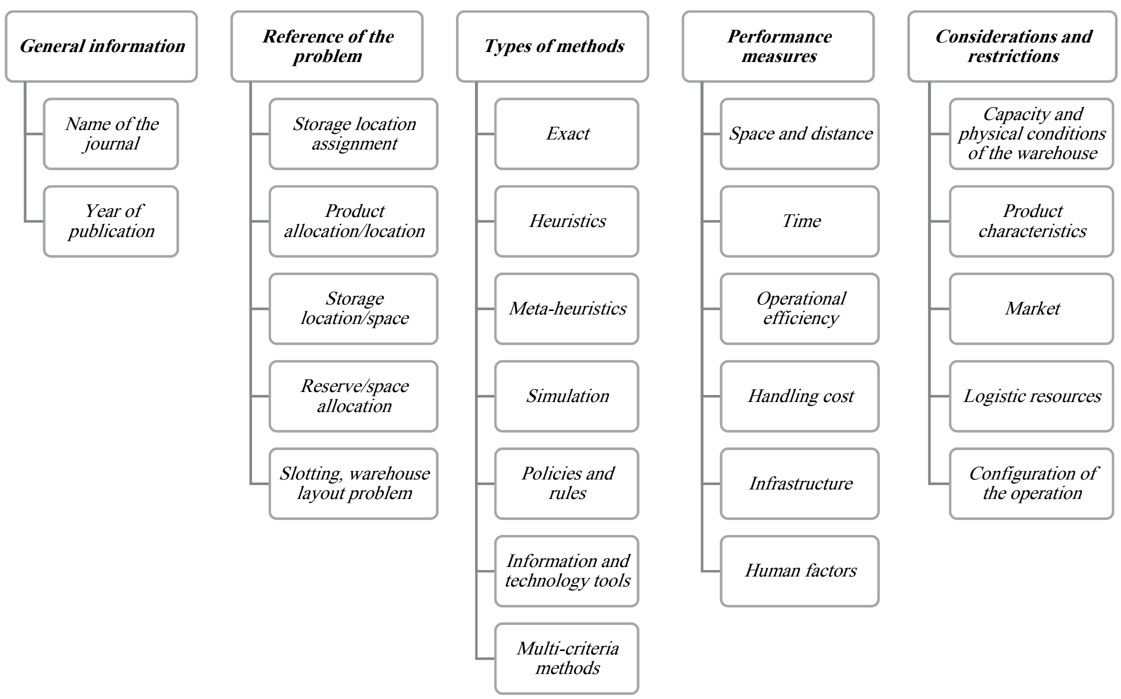

Fig. 2. Methodological structure of document classification

The proposed categories for the article's classification were:

(1) *General information of the article*: This category included the name of the journal and year of publication.
(2) *Reference of the problem*: This category captured the terminology used to identify the *SLAP*. The following terms were considered: *Storage location assignment*, *product allocation/location*, *storage location/space*, *storage/reserve/space allocation*, and *slotting* or *warehouse layout problem*.

(3) *Solution methods*: This category covered a global classification of the solution models, such as: *exact*, *heuristics*, *meta-heuristics*, *simulation*, *policies and rules*, and *multicriteria methods,* as well as *technology and information tools*. The specific methods used were also described.
(4) *Performance measures*: This category focused on the objective functions that were optimized within the literature: *space and distance*, *time*, *operational efficiency*, *handling costs*, *infrastructure*, and *human factors*. The associated variables were also specifically described.
(5) *Restrictions and considerations*: This category covered the most important parameters that limited the analyzed models, including: *capacity and physical conditions of the warehouse, product characteristics, market, logistics resources*, and *operation configuration*. The specific variables related to each category are discussed.

2.4. Material Evaluation

The selected publications were reviewed according to the criteria presented in section 2.1. We developed these criteria to ensure relevance and reliability in the review. The selection criteria for each category were designed and validated through a discussion focused on the comparison of decisions related to the categorization. A count was made that depended on the number of applications in each category, as a given publication can contain several approaches to a solution. Finally, we synthesized the information in pre-established classification formats, and then analyzed the results obtained, discussing some specific articles in accordance with their level of impact as measured within the databases consulted.

3. Findings

After the methodology described in section 2 was applied, an initial set of 190 publications were obtained from the database search. After an exhaustive and detailed analysis of these documents, 71 papers were selected due to their relevance and quality. In general, we observed that, based on the selected literature, the number of publications on the subject of storage allocation increased over the period analyzed (2005–2017). On average, however, 5.5 relevant articles per year were published during the 13 years analyzed. Fig. 3 shows the distribution of publications over time; relevant articles were found in 38 different scientific journals. The *International Journal of Production Research* and *Computers & Industrial Engineering* had the highest number of relevant articles, with 13 and 11 respectively. These were followed by the *International Journal of Advanced Manufacturing Technology,* with four articles, and then *Applied Mathematical Modelling,* the *International Journal of Engineering Business Management*, and the *International Journal of Logistics Research and Applications*, each with three articles.

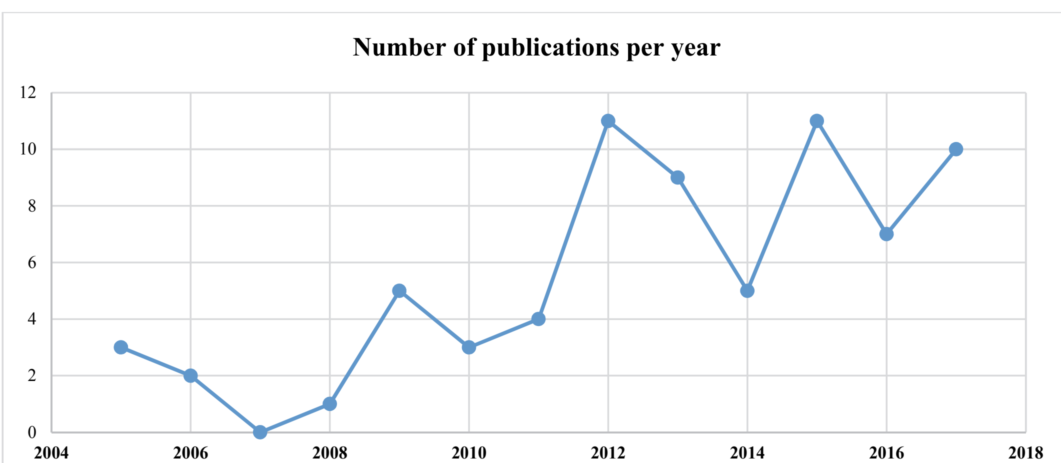

Fig. 3. Distribution of publications regarding time

Within the same given publication, there are sometimes multiple-solution approaches that combine or alternate between methods, either to propose hybrid models or to compare alternatives with other methods. All the reviewed publications made use of experimental data to validate models. However, only 34 of the 71 total publications explicitly described the application of their proposals in particular case studies. Fig. 4 shows the distribution by type of application.

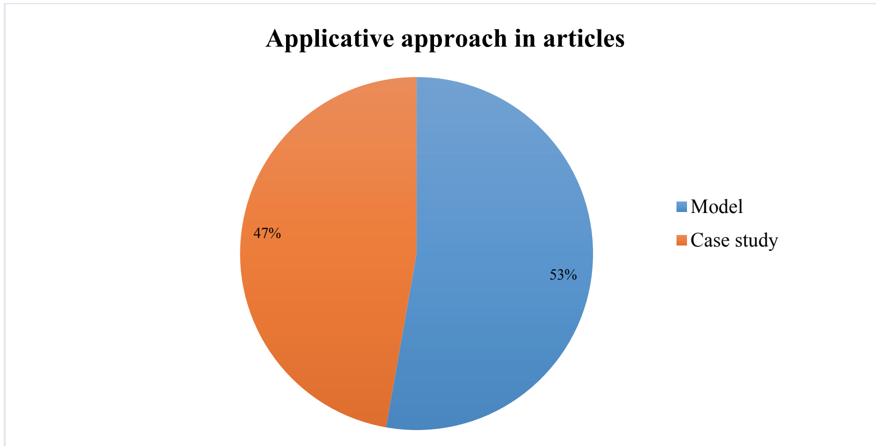

Fig. 4. Distribution of the type of application

In terms of the definition of the problem, we found several variations. Otto et al. (2017) generalized the *combined ergonomic storage assignment and zoning problem* with the objective of minimizing the maximum ergonomic load among all workers. Bortolini et al. (2015) addressed the *unit-load assignment problem*, which consists of defining an effective strategy of unit assignment to minimize the average travel time in storage and recovery operations. Another variation was called the *space allocation and aisle-positioning problem* by Bodnar and Lysgaard (2014), in a shelving system with gravity flow that sought to minimize the total number of replacements in a period, subject to accessibility and security of storage locations. In addition, Walter et al. (2013) addressed the *discrete forward–reserve problem*, which consisted of dividing the warehouse into reserve and front areas to facilitate the preparation work by means of the location of products and space, looking to minimize the amount of replenishment between these areas. Table 1 presents the characterization of the articles according to the criteria proposed in section 2.3.

From the applications considered in case studies, the following industries stand out: industrial machinery manufacturing, tobacco manufacturing, automotive distribution centers, food manufacturers and distributors, logistics outsourcing operators, retail distributors, lithographic printing, the flower market, gift item manufacturing, hospital entities, pharmaceutical companies, and warehouses with multiple types of products, such as hardware, furniture, and household items. Table 2 presents publications focused on a particular industrial sector.

There has also been discussion of applications for different types of warehouses, including the multi-level type (Fontana & Nepomuceno, 2017; Guerriero et al., 2015; Guerriero et al., 2013; Chan & Chan, 2011), multi-aisle (Battini et al., 2016; Le-Duc & de Koster, 2005), cascade (Chou et al., 2012), mono-block with multi-aisle (Ramtin & Pazour, 2015; Xiao & Zheng, 2010), pick-and-pass system with multiple order picking lines (Pan et al. 2015), and order-picking system with bucket-brigade method (Webster et al., 2012), as well as warehouses with a single aisle (Boysen & Stephan, 2013; Chuang et al. 2012) and chaotic warehouses (Quintanilla et al. 2015). In the following subsections, the findings for each category are explained in detail and relevant works are discussed.

Table 1
Classification of the selected articles

AUTHORS	SOLUTION METHODS							PERFORMANCE MEASURES						RESTRICTIONS AND CONSIDERATIONS				
	EX	HEU	MHEU	SIM	SP&R	OT	MC	SPD	TMP	CT	OE	HF	INF	CAP	MER	PROD	REC	OPE
Choy et al. (2017)					√	√						√		√				
Dijkstra and Roodbergen (2017)	√							√						√		√		
Elbert and Müller (2017)				√				√						√			√	
Fontana and Nepomuceno (2017)							√		√					√	√			
Franzke et al. (2017)				√	√			√	√					√	√		√	
Larco et al. (2017)	√							√						√				
Otto et al. (2017)			√						√					√				
Pang and Chan (2017)						√					√			√	√	√		
Yang et al. (2017)	√		√					√						√			√	
Zhang et al. (2017)	√								√					√	√			
Battini et al. (2016)	√										√			√	√			
Cruz-Domínguez and Santos-Mayorga (2016)			√					√						√	√	√		
Ene et al. (2016)			√		√					√				√				√
Hui et al. (2016)						√		√						√		√		
Li et al. (2016)			√			√		√						√		√		
Rai and Ettam (2016)					√				√					√				
Wang et al. (2016)			√							√				√				
Battini et al. (2015)		√							√					√		√		
Bortolini et al. (2015)	√									√				√				
da Silva et al. (2015)							√		√					√	√			
Guerriero et al. (2015)		√	√						√					√	√			
Pan et al. (2015)			√	√					√					√				
Qin et al. (2015)				√	√			√						√				
Quintanilla et al. (2015)	√		√					√						√				
Ramtin and Pazour (2015)	√	√								√				√	√			
Sharma and Shah (2015)					√			√						√				
Wutthisirisart et al. (2015)		√							√					√		√		
Yang et al. (2015)	√		√					√						√			√	
Bodnar and Lysgaard (2014)	√								√					√				√
Fontana and Cavalcante (2014)				√	√				√					√				
Gagliardi et al.(2014)	√	√		√				√	√					√				√
Meneghetti and Monti (2014)					√						√			√				
Ming-Huang et al. (2014)		√				√		√	√					√		√		
Atmaca and Ozturk (2013)	√		√						√		√			√	√			
Boysen and Stephan (2013)	√										√			√		√		
Fumi et al. (2013)	√	√		√	√				√					√		√		
Grosse et al. (2013)	√								√					√	√		√	
Guerriero et al. (2013)	√		√							√				√	√	√		
Meneghetti and Monti (2013)					√			√						√				√
Walter et al. (2013)	√	√						√						√				
Yu and de Koster (2013)					√						√			√	√			
Zaerpour et al. (2013)	√				√					√				√				
Accorsi et al. (2012)		√						√						√				
Ang et al. (2012)	√							√						√	√			
Carlo and Giraldo (2012)		√	√		√				√					√				
Chou et al. (2012)	√							√						√	√			

AUTHORS	SOLUTION METHODS							PERFORMANCE MEASURES						RESTRICTIONS AND CONSIDERATIONS				
	EX	HEU	MHEU	SIM	SP&R	OT	MC	SPD	TMP	CT	OE	HF	INF	CAP	MER	PROD	REC	OPE
Chuang et al. (2012)	√							√		√				√	√	√		
Gagliardi et al.(2012)				√	√			√						√			√	
Glock and Grosse (2012)				√	√			√						√				
Kim and Smith (2012)	√		√									√		√	√	√		
Pan et al. (2012)		√		√				√						√			√	
Webster et al. (2012)				√				√						√	√		√	
Chan and Chan (2011)				√					√					√	√			
Chen et al. (2011)	√	√	√					√	√					√				
Chiang et al.(2011)	√					√		√						√				
Kovács (2011)	√				√				√					√		√		
Chen et al. (2010)	√	√	√		√						√			√		√	√	
Gu et al. (2010)	√							√						√				
Xiao and Zheng (2010)		√			√				√					√				√
Bindi et al. (2009)					√						√			√		√		
Chen et al. (2009)	√							√						√				
Cheung et al. (2009)					√	√		√						√	√			
Lam et al. (2009)					√	√				√				√				
Pan and Wu (2009)		√						√						√	√			
Yang (2008)				√	√				√					√	√			
Hsieh and Tsai (2006)					√					√				√				
Manzini (2006)					√				√					√		√		
Heragu et al. (2005)	√	√								√				√				
Ho and Liu (2005)					√				√					√				
Le-Duc and de Koster (2005)	√	√		√	√				√					√				

EX Exact
HEU Heuristics
MHEU Metaheuristics
SIM Simulation
SP&R Policies and rules
OT Other trends and support tools
MC Multi-criteria methods
SPD Space and distance
TMP Time
CT Costs
OE Operational efficiency
HF Human factors
INF Infrastructure
CAP Warehouse capacity
MER Market
PROD Products
REC Logistics resources
OPE Operational configuration

Table 2
Industrial sectors of the case studies

Sector of the company case study	Authors
Industrial machinery manufacturing	Choy et al. (2017).
Tobacco	Wang et al. (2016).
Automotive	Larco et al. (2017); Ene and Öztürk (2012).
Hardware	Pang and Chan (2017), Battini et al. (2015); van den Berg and Zijm (1999)
Foods	Bortolini et al. (2015); Selviaridis and Norrman (2014); Gagliardi et al. (2012); Chiang et al. (2011); Kovács (2011); Obeid et al. (2018); Khandebharad et al. (2018).
Flowers	Qin et al. (2015).
Gifts	Fumi et al. (2013).
Lithographic printing	Rai and Ettam (2016).
Hospital	Chou et al. (2012).
Pharmaceutical	Chuang et al. (2012).
Furniture and household items	Battini et al. (2015).
Logistics outsourcing	Lam et al. (2009); Cheung et al. (2009).
Retail distribution	Cruz-Domínguez and Santos-Mayorga (2016); Hui et al. (2016).

3.1. References to the SLAP

The published literature uses different terminology to refer to identical problems or similar to the *SLAP*, which can make searches confusing. For this reason, we chose to synthesize different key terms to explore the types of terminology used by different authors.

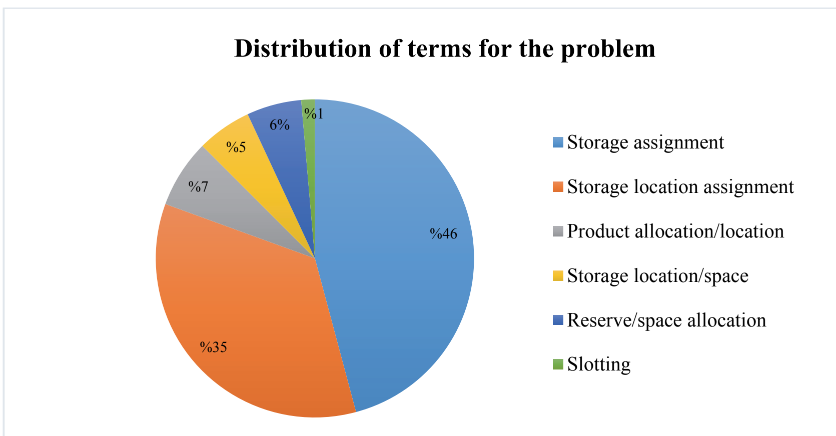

Fig. 5. Distribution of terms for the problem

We found that the most-used terms were *storage assignment* and *storage location assignment*, which together make up 81% of the examples in the present literature review and which are often accompanied by complementary terms such as *problem* or *policy*. Fig. 5 shows the distribution of various terms for the *SLAP* that predominated in the selected publications. Some authors have also referred to the *SLAP* in terms of *product allocation* (Guerriero et al., 2015; Ramtin & Pazour, 2015; Guerriero et al., 2013, Heragu et al., 2005) or *product location* (Boysen & Stephan, 2013); others have used *reserve allocation* (Bodnar & Lysgaard, 2014) or *space allocation* (Bodnar & Lysgaard, 2014). It has also been referred to as *slotting* (Kim & Smith, 2012), and some authors have even used the term *dynamic* (Li et al., 2016).

3.2. Solution Methods

In this section, we present the results of the classifications described in section 2.3 for *SLAP* solution methods. Fig. 6 presents a bar diagram showing the number of applications of each of the methods found within the analyzed literature. It should be noted that this count considers the total number of applications of each method in the analyzed research, as a given individual publication can address several different methods.

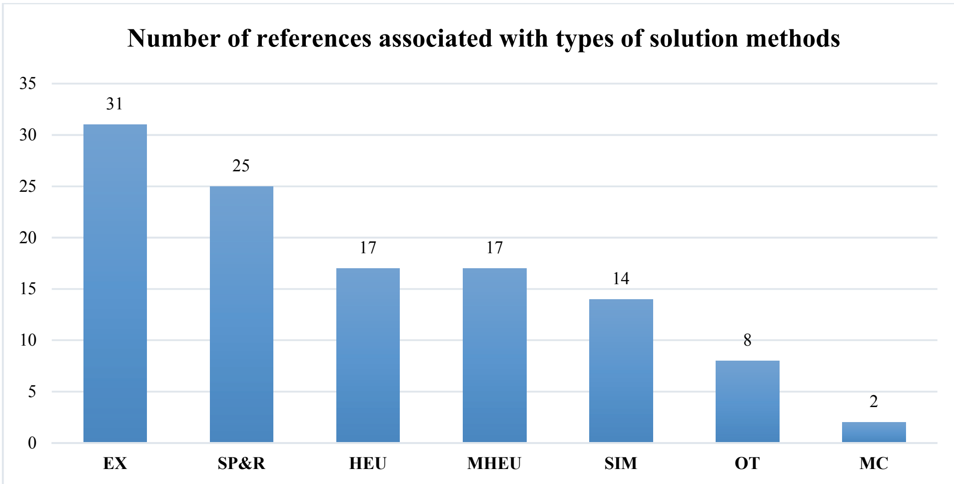

Fig. 6. References by type of solution method

As can be seen in Fig. 6, *exact* methods were the most used; however, in many cases, the proposed models were not in fact executed, due to the complexity of the problem. *Storage policies and rules* are widely used and accepted by the research community, as are *heuristic* and *metaheuristic* methods. Moreover, *simulation* methods are often used to compare the effects of particular policies on the storage system. In recent years, the use of tools based on information technologies has increased in order to provide systems for decision support (*DSS*) focused on the *SLAP*. On the other hand, *multi-criteria* techniques have also been used to propose alternative solutions.

3.2.1. Exact Methods

The exact methods used in the literature were mathematical models of mixed integer programming (*MILP*), binary programming (*BL*), robust optimization (*RO*), non-linear programming (*NLP*), Pareto borders (*PF*), and branch and bound algorithms (*B&B*). Fig. 7 shows the percentages of use of each of these methods in the 31 publications associated with this category.

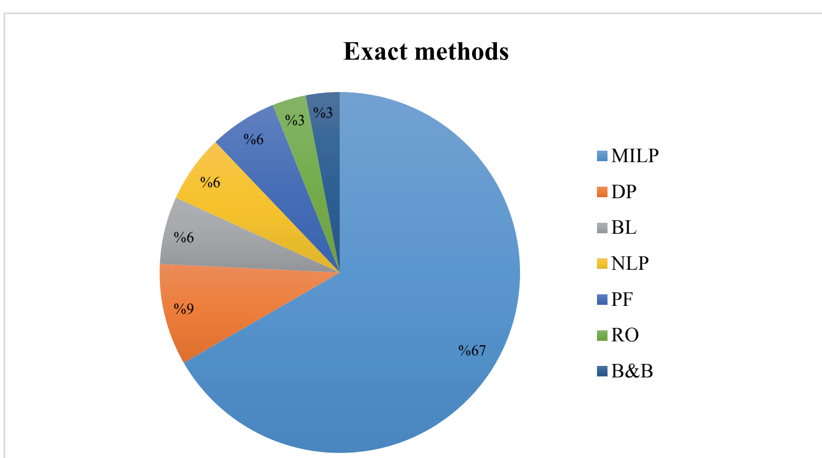

Fig. 7. Distribution of exact solution methods

Mixed integer programming models were the most used, while robust optimization was the least implemented. Table 3 shows which authors have modeled solutions based on exact methods.

Table 3
Relationship between exact methods and authors

Method	Authors
MILP	Yang et al. (2015); Ramtin and Pazour (2015); Guerriero et al. (2013); Heragu et al. (2005); Walter et al. (2013); Kim and Smith (2012); Kovács (2011); Larco et al. (2017); Bortolini et al. (2015); Chou et al. (2012); Gagliardi et al. (2014); Atmaca and Ozturk (2013); Grosse et al. (2013); Zaerpour et al. (2013); Chen et al. (2011); Zhang et al. (2017); Chen et al. (2010); Quintanilla et al. (2015); Chen et al. (2009); Chuang et al. (2012); Ene and Öztürk (2012); Le-Duc and de Koster (2005).
DP	Dijkstra and Roodbergen (2017); Bodnar and Lysgaard (2014); Boysen and Stephan (2013).
BL	Chiang et al. (2011); Fumi et al. (2013).
NLP	Yang et al. (2017); Guerriero et al. (2013).
PF	Battini et al. (2016); Ene and Öztürk (2012).
RO	Ang et al. (2012).
B&B	Gu et al. (2010).

Regarding particular applications of exact methods, Larco et al. (2017) proposed a methodology focused on the allocation of storage in which *MILP* used multi-objectives to minimize the time in the cycle of preparation of orders and the discomfort of workers. On the other hand, Ene and Öztürk (2012) solved the class-based storage allocation with *MILP* and proposed a genetic algorithm to minimize travel time for storage and recovery in the automotive industry. In addition, Fumi et al. (2013) solved multi-product storage allocation in a gift manufacturing company through a dedicated policy and integer mathematical model to minimize the total number of locations used. Ang et al. (2012) proposed a robust optimization model to minimize the total storage cost, considering demand factors. Finally, Bodnar and Lysgaard (2014) developed a dynamic programming algorithm to minimize the total number of replacements.

3.2.2. Heuristics

Within the literature, there were 17 applications of heuristics, distributed between: algorithms and procedures (*SA&P*), multi-stages procedures (*MS*), hierarchical procedures (*HH*), sequencing procedures (*SEQ*), rollout heuristics (*RBH*), 2-opt exchange heuristics (*EH*), class-based heuristics (*CBH*), greedy heuristics (*GH*), and also applications such as multi-product optimization heuristics (*MPO*). Fig. 8 shows the percentages of use for these heuristic methods within the 17 publications that used them.

Algorithms and specific procedures were the most used heuristic methods. There were also several uses of multi-stage heuristics, and efforts have been made to study other types of heuristics, such as exchange, sequencing, and hierarchical. Table 4 shows the authors who have applied heuristic methods.

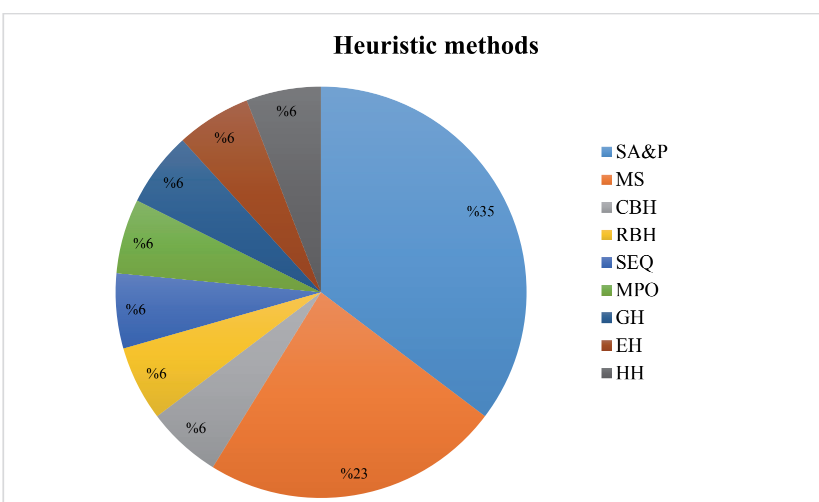

Fig. 8. Distribution of heuristic methods

Table 4
Relationship between heuristic methods and authors

Method	Authors
SA&P	Battini et al. (2015); Ramtin and Pazour (2015); Walter et al. (2013); Pan et al. (2012); Pan and Wu (2009); Heragu et al. (2005).
MS	Wutthisirisart et al. (2015); Chen et al. (2011); Chen et al. (2010); Xiao and Zheng (2010).
CBH	Ming-Huang et al. (2014).
RBH	Guerriero et al. (2015).
SEQ	Gagliardi et al. (2014).
MPO	Fumi et al. (2013).
GH	Carlo and Giraldo (2012).
EH	Le-Duc and de Koster (2005).
HH	Accorsi et al. (2012).

Regarding the use of these heuristic methods, Wutthisirisart et al. (2015) proposed a heuristic model in two phases *(sequencing and location)* to minimize the travel distance of order preparation. In addition, Guerriero et al. (2015) designed deployment heuristics to assign locations and reduce handling costs, considering product compatibility factors in multi-level warehouses. On the other hand, Boysen and Stephan (2013) introduced a location allocation algorithm based on dynamic programming and two greedy heuristics to reduce the travel distance of order preparation. Finally, Accorsi et al. (2012) developed a systematic hierarchical descending procedure that allows the combination of sequential decision steps in storage allocation.

3.2.3. Meta-heuristics

The meta-heuristic methods used in the analyzed investigations were taboo search (*TS*), genetic algorithms (*GA*), local iterated search (*ILS*), simulated annealing (SA), ant colony (*AC*), local search (*LS*), and artificial neural networks (*ANN*). Fig. 9 shows the percentages of use for these methods in the 17 publications found in this category.

The most-used meta-heuristic method to solve the *SLAP* in the analyzed publications was the taboo search. There was also considerable use of genetic algorithms. The least-used meta-heuristic methods were local search, ant colony, and neural networks. Table 5 shows which authors developed models based on meta-heuristics.

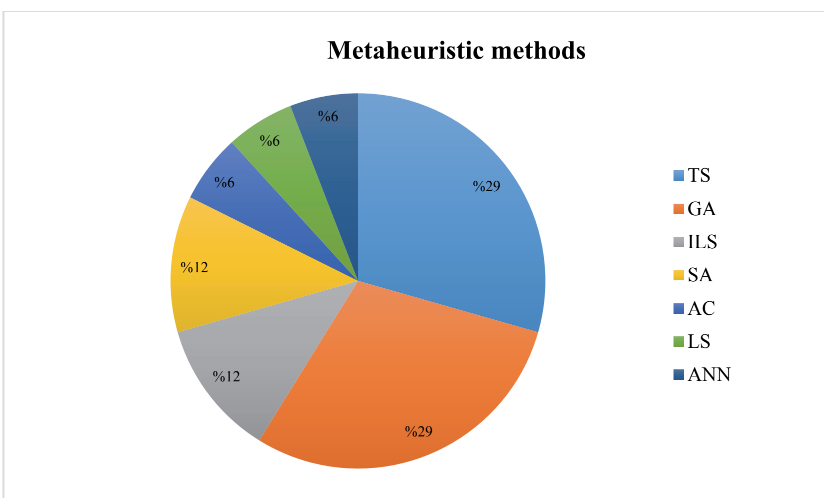

Fig. 9. Distribution of solution metaheuristic methods

Table 5
Relationship between metaheuristic methods and authors

Method	Authors
TS	Otto et al. (2017); Yang et al. (2017); Yang et al. (2015); Chen et al. (2011); Chen et al. (2010).
GA	Ene et al. (2016); Li et al. (2016); Pan et al. (2015); Carlo and Giraldo (2012); Ene and Öztürk (2012).
ILS	Guerriero et al. (2015); Guerriero et al. (2013).
SA	Atmaca and Ozturk (2013); Kim and Smith (2012).
ANN	Cruz-Domínguez and Santos-Mayorga (2016).
AC	Wang et al. (2016).
LS	Quintanilla et al. (2015).

Pan et al. (2015) applied *GA* to solve storage allocation in a pick-and-pass system with multiple collectors to determine the appropriate storage space for each product and to balance the workload of each selection zone. On the other hand, Cruz-Domínguez and Santos-Mayorga (2016) presented a system based on *ANN* and *GA* for the allocation of storage based on certain inputs to minimize the distances of preparation of orders. Guerriero et al. (2013) developed a model based on *ILS* to solve the assignment of storage locations with multiple levels and compatibility restrictions efficiently. In addition, Kim and Smith (2012) solved the storage allocation problem using *SA*, based on the correlated exchange to minimize the travel time for order preparation. Finally, Chen et al. (2010) used *TS* to reduce travel time in an automated storage system.

3.2.4. Simulation

Regarding simulation, the most used criterion to model the *SLAP* in the reviewed literature was based on discrete events (*DE*). There have also been efforts to apply agent-based simulation (*AB*). Fig. 10 shows the percentages of use of simulation-based methods within to the 14 publications in this category. In general, simulation has been used to examine the behavior of different policies and to compare different configuration options for storage operations based on the preparation of orders. The wide use of discrete event simulation over a period of 10 years is remarkable, although the most recent applications have been focused on agent-based simulation. Table 6 shows which authors have designed solutions based on simulation.

Table 6
Relationship between simulation methods and authors

Method	Authors
DE	Pan et al. (2015); Qin et al. (2015); Fontana and Cavalcante (2014); Gagliardi et al. (2014); Fumi et al. (2013); Glock and Grosse (2012); Pan et al. (2012); Webster et al. (2012); Chan and Chan (2011); Yang (2008); Le-Duc and de Koster (2005)
AB	Elbert and Müller (2017); Franzke et al. (2017); Gagliardi et al. (2012)

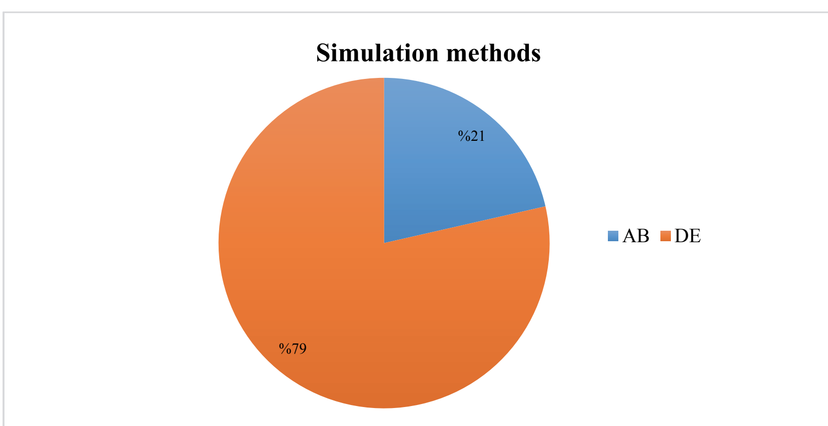

Fig. 10. Distribution of simulation methods

Franzke et al. (2017) used agent-based simulation to evaluate the effects of storage and routing allocation on the operational performance of manual processes for order picking. In addition, Gagliardi et al. (2014)

proposed the use of discrete event-based simulation to compare distance traveled according to different storage allocation policies in an automated environment. Finally, Yang (2008) used discrete simulation to evaluate the behavior of the system, considering different storage policies and order preparation.

3.2.5. Policies and Rules

The policies used in the analyzed publications were: class-based (*CB*), cube order per index (*COI*), correlation-based assignment (*CoB*), full turnover-based storage (*TOB*), random-based (*RB*), shared-based (*SB*), dedicated storage (*DSP*), closest-open location (*COL*), duration-of-stay based (*DSB*), and frequency-based (*FB*). In addition, rules such as horizontal assignment (*HA*), vertical assignment (*VA*), lower and upper assignment (*ULA*) or fuzzy rules (*FR*) have also been used. Newer proposals are also appearing, such as rearrange-while-working (*RWW*), autonomous cell based (*ACB*), and energy consumption based (*EB*). Fig. 11 shows the percentages of use of storage policies and rules in the 25 relevant publications from the reviewed literature.

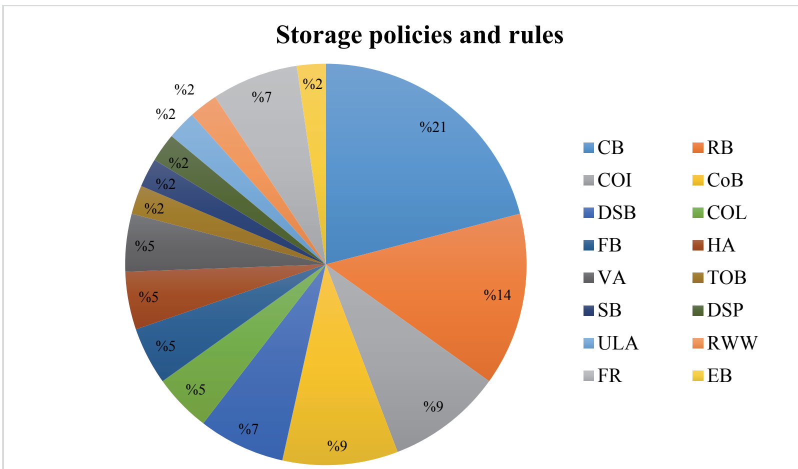

Fig. 11. Distribution of storage policies and rules

The most-used policies have been *CB* and *RB*; it is observed that they have been frequently used as points of comparison to validate the performance of other methods. There have also been important contributions to the literature based on consideration of *COI* and *CoB* policies. Table 7 shows which authors have developed solutions based on storage policies and rules.

Table 7
Relationship between storage policies and authors

SP&R	Authors
CB	Ene et al. (2016); Qin et al. (2015); Sharma and Shah (2015); Fontana and Cavalcante (2014); Meneghetti and Monti (2014); Zaerpour et al. (2013); Ene and Öztürk (2012); Kovács (2011); Le-Duc and de Koster (2005)
COI	Fontana and Cavalcante (2014); Kovács (2011); Rai and Ettam (2016); Xiao and Zheng (2010)
CoB	Glock and Grosse (201(2); Bindi et al. (2009); Hsieh and Tsai (2006); Ho and Liu (2005)
TOB	Yu and de Koster (2013)
RB	Ene et al. (2016); Meneghetti and Monti (2014); Zaerpour et al. (2013); Fumi et al. (2013); Gagliardi et al. (2012); Glock and Grosse (2012)
DSB	Meneghetti and Monti (2014); Meneghetti and Monti (2013); Chen et al. (2010)
COL	Gagliardi et al. (2012); Qin et al. (2015)
HA	Sharma and Shah (2015); Glock and Grosse (2012)
VA	Sharma and Shah (2015); Glock and Grosse (2012)
SB	Chen et al. (2010)
ULA	Glock and Grosse (2012)
DSP	Fumi et al. (2013)
FB	Hsieh and Tsai (2006); Yang (2008)
RWW	Carlo and Giraldo (2012)
ACB	Rai and Ettam (2016)
FR	Choy et al. (2017); Lam et al. (2009); Cheung et al. (2009)
EB	Meneghetti and Monti (2014)

Particularly relevant studies include Sharma and Shah (2015), who designed a storage allocation solution based on classes and volume, and Meneghetti and Monti (2014), who designed a new storage policy based on energy efficiency. Other authors, such as Yu and de Koster (2013), have adapted classic storage allocation models focused on optimizing travel time to a sales volume policy. On the other hand, Zaerpour et al. (2013) analyzed the impact on the travel time performance of the warehouse form and random allocation policies, based on classes and rotation. Xiao and Zheng (2010) studied the correlated storage allocation policy in a multi-block and aisle warehouse, considering the information of the production area. In addition, Bindi et al. (2009) addressed the correlated allocation strategy through the development and testing of a set of different rules, based on grouping techniques. Finally, Ho and Liu (2005) determined the locations of articles in each zone using rules based on correlated storage.

3.2.6. Multi-criteria Methods

The multi-criteria techniques reviewed have been used to propose alternative solutions based on the behavior of and interaction between different criteria focused on specific attributes of the warehouse. The documented methods are *Electre III (ELT)* and *Smarter (SMT)*. We identified two articles within this category, and Table 8 identifies their authors.

Table 8
Relationship between multi-criteria methods and authors

Method	Authors
ELT	Fontana and Nepomuceno (2017).
SMT	da Silva et al. (2015).

As can been seen, research classified in this category has been limited to Fontana and Nepomuceno (2017), who designed an allocation model using *Electre III* based on product characteristics in a multilayer warehouse seeking to improve order preparation time and inventory control, and da Silva et al. (2015), who provided a multicriteria methodology based on *Smarter* that allows the classification of products and assigns them in the warehouse in descending order from the best to the worst location options for each product.

3.2.7. Other solution trends and support tools

With regard to other trends and support tools, these have been focused principally on technology and information tools (*ITT)* based on the cloud (*CdB*), data mining (*DM*), radio-frequency identification (*RFID*), and online analytical processing (*OLAP*). Fig. 12 shows the percentage of use for these various trends and support tools within the reviewed literature. The most-used method has been data mining; some studies have also proposed integrated solutions with *RFID*. Table 9 shows which authors have addressed these other trends and support tools within the eight relevant publications found.

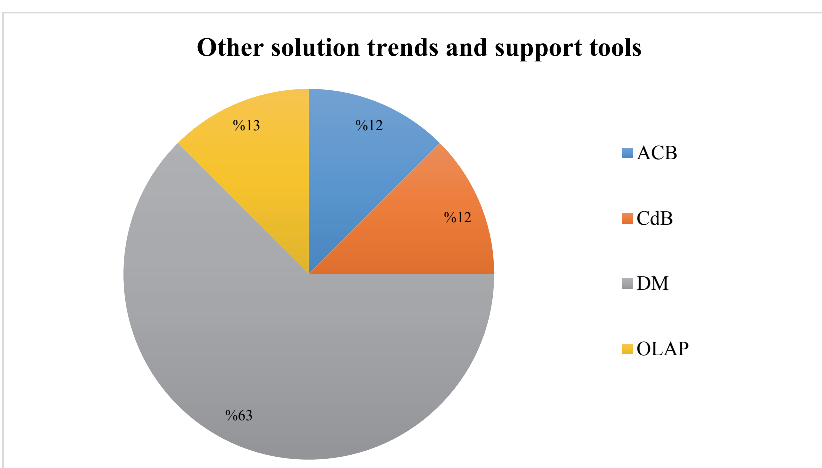

Fig. 12. Distribution of other solution trends and support tools

Table 9

Relationship between other solution trends and authors. Source: the authors

Method	Authors
DM	Pang and Chan (2017); Hui et al. (2016); Li et al. (2016); Ming-Huang et al. (2014); Chiang et al. (2011).
RFID	Choy et al. (2017); Cheung et al. (2009).
CdB	Hui et al. (2016).
OLAP	Lam et al. (2009).

Of particular note are Pang and Chan (2017), who designed a storage allocation algorithm based on data mining that considers the correlation between products to minimize the distance traveled to store and retrieve products. Choy et al. (2017) presented a *DSS* designed as an intelligent system, based on *RFID* and fuzzy logic. In addition, Hui et al. (2016) presented a system for decision-making that applies *CdB* infrastructure and fuzzy logic to the allocation of locations in the food-packaging industry. Finally, Lam et al. (2009) developed an intelligent system based on *OLAP* and fuzzy rules to increase the availability of data and integrate human knowledge into a system to address storage location decisions.

3.3. Performance Measures

In this section, the variables optimized in the literature are presented and classified in accordance with the proposed methodology. Fig. 13 shows the organization of the relevant categories, and Fig. 14 shows the distribution of use for each category according to the number of times it was applied within the research analyzed for the present review.

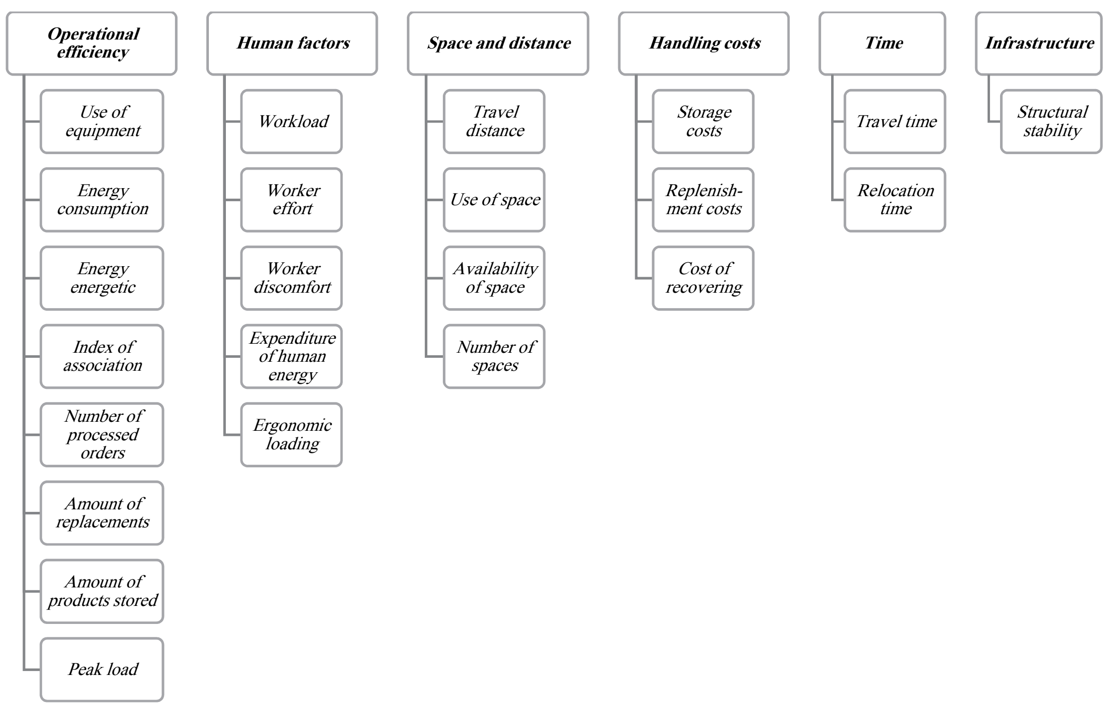

Fig. 13. Classification of performance measures

The category of *operational efficiency* includes variables focused on improving the use of resources within the storage system; for this reason, the use of equipment, energy consumption, the association index, the number of orders processed, the number of replacements, and the maximum load are considered. On the other hand, the *space and distance* category include variables related to the use of the area and storage capacity, *e.g.*, locations and travel, as well as space use and availability, the number of locations, and the travel distance.

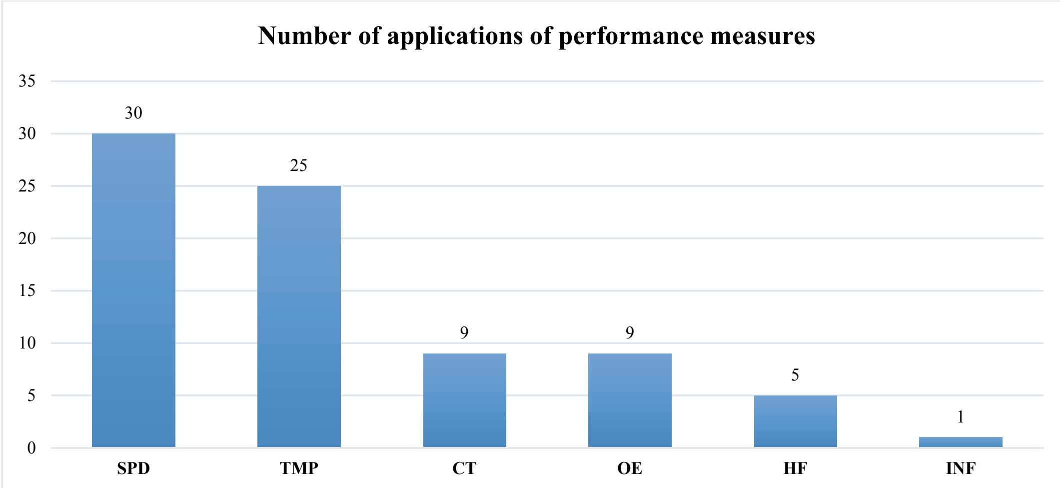

Fig. 14. Distribution of performance measures

Within the *time* category, measurements of chronological duration for certain operations are summed; for example, travel time, picking time, and relocation time. The *human factors* category includes variables focused on workers and related activities; for this reason, they include workload, effort, discomfort, and energy used by the workers. The *infrastructure* category includes variables focused on resistance issues and geological conditions in the operations center, including structural stability. Finally, the *cost* category is related to monetary measures, including costs of storage, replenishment, and recovery. Table 10 presents the performance measures according to their category and optimization approach, either maximized *(Max)* or minimized *(Min)*, and the authors who used them.

Within the literature reviewed, the variables most used to optimize the *SLAP* were *travel distance* and *travel time*, with usage percentages of 38% and 32%, respectively. We would emphasize that travel time has only begun to be studied since 2008, and travel distance since 2005. Since 2015, variables related to *human factors* and *infrastructure* have also begun to be considered, adding a new focus on operational optimization objectives. Moreover, there is an emerging interest in conducting studies focused on other measures of operational performance, such as consumption and energy efficiency, in addition to the use of order-picking equipment. Some studies have preserved the classical approach of optimizing measurements related to distance and time. For example, Li et al. (2016) developed an optimization mechanism based on *DM* and *GA*, considering the affinity of products to optimize the distances traveled to store and retrieve products. Battini et al. (2015) presented a procedure for storage allocation and travel distance estimation that provides guidelines for choosing the design of the warehouse and improving operational efficiency by minimizing the quantity of travels. Other authors have sought to introduce new performance measures, such as Chiang et al. (2011), who proposed a *DM*-based model to improve order-picking efficiency and, moreover, introduced the association index *(AIX)* to evaluate the appropriateness of storage locations for products. On the other hand, in recent years, some authors have developed new approaches based on environmental sustainability and human factors. These include Ene et al. (2016), who considered the minimization of energy consumption in manual warehouses through a model based on GA, and Battini et al. (2016), who investigated the problem of storage allocation in manual selection systems, considering human energy expenditure and order processing time. Finally, Bortolini et al. (2015) proposed the introduction of structural stability as a measure of performance in areas of high seismicity.

Table 10
Approaches and authors of performance measures

Category	Performance measure	Approach Min	Max	Authors
Operational efficiency	Use of equipment		√	Wang et al. (2016).
	Energy consumption	√		Ene et al. (2016).
	Energy efficiency		√	Meneghetti and Monti (2014).
	Index of association		√	Chiang et al. (2011).
	Number of orders		√	Franzke et al. (2017).
	Amount of replacements	√		Bodnar and Lysgaard (2014).
	Peak load	√		Chen et al. (2011); Chen et al. (2009).
Space and distance	Travel distance	√		Choy et al. (2017); Dijkstra and Roodbergen (2017); Fontana and Nepomuceno (2017); Pang and Chan (2017); Cruz-Domínguez and Santos-Mayorga (2016); Li et al. (2016); Battini et al. (2015); da Silva et al. (2015); Qin et al. (2015); Sharma and Shah (2015); Wutthisirisart et al. (2015); Fontana and Cavalcante (2014); Ming-Huang Chiang et al. (2014); Gagliardi et al. (2014); Boysen and Stephan (2013); Ang et al. (2012); Carlo and Giraldo (2012); Chuang et al. (2012); Chan and Chan (2011); Xiao and Zheng (2010); Bindi et al. (2009); Pan and Wu (2009); Hsieh and Tsai (2006); Le-Duc and de Koster (2005); Ho and Liu (2005).
	Number of products stored		√	Webster et al. (2012).
	Use of space		√	Guerriero et al. (2015); Cheung et al. (2009).
	Availability of space		√	Quintanilla et al. (2015).
	Number of spaces	√		Fumi et al. (2013).
Human factors	Workload	√		Pan et al. (2015).
	Worker effort	√		Fontana and Nepomuceno (2017).
	Worker discomfort	√		Larco et al. (2017).
	Expenditure of human energy	√		Battini et al. (2016).
	Load ergonomics	√		Otto et al. (2017).
Handling costs	Storage costs	√		Zhang et al. (2017); Atmaca and Ozturk (2013); Guerriero et al. (2013); Gu et al. (2010); Lam et al. (2009); Manzini (2006); Heragu et al. (2005).
	Replenishment costs	√		Walter et al. (2013); Gu et al. (2010).
	Cost of recovery	√		Zhang et al. (2017); Atmaca and Ozturk (2013); Guerriero et al. (2013); Chou et al. (2012); Gu et al. (2010); Lam et al. (2009); Manzini (2006); Heragu et al. (2005).
Time	Travel time	√		Elbert and Philipp Müller (2017); Yang et al. (2017); Hui et al. (2016); Rai and Ettam (2016); Ramtin and Pazour (2015); Yang et al. (2015); Gagliardi et al. (2014); Grosse et al. (2013); Meneghetti and Monti (2013); Yu and de Koster (2013); Zaerpour et al. (2013); Accorsi et al. (2012); Ene and Öztürk (2012); Glock and Grosse (2012); Kim and Smith (2012); Chen et al. (2010); Yang (2008).
	Relocation time	√		Chen et al. (2011).
	Order cycle time	√		Larco et al. (2017); Battini et al. (2016); Pan et al. (2012); Chan and Chan (2011); Kovács (2011); Lam et al. (2009).
Infrastructure	Structural stability		√	Bortolini et al. (2015).

3.4. Constraints and Considerations

Fig. 15 shows the distribution of observations for each category of approach in the analyzed publications according to the classification scheme presented in section 2.3. The most important category has been the capacity and physical conditions of the warehouse, which are related to the physical dimensions of the locations and distribution of the storage area. In addition, we note that the demand and the characteristics of products have an interesting impact on storage allocation. Finally, it is observed that the logistics resources and configurations of the operations have been the least considered aspects within the analyzed literature.Within the publications related to product characteristics, the terms *correlation*, *compatibility*, and *association* are recurrent. *Correlation* refers to the physical characteristics that certain products share, enabling them to be grouped together in the same set. *Compatibility* refers to the characteristics considered between product and locations to execute storage allocation. Finally, *association* refers to the abstract relationship between certain product references given by variables such as turnover or sales volume. Table 11 shows how different authors have approached each category.

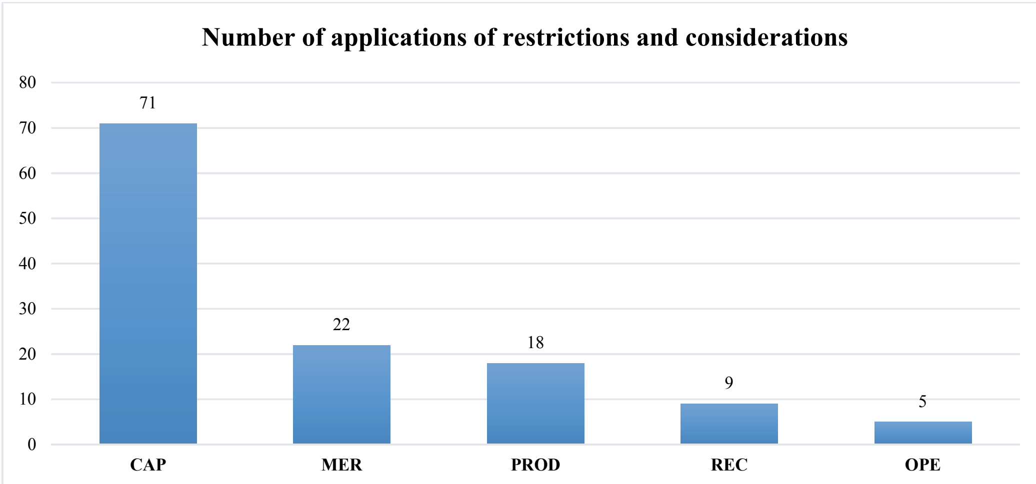

Fig. 15. Distribution of restrictions and considerations

Table 11
List of authors and SLAP considerations

Category	Restrictions and considerations	Authors
Capacity and conditions of the warehouse	Locations and assignment	Choy et al. (2017); Dijkstra and Roodbergen (2017); Elbert and Müller (2017); Fontana and Nepomuceno (2017); Franzke et al. (2017); Larco et al. (2017); Otto et al. (2017); Pang and Chan (2017); Yang et al. (2017); Zhang et al. (2017); Battini et al. (2016); Cruz-Domínguez and Santos-Mayorga (2016); Ene et al. (2016); Hui et al. (2016); Li et al. (2016); Rai and Ettam (2016); Wang et al. (2016); Battini et al. (2015); Bortolini et al. (2015); da Silva et al. (2015); Guerriero et al. (2015); Pan et al. (2015); Qin et al. (2015); Quintanilla et al. (2015); Ramtin and Pazour (2015); Sharma and Shah (2015); Wutthisirisart et al. (2015); Yang et al. (2015); Bodnar and Lysgaard (2014); Fontana and Cavalcante (2014); Gagliardi et al. (2014); Meneghetti and Monti (2014); Ming-Huang et al. (2014); Atmaca and Ozturk (2013); Boysen and Stephan (2013); Fumi et al. (2013); Grosse et al. (2013); Guerriero et al. (2013); Meneghetti and Monti (2013); Walter et al. (2013); Yu and de Koster (2013); Zaerpour et al. (2013); Accorsi et al. (2012); Ang et al. (2012); Carlo and Giraldo (2012); Chou et al. (2012); Chuang et al. (2012); Ene and Öztürk (2012); Gagliardi et al. (2012); Glock and Grosse (2012); Kim and Smith (2012); Pan et al. (2012); Webster et al. (2012); Chan and Chan (2011); Chen et al. (2011); Chiang et al. (2011); Kovács (2011); Chen et al. (2010); Gu et al. (2010); Xiao and Zheng (2010); Bindi et al. (2009); Chen et al. (2009); Lam et al. (2009); Cheung et al. (2009); Pan and Wu (2009); Yang (2008); Hsieh and Tsai (2006); Manzini (2006); Heragu et al. (2005); Ho and Liu (2005); Le-Duc and de Koster (2005).
	Seismic conditions	Bortolini et al. (2015)
Characteristics of the products	Association	Ming-Huang et al. (2014); Boysen and Stephan (2013); Guerriero et al. (2013); Chuang et al. (2012).
	Correlation	Kim and Smith (2012); Kovács (2011); Bindi et al. (2009); Manzini (2006).
	Compatibility	Fumi et al. (2013); Ene and Öztürk (2012); Chen et al. (2010).
	Expiration	Hui et al. (2016).
Configuration of the operation	Lots and routing	Ene et al. (2016); Gagliardi et al. (2014); Xiao and Zheng (2010).
	Security	Bodnar and Lysgaard (2014).
	Energy	Ene et al. (2016); Meneghetti and Monti (2013).
Market	Demand, sales and rotation	Fontana and Nepomuceno (2017); Franzke et al. (2017); Pang and Chan (2017); Zhang et al. (2017); Battini et al. (2016); Cruz-Domínguez and Santos-Mayorga (2016); da Silva et al. (2015); Guerriero et al. (2015); Ramtin and Pazour (2015); Atmaca and Ozturk (2013); Grosse et al. (2013); Guerriero et al. (2013); Yu and de Koster (2013); Ang et al. (2012); Chou et al. (2012); Chuang et al. (2012); Kim and Smith (2012); Webster et al. (2012); Chan and Chan (2011); Cheung et al. (2009); Pan and Wu (2009); Yang (2008).
Logistics resources	Equipment and workers	Elbert and Müller (2017); Franzke et al. (2017); Yang et al. (2017); Yang et al. (2015); Grosse et al. (2013); Gagliardi et al. (2014); Pan et al. (2012); Webster et al. (2012); Chen et al. (2010).

Of particular note here is the work by Ming-Huang et al. (2014), which proposed a new measure of association called *weighted support counting* to represent both the intensity and the nature of the relationships between products. Bodnar and Lysgaard (2014) studied the *SLAP* with consideration for the conditions of accessibility and security at the locations. On the other hand, Hui et al. (2016) analyzed the storage allocation decision, considering perishable products in a food company. Finally, Chan and Chan (2011) proposed class-based storage to improve the productivity of order preparation, considering aspects of product demand.

4. Discussion of Trends and Future Research

The complexity of the *SLAP* increases when there are variations in supply and uncertain demand (Ang et al., 2012), which represent new challenges for storage systems in industries sensitive to the globalized market, e.g., food, appliances, and fashion (Hui et al., 2016). In this section, we identify the main trends and suggest future research directions focused on operational sustainability from the perspective of storage assignment. Four main axes guide the discussion: *human approaches*, *configuration of the operation*, *information management*, and *environmental aspects*. Fig. 16 outlines the main research opportunities associated with *SLAP*.

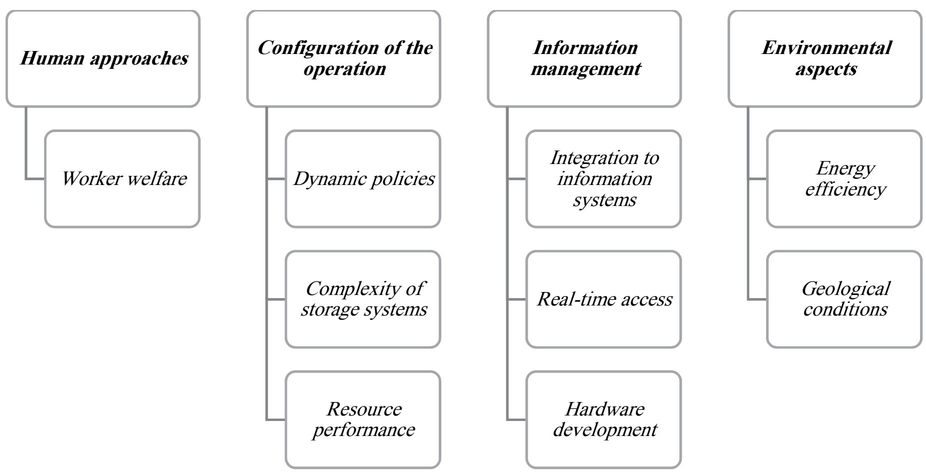

Fig. 16. Research opportunities

Human approaches are projected as one of the main research topics for storage systems in which manual collection predominates, due to problems such as high workloads or imbalances in the use of resources. Efforts should be increased to investigate the long-term relationships between storage allocation decisions that have effects on workers' health, considering factors such as lower-back pain, absenteeism rates, and long-term fatigue (Larco et al., 2017). The expected effects of such research would be improvements in working conditions and increased productivity, aligned with a balance between social and operational aspects.

At the same time, the *operational performance* of a warehouse is influenced by design decisions concerning the operational policy being implemented (Zaerpour et al., 2013). For this reason, trends related to the configuration of the operation should be focused on the design of dynamic policies, the study of the complexity of storage systems, and the optimization of resources aligned with overall system performance. Consequently, it is necessary to design integrated models with considerations such as order volumes, the means of transport used, aisle characteristics, routing policies, and the possible creation of selection waves (Battini et al., 2015). In addition, we propose further study on the relationships between the allocation of location and decisions related to both the design and operation of warehouses (Pan et al., 2015; de Koster et al., 2007), as well as the design of heuristic methods to reduce gaps within complex storage scenarios (Guerriero et al., 2013). Simultaneously, new solution models are needed for the assignment of products to locations, considering different warehouse types and configurations, as well as performance testing for different types of solutions, depending on the configuration of each warehouse (Boysen & Stephan, 2013). On the other hand, it is also important to expand studies on dynamic storage policies in automated systems (Chen et al., 2010).

In terms of *information management*, it is currently observed that the application of data processing technologies such as data mining can effectively support the development of decision-support systems to improve the operational performance of storage systems (Hui et al., 2016; Choy et al., 2017; Lam et al., 2009). However, challenges also arise, such as those involving the integration of decision modules into storage management systems *(WMS)*, real-time access, and hardware development. The importance of designing efficient *ITT* tools to support storage allocation models has been highlighted (Fumi et al., 2013), but we additionally suggest extending the study of storage allocation strategies in other industrial sectors through the adaptation of *DSS* (Bindi et al., 2009) and applying theories and principles of collaborative control to the real-time management of warehouse operations dealing with complex networks of sensors, robots, and humans (Li et al., 2016).

Within the framework of *environmental aspects*, important points of study have included seismic conditions and energy efficiency. For such reasons, we suggest more analysis of configurations and storage policies based on load units, structural stability of storage locations and the influence of geological conditions (Bortolini et al., 2015). Moreover, greater consideration of energy consumption within optimization approaches should contribute to better environmental practices (Ene et al., 2016). In summary, future research on storage allocation should be aimed at developing practical effectiveness models using technological tools to support efficient and balanced decision-making in operational, environmental, and human aspects.

5. Conclusions

This paper presents a systematic literature review on the storage location assignment problem (*SLAP*), applying the methodology proposed by Seuring et al. (2005), in which 71 representative papers published between 2005 and 2017 were classified according to the methods of solution, performance measures, and restrictions or considerations. We found that there is no standard terminology for the *SLAP*, as many authors refer to it with varying labels, such as *product allocation*, *product location*, *reserve allocation*, *space allocation,* or *slotting*. Therefore, we would suggest that the term should be standardized to *storage location assignment problem* (*SLAP*). The solution methods examined in the reviewed literature include classic approaches such as *exact* methods, *heuristic* and *metaheuristic* methods, and *storage policies*; however, recent years have seen other methods being used with greater frequency, including *simulation* and the development of applications based on *ITT*. The main performance measures used for optimization approaches in the reviewed literature were classified as *operational efficiency*, *space and distance*, *time*, *human factors*, and *handling costs*, as well as *infrastructure*. We emphasize that, in recent years, the issue of human factors has been considered within manual recovery systems, recognizing that storage allocation directly affects workers' health. Additionally, issues related to seismic conditions have been considered, with thought toward mitigating the effects of natural disasters through the correct assignment of loads within warehouse infrastructure. Among the most representative considerations of the literature have been those related to the physical capacity of locations and general conditions of warehouses, product characteristics, human factors, market dynamics, logistical resources, and configuration of the operation.

Although there have been a number of contributions on the *SLAP*, we consider the present review to be the most extensive and exhaustive to date. We also highlight the need for more research on the development of management tools that support decision-making through the application of machine-learning tools and hybrid approaches based on artificial intelligence. Considering that this review was limited to academic papers published in peer-evaluated journals, we also suggest that future research should include other types of relevant studies.

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