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REVIEW ARTICLE

A Bibliometric Analysis of Simulation Studies in the Field of Container Logistics Using VOSviewer

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ABSTRACT
Productive and uninterrupted operation of ports and their provision of value-added services to customers have become necessities brought about by competition. A performance measurement tool is needed in ports to ensure that the service ports provide is uninterrupted and productive. Four basic logistics processes occur in container terminals: ship operations, transportation, storage, and handling of containers in the port area. Thus, this study aims to develop a logistics-oriented decision support model that will function as a decision support tool for port management to help in understanding, analyzing, and evaluating a port's logistics structure and port performance indicators for planning port capacity, increasing port productivity, improving intra-port logistics processes, and predicting a port's future needs. This study offers an extensive analysis of the literature on simulating the processes in container terminals using the bibliometric analysis method. The study preforms an in-depth analysis of 51 studies in the Scopus database. The study also performs co-citation and author-keyword analyses on the obtained data with the help of the software program VOSviewer. The study concludes by presenting authors some recommendations based on the analyzed studies.

Keywords: simulation, VOSviewer, container logistics

1. Introduction

The rise in globalization has increased international trade, resulting in a massive surge in logistics activities. Maritime transportation is the preferred mode of transportation due to being simultaneously inexpensive and able to handle large quantities of cargo. The increase in the load on maritime transportation has triggered port operators to seek optimization solutions for container transportation. When considering this, the speed of port processes is seen to be critical for logistics processes to be maintained without interruption. Port management is a complex system where strategic decisions must be made quickly. Management should examine each stage and find the optimal solution in order to keep its profits high, such as improving port services and ensuring sustainability, which assist ports in gaining an advantage over their competitors (Mollaoglu et al., 2023a). The literature on port logistics shows many methods to have been developed to solve the problems experienced in the field of port logistics and container transportation. Articles frequently make use of simulation programs for analyzing these methods. Yun and Choi (1999) mentioned the problems of increasing container trade in Korea. Establishing these new container terminals has made examining flow control and planning to ensure the optimal use of cranes important, and the application of simulation systems will facilitate these efforts (p. 222). When considering the purposes of simulation systems, evaluating alternative ship loading and unloading operations in terms of time and cost, evaluating various storage policies, and evaluating various resource allocation procedures stand out in regard to the management processes of container ports (Bielli et al., 2006, p. 1732). Derse and Göçmen (2018) developed a model for determining the efficient and effective movement of containers in a terminal. The proposed model was analyzed with the help of the Arena computer program. Benantar et al. (2020) presented a set of road and rail transport routes, aiming for the shortest route and lowest service cost. The problem was analyzed with the help of the simulation software AnyLogic. Wang et al. (2023) developed a model to estimate arrival time of export containers and to identify the factors affecting it. Their results showed the accuracy of the proposed model to be 72% (not high/limited). Literature review studies on container terminal simulation studies have been previously carried out. Angeloudis and Bell (2011) conducted a literature review on container terminal simulations and found the literature have classified models. Dragović et al. (2017) examined studies involving the application of simulation models in container ports between 1961-2015. The analyses in both studies were carried out without the assistance of any software

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program. Meanwhile, the current study will utilize the program VOSviewer for its analysis. Other studies have not utilized any particular database, while this study has preferred using the Scopus database. The current study is more recent than other studies in terms of the examined period.

VOSviewer as a bibliometric analysis method provides visualization and easy examination of bibliometric analyses with the VOS mapping technique. Bibliometric analyses follow trends in studies conducted in a particular field and provide a collective analysis of studies. This study analyzes academic studies that have developed simulation methods to produce solutions for container logistics using the VOSviewer mapping technique. VOSviewer is more user-friendly visualization program and offers higher graphical quality than CiteSpace and Bibliometrix (Arruda et al., 2022; Markscheffel & Schröter, 2021). Very robust studies benefitting from the VOSviewer mapping technique are found in the field (see Mollaoglu et al., 2023b; Mollaoglu et al., 2024). The next part of the current study explains and details the methodology before analyzing the methodology results and presenting the conclusions.

2. Methodology

Scopus contains a broader range of content than the Web of Science (WoS) database (Pranckutė, 2021), and the Scopus database has been preferred over the WoS database in bibliometric analyses (Zupic & Čater, 2015). For the current analysis, the article has obtained 515 studies by first searching the Scopus database using the keywords "logistics", "simulation", and "container". The keyword "supply chain" has also been included to further narrow the scope of the search. The results of the search were then limited to English as a language, and in this way, the current research has obtained 299 studies that could be examined in depth. Regarding these 299 studies, Figure 1 shows the annual number of studies by journal. Figure 2 shows the annual number of studies on container logistics simulations from past to present, while Figure 3 presents the list of most published authors in this field.

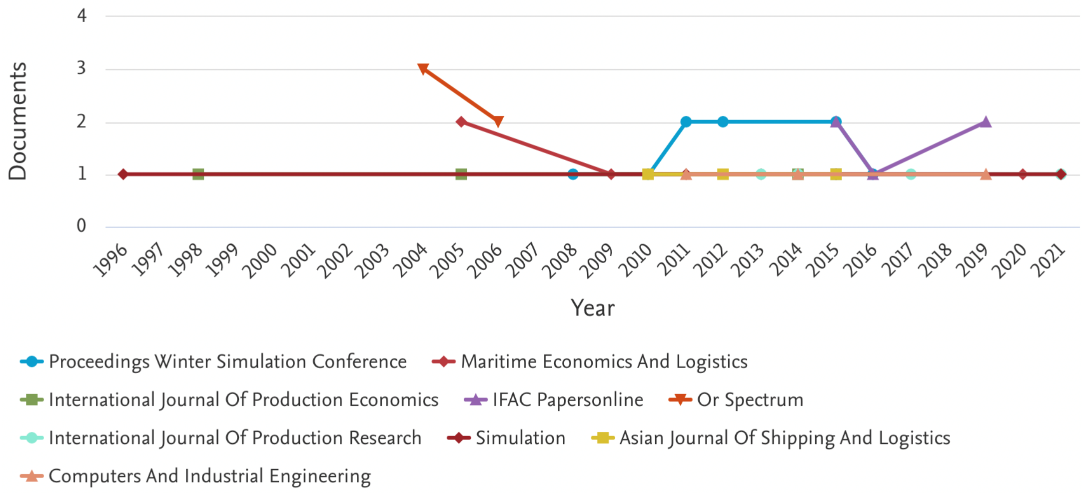

Figure 1. Annual number of studies on container logistics simulations by journal.

Figure 1 indicates the annual number of studies on container logistics simulation by journal. Accordingly, most studies on the subject were published in the *Proceedings of the Winter Simulation Conference* (WSC) between 2011-2015. Studies published in *IFAC-PapersOnLine* gradually increased as of 2016 and reached the same number as *Proceedings of the WSC* in 2019.

As shown in Figure 2, the most studies on container logistics simulations were carried out in 2007, 2009, and 2015. In recent years, the number of studies on the subject has decreased, with the number of studies conducted in 2021 being quite low compared to recent years. This provides an opportunity for researchers to conduct research using simulation models that have started being used in recent years in the field of container logistics.

Figure 3 shows the authors who've published the most studies on the subject. Because these authors also publish studies that may be fundamental to the subject, Figure 3 can facilitate future researchers' ability to find reference works.

In the next step, the study analyzes the Scopus data for these 299 studies using VOSviewer. Among the 6,406 references cited in the co-citation analysis, the minimum number of citations was limited to five in order to facilitate the naming and interpretation of the clusters, with 51 studies being obtained as a result. When examining the 299 studies through an author-keyword analysis for guiding researchers and their future studies, the analysis obtained 738 keywords. When limiting the minimum number of keyword repetitions to three keywords to facilitate the the keyword interpretation, 52 keywords were found. The study determined the 10 most and 10 least used keywords from among these 52.

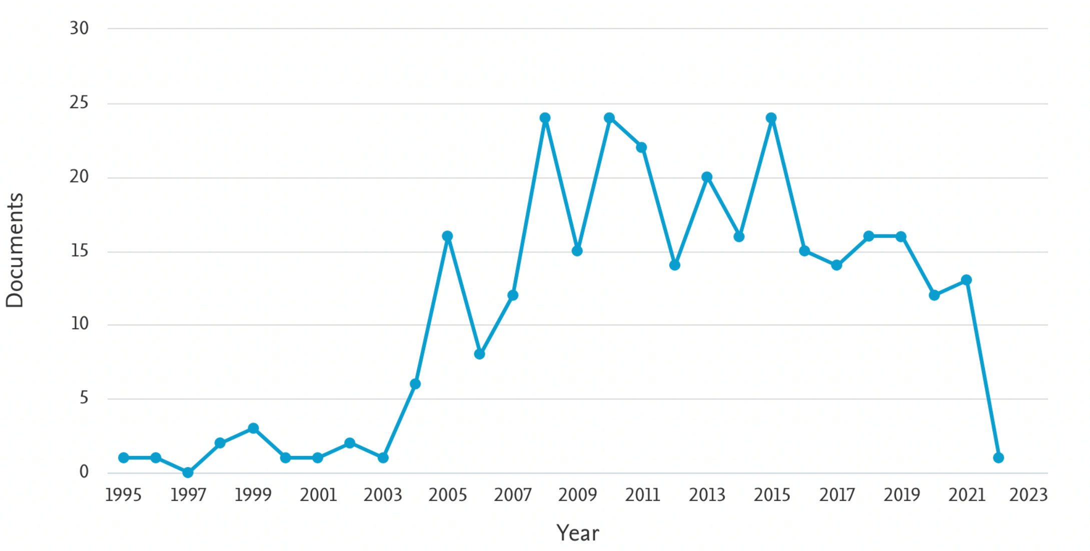

Figure 2. Annual number of studies on container logistics simulations.

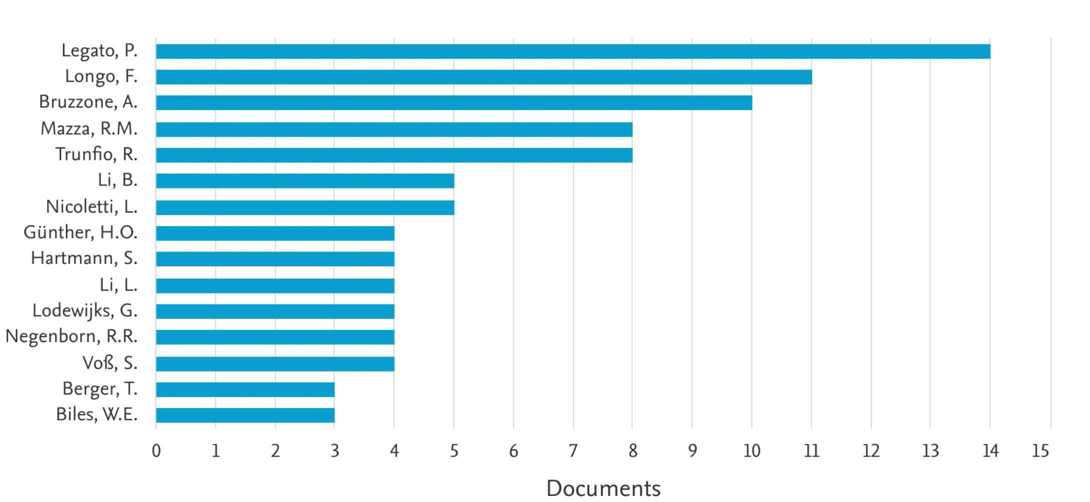

Figure 3. Most published authors of studies on container logistics simulations.

Lastly, the study has interpreted the results of the two analyses. In order to interpret and name each cluster that emerged from the analysis, the study accessed all the articles that had been retrieved from the Scopus database; however, no books were accessible. The study analyzes Clusters A, B, C, and D to interpret and name the cornerstones of container logistics simulation research using a co-citation analysis (See Section 3.1). Clustering was not applied in the author-keyword analysis. Among the 52 keywords that emerged from the analysis, article mentions the 10 most and 10 least popular keywords (See Section 3.2).

Co-citation analysis aims to measure the relationship between citing and cited studies. Both types of documents should be cited as a pair over many reference works to obtain a robust measure of co-citation. Once the studies to be used as references are published, the co-citation frequency of the two documents changes over time (Baker, 1990, p. 7). Two journals that cite the same work is called bibliographic coupling. The number of identical and different studies cited by two journals reflects the strength of bibliographic coupling (Small & Koenig, 1977, p. 278). The current research has considered the studies of Van Eck and Waltman (2010) and Boyack and Klavans (2010) for the co-citation analysis and bibliographic coupling analysis. This study also performs an author-keyword analysis so that future researchers can explore and head toward less studied areas in the literature. Al-Emran et al. (2020) showed the gaps in the field. In addition, no literature review has been found on container logistics simulation research.

The study uses VOSviewer to create and visualize bibliometric networks. Authors can use this program to reveal the co-citation, bibliographic coupling, author-keyword, or co-authorship relations of published studies.

3. Findings

3.1. The Cornerstones of Container Logistics Simulation Research

Figure 4 shows the bibliographic network and cornerstones of container logistics simulation research based on the co-citation analysis. This articles' examination of all studies has obtained a total of 6,406 cited references. To facilitate the naming and interpretation of clusters, the study has limited the minimum number of citations to five and obtained 51 studies as a result. This was done to facilitate focusing on the important studies during the research. The larger clusters in Figure 4 indicate studies being cited more than those in smaller clusters. Studies relatively close to each other are more likely to be co-cited than studies far apart.

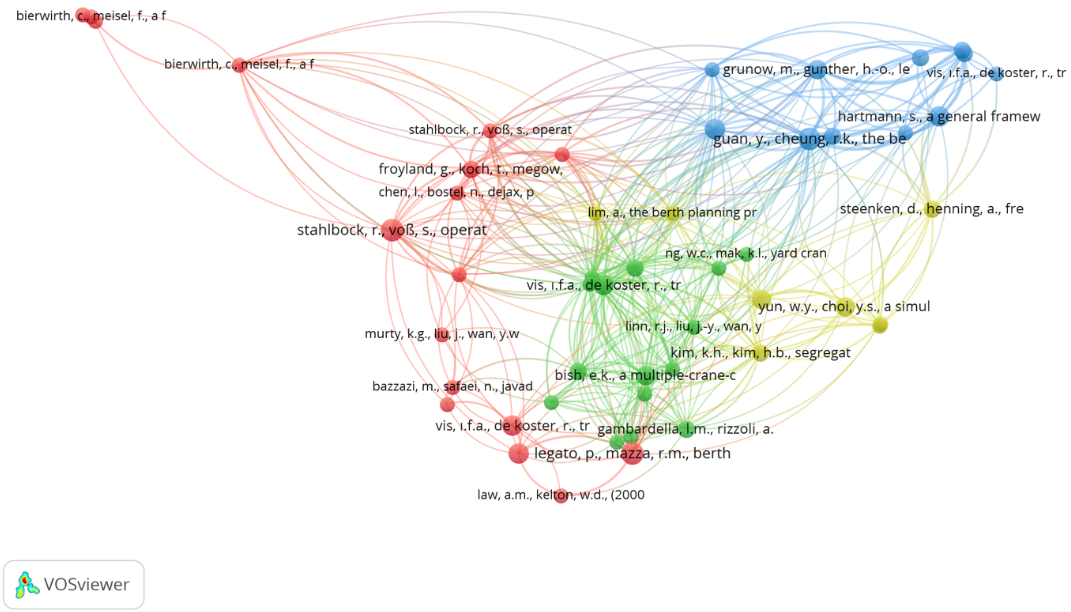

Figure 4. Bibliographic network based on co-citation analysis on container logistics simulation.

For the four clusters seen in Figure 4, red represents Cluster A, green represents Cluster B, blue represents Cluster C, and yellow represents Cluster D. The clusters are named as follows: Cluster A is crane scheduling, Cluster B is container operations processes, Cluster C is vehicle problems, and Cluster is port operations. Figure 4 shows that Cluster B is in the middle of the visual map in relation to the other clusters. Clusters A and D are also related to all the other clusters, while Cluster C is only related to Clusters B and D more than Cluster A.

3.2. Cluster Analyses

3.2.1. Cluster A: Crane Scheduling

Cluster A contains 17 articles, of which only 15 were subjected to a detailed analysis because one study appeared twice in the cluster, and the content of another study could not be accessed. Based on the articles in Cluster A, four main research areas were determined: overview, container loading and unloading, ship berthing and storage processes, and terminal productivity. The authors of these articles are seen to have focused more on container loading and unloading and ship berthing and storage.

With regard to the first research area (i.e., overview), Bierwirth and Meisel (2015) aimed to examine recent studies on berth allocation, quay crane assignment, and quay crane scheduling problems encountered in port container terminals. Stahlbock and Voss (2008) addressed studies examining the methods applied in sea container terminal operations. Steenken et al. (2004) defined and classified container terminals' main logistics processes and operations. Vis and De Koster (2003) examined the literature on various decision problems experienced in container terminals and made a classification.

With regard to the second research area (i.e., container loading and unloading), Bierwirth and Meisel (2009) proposed a heuristic solution to the scheduling problem of quay cranes used to load and unload containers in port terminals. When comparing the proposed heuristic method with the other algorithms in the literature, the proposed heuristic method produced much more effective solutions in a much shorter working time. Legato et al. (2010) proposed a simulation model on a container ship's unloading and loading process with multiple quay cranes and shuttle vehicles moving back and forth from the quay to the yard and back. The simulation model was concluded to encourage research efforts toward optimizing logistics activities from the terminal yard. Zeng and Yang (2009) developed a method for scheduling container loading and unloading operations. They used ARENA 7.0 and Microsoft Visual Basic 6.0 to create the simulation model. Based on their numerical tests, they demonstrated the proposed method to be able to provide an efficient solution to the problem.

Froyland et al. (2008) presented an algorithm to solve the problem of operating a site serviced by more than one semi-automatic rail-mounted gantry crane (RMG). The algorithm provided an efficiency increase of more than 8% for site operations using an RMG. Kemme (2012) offered a simulation model for the problem of the effects of crane systems and yard block layouts on the strategic decisions of RMG storage areas in seaport container terminals. Kemme created the simulation model using Tecnomatix Plant Simulation v8.2, and the proposed simulation model showed better performance than other models. Ng (2005) proposed a solution to the problem of scheduling more than one yard crane to minimize total wait times. The proposed solution decreased the total wait time by 7.3% and increased performance.

For the third research area (i.e., ship berthing and storage processes), Legato and Mazza (2001) presented a queuing network simulation model for ships' arrival, berthing, and departure processes in a container terminal. They used the Visual SLAM software language for the simulation model. The proposed model was shown to be an effective method for decision-making in the container terminal, and the tests proved to be satisfactory. Murty et al. (2005) examined daily operation decisions for optimizing ships' berthing times, the resources required for handling the workload, the waiting times for customer trucks, and congestion on the roads and at the storage blocks and docks inside the terminal, as well as how to use the storage space most efficiently. Bazazi et al. (2009) aimed to present an efficient genetic algorithm (GA) as a solution to the storage space allocation problem (SSAP), which is described as the temporary allocation of incoming and outgoing containers to storage blocks to optimize container storage times. Their results showed a relative gap of approximately 5% between the GA and the optimum solution in the context of the objective function. Petering and Murthy's (2009) simulation study aimed to show how a terminal's long-term average quay crane rate depends on the length of the storage blocks in the terminal's container yard and the system for using shipyard cranes among the blocks in the zone. They created their simulation model using Microsoft Visual C++ 6.0. The results indicated the highest quay crane work rate to have been achieved by a block length of 56-72 20-ft slots, as well as a higher quay crane work rate to be achieved by a yard crane deployment system restricting crane movement compared to a system allowing greater yard crane mobility.

With regard to the fourth research area (i.e., terminal productivity), Chen et al. (2007) developed a model to improve coordination among container handling equipment in marine terminals in order to increase terminal productivity. The model was shown to perform better in terms of solution quality and efficiency when the problem size was increased.

3.2.2. Cluster B: Container Operations Processes

Cluster B contains 15 articles. Based on the articles included in Cluster B, four main research areas have been determined: overview, container operations, cost reduction, and port operations. The authors in this cluster are seen to have focused more on container and port operations.

For the first research area (i.e., overview), Gambardella et al. (1998) aimed to show how they could use operations research techniques to create resource allocation plans that can support terminal managers regarding management strategy. They examined the Contship La Spezia container terminal in Italy as a case. Vis and De Koster (2003) examined the literature on various decision problems experienced in container terminals and made a classification.

For the second research area (i.e., container operations), Bish (2003) dealt with the multi-crane constrained vehicle scheduling and location (MVSL) problem. Bish proposed a method for determining a storage location for each unloaded container, for conducting the loading and unloading operations to minimize the time, and for dispatching containers and vehicles. The proposed method yielded quite effective results for 500 or more containers. Cheung and Chen (1998) proposed a stochastic model that aims to help ship operators allocate their empty containers effectively, thereby reducing leasing costs and inventory levels in ports. The proposed stochastic model yielded better results than other deterministic models.

Crainic et al. (1993) aimed to propose a model to dispatch empty containers of appropriate types based on customer demands and to reposition other containers to storage depots or ports in line with future demands. Their results showed the proposed model to be effective. Kim and Park (2003) proposed a method aimed at attaining maximum productivity in loading operations by pre-allocating storage areas for incoming containers. Their proposed method was seen to use less space than other methods. Kim and Kim (1999) presented an algorithm that aims to minimize the container handling time of a straddle carrier (SC) by optimally determining the order in which the SC will receive its containers and the number of containers it will receive in each go. Their results showed the algorithm to yield productive results. Kim and Kim (2003) also proposed another algorithm aimed at minimizing total container handling time by determining the route of a single quay crane and yard-side equipment (straddle carriers or transfer cranes). Their proposed algorithm also yielded good results.

For the third research area (i.e., cost reduction), Kim et al. (2003) aimed to test various sequencing methods to ensure that vehicles are optimally sequenced to reduce driver complaints during transfer operations in container yards and to reduce service delay costs. The tested methods outperformed other methods with regard to each purpose. Peterkofsky and Daganzo (1990) aimed to present a method minimizing the delay costs encountered in ports' loading and unloading operations. Their proposed method yielded satisfactory results for up to six ships. With regard to the fourth research area (i.e., port operations), Bruzzone and Signorile (1998) presented a new approach to simulate a congested port terminal, incorporating both ship planning and shipyard layout into the traditional operational model. They created the simulation model using the SIMPACK application developed in C language and ARENA software. Their results gave the best results for a combination of ship planning and layout. Linn et al. (2003) proposed a model for the optimal distribution of yard crane deployment. The model was tested through operational data from a large container yard in Hong Kong, and the analysis demonstrated the model's capacity and potential to minimize crane workload. Ng and Mak (2005) proposed an algorithm for the yard crane scheduling problem to minimize job wait times. Their results showed the algorithm to be able to find the optimal sequence for most problems with realistic dimensions. Park and Kim (2005) presented a method for scheduling berth and quay cranes in port container terminals. The proposed method was the most optimal solution for the quay scheduling problem. Vis et al. (2001) proposed a flow algorithm to determine the number of automated guided vehicles (AGVs) required for semi-automatic container terminals. Their proposed algorithm yielded good results as a result of being a robust time algorithm.

3.2.3. Cluster C: Vehicle Problem

Cluster C contains 11 articles. Based on the articles in Cluster C, three main research areas have been determined: overview, use of AGVs, and port operations. The authors in this cluster are seen to have focused more on the use of AGVs and port operations.

For the first research area (i.e., overview), Steenken et al. (2004) defined and classified the main logistics processes and operations in container terminals. Vis and De Koster (2003) examined the literature on various decision problems experienced in container terminals and made a classification.

Regarding the second research area (i.e., the use of AGVs), Grunow et al. (2004) aimed to develop their proposed approach on AGV dispatching in port container terminals. Their numerical results showed that using AGVs in multi-load mode instead of single load mode would reduce delays and that using AGVs in container ports would increase overall performance. Hartmann (2004a) aimed to present a general framework for the scheduling problems of straddle carriers, AGVs, stacker cranes, and reefer container handling workers in port logistics. The results showed the proposed model to lead to better results than previous models. Hwang and Kim (1998) proposed a new AGV dispatching algorithm that yielded better results compared to previous data. Yang et al. (2004) aimed to present an algorithm to analyze how an increase in the use of automatic lift vehicles (ALVs) instead of AGVs affects automatic container terminals (ACTs). They developed the simulation model using Visual BASIC and showed ALVs to be superior to AGVs as they reduce wait times in buffer zones. Vis and Harika (2004) aimed to examine the effect of using AGVs and ALVs on ship unloading times through a simulation model. They created the simulation model in ARENA 3.5 and showed that AGVs need to be used 38% more than ALVs. ALVs were also determined to be more affordable than AGVs.

With regard to the third research area (i.e., port operations), De Koster et al. (2004) aimed to define a new rule to evaluate the performance of real-time vehicle dispatching rules using three companies' simulation models. Their results showed the proposed rule to perform well. Guan and Cheung (2004) presented a model that aims to minimize the total weighted flow time, which allows more than one ship to be moored per berth and considers ship arrival times. Their results showed the model to be quite effective. Hartmann (2004b) aimed to use the algorithm proposed in the study to summarize which parameters are important for generating realistic and practical scenarios in ports and for calculating scenarios based on these parameters. The proposed algorithm was tested in the HHLA Container Terminal in Altenwerder, Hamburg, Germany, and was very suitable for projects in practice. Kim et al. (2004) developed an algorithm for the load-sequencing problem encountered in ports. Their results showed the proposed algorithm to provide better results than other algorithms.

3.2.4. Cluster D: Port Operations

Cluster D contains eight articles. Based on the articles in Cluster D, three main research areas were determined: cost reduction, port planning, and berth planning. The authors in this cluster are seen to have focused more on automated guided port planning and berth planning.

For the first research area (i.e., cost reduction), Daganzo (1989) aimed to present a solution method to the crane scheduling problem concerning ship turnaround while minimizing total delay costs. The results showed minimized crane idle times, maximized berth throughput, and reduced queuing delays. Peterkofsky and Daganzo (1990) aimed to present a method that minimizes the delay costs encountered in ports' loading and unloading operations. Their proposed method yielded satisfactory results for up to six ships.

Regarding the second research area (i.e., port planning), Kim and Kim (1999) aimed for their proposed model to optimally allocate storage space for export containers, reduce the amount of reprocessing, and increase customer satisfaction. Their model yielded positive results. Legato et al. (2001) presented a queuing network simulation model for ships' arrival, berthing, and departure processes in a container terminal. The proposed model was effective for decision-making in the container terminal, and the tests proved satisfactory. Steenken et al. (1993) aimed to simulate vehicle routing to minimize the roads vehicles use in the port. The study found that simulation with accurate data showed a total savings of 20%-35% in no-load distances, corresponding to approximately 20,000 km a year. Yun and Choi (1999) aimed to develop a simulation model to analyze the container terminal system (CTS) located in Pusan, Korea, which involves container handling, container transfer between equipment, and equipment control. They developed the simulation model using the SiMPLE++ language. Their results indicated the simulation model to be effective and efficient.

As for the last research area (i.e., berth planning), Lim (1998) proposed a new method for the berth planning problem and showed the method to perform well on past test data. Park and Kim (2003) presented a method for scheduling berth and quay cranes in port container terminals. Their proposed method was the most optimal solution for the quay scheduling problem.

3.3. Knowledge Gap

To identify gaps in the literature and to light the way for future researchers, this study has also carried out an author-keyword analysis over 299 studies, with Figure 5 having been formed based on this analysis. Upon examining all the studies, 738 keywords were obtained. To facilitate the process of interpreting the keywords, the minimum number of keyword repetitions was limited to three words, with 52 keywords being obtained as a result of this limitation. This makes identifying gaps that could be addressed in the future easier. In Figure 5, larger clusters indicate the keywords that have been preferred more compared to the smaller clusters. The analysis shows the 10 most repeated keywords to be: simulation, logistics, container terminals, optimization, containers, modeling, ports, container logistics, genetic algorithms, and planning.

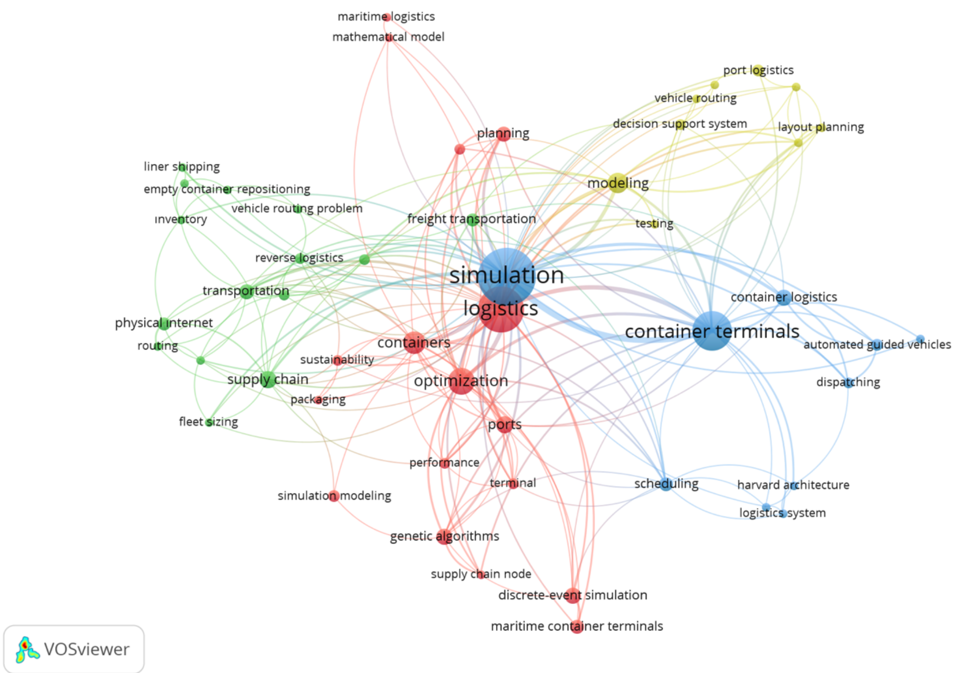

Figure 5. The authors' most frequently mentioned keywords in the context of container logistics simulation research.

4. Conclusion

The previous sections have presented a new systematic research review of 299 studies for container logistics simulation research. Initially, the study determined the bibliographic network and the cornerstones of container logistics simulation research based on a co-citation analysis. To facilitate the naming and interpretation of the clusters, the minimum number of citations was limited to five. The cornerstones were obtained from the 6,406 cited references. As a result, 51 studies were included in the review. The clusters have the following names: Cluster A is crane scheduling, Cluster B is container operations processes, Cluster C is vehicle problem, and Cluster D is port operations. As shown in Figure 4, Cluster B is in the middle of the visual map and is related to the other clusters. Clusters A and D are also related to all the other clusters, while Cluster C is related to Clusters B and D much more than to Cluster A.

Secondly, an author-keyword analysis was carried out, through which 738 keywords were obtained from 299 studies to determine the gaps and future areas of study. To facilitate the process of interpreting the keywords, the minimum number of keyword repetitions was limited to three words, with 52 keywords being obtained as a result. The analysis showed the 10 most repeated keywords to be simulation, logistics, container terminals, optimization, containers, modeling, ports, container logistics, genetic algorithms, and planning. The 10 least popular keywords are simulation analyses, maritime transport, simulation modeling, vehicle routing problems, logistics management, vehicle routing, AGV dispatching, container loading, logistics systems, and mathematical models. The analysis showed the number of studies focusing on simulating container logistics processes to have decreased recently. More research is needed to optimize and improve container logistics processes, as this will keep with more problems from actively increasing with each passing day. This study has scrutinized and revealed the gaps in the field for future researchers.

Discussing all the theoretical concepts put forward by the 299 studies is impossible. Therefore, this review is limited to identifying the theoretical cornerstones and the main discussion trends in the field of container logistics simulations. Furthermore, the study is limited to only the Scopus database. Apart from Scopus, future studies can also use the Google Scholar database.

4.1. Future Research

This study analyzed 51 studies in depth. As a result of these analyses, the study can make the following recommendations to authors who will work in this field in the future. As a result of the heavy materials containers carry and tower cranes working simultaneously, load imbalances can occur on a ship. Therefore, future studies can add stability constraints to their solution models. Crane speed, crane placement location, and cargo storage strategies in container ports can also be analyzed in detail. The container priority constraint can also be added to the solution model of the multiple crane scheduling problem.

In addition to these recommendations, artificial intelligence, machine learning, robotization, driverless vehicles (next generation AGV), blockchain, digital twin, telecommunications (5G), Internet of Things (IoT), the cloud, augmented reality (AR), virtual reality (VR), and big data technologies are developing daily. Future studies can also investigate the impact these technological developments have on efficiency, energy consumption, improving storage areas, reducing dock congestion, reducing workload, loading and unloading times, ship berthing times, dock crane programming, queuing time, and delays in container ports.

4.2. Limitations

This study has preferred Scopus as the database. Future studies could add the Web of Science (WoS), Google Scholar, and Dimensions databases. Also, VOSviewer software programs can be preferred as external programs. The co-citation and author-keyword analyses were made with the help of the VOSviewer visual mapping program. Future studies can perform a bibliographic coupling analysis. Not many studies are found in this field, and thus further studies should be conducted in the future.

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