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The global trends of automated container terminal: a systematic literature review

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Abstract

Purpose – Since the first automated container terminal (ACT) was introduced at Europe Container Terminals Delta Terminal in Port Rotterdam back in the year 1992, a lot of research had been done to improve the management of ACT. However, up until recently, the number of literature available still appeared scarce. Hence, this paper aims to review the collection of literature about ACT to generate an exhaustive summary to answer the formulated review question in this study.

Design/methodology/approach – Preferred reporting items for systematic reviews and meta-analyses to narrow down the search parameters of literature retrieved so that only relevant articles were only selected. The systematic literature reviews were applied to analyse the content of the articles retrieved to determine its journal ranking, research findings and timeline of publications.

Findings – The adoption of ACT technology by container terminal operators could increase the terminal efficiency in productivity, cost reduction and environmental sustainability. Owing to global environmental awareness, the research trend of container terminal field and container terminal operator in the terminal design is much more environmentally friendly oriented.

Research limitations/implications – The limited numbers of experts in the management of ACT are causing challenges in data collections.

Practical implications – The analysis of the global ACT trend could help academicians and industrial investors to review the revolution timeline of maritime technology in port and shipping that is happening rapidly.

Originality/value – The analysis of timeline and collective literature leads to the propose of the conceptual framework to determine the relationship between increased productivity, cost reduction and environmentally sustainable.

Keywords Technology, Systematic literature review, PRISMA, Container terminal, Automated container terminal

Paper type Research paper

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1. Introduction

The rapid economic growth due to global trade is causing the container terminal operator to increase the handling capacity of the terminal; the importance of automated container terminal (ACT) is becoming increasingly prominent due to the fact (Zhao *et al.*, 2019). The dynamicity of the global trade market required the modern-day container terminal to increase their strength in handling the large volume of containers, currently ACT implementation is in the favourite list of Port and shipping Stakeholders (Wang *et al.*, 2019b). The development of ACT speared the new direction of the port industry in the future, it could be considered as the major revolution in port construction; as the first ACT was built at the Port of Rotterdam in Netherland, other countries such as Singapore, German, UK and Japan had successively emulated the strategy of port automation and the commissioning of ACT (Wang *et al.*, 2019b). Figure 1 shows the numbers of the ACT being built every year. Since the year 2012, the development of ACT had been gaining popularity. Until 2017, 30 ACT was built during the time duration, this number makes up 60% of the ACT available worldwide (PEMA, 2016; UNCTAD, 2018).

The construction of ACT requires large capital investment and it would have generated a lot of impacts on the surrounding area. The container terminal operator would have to take a lot of aspects into consideration before decided to build one. Hence, the question to be answered within this study was formulated as follows:

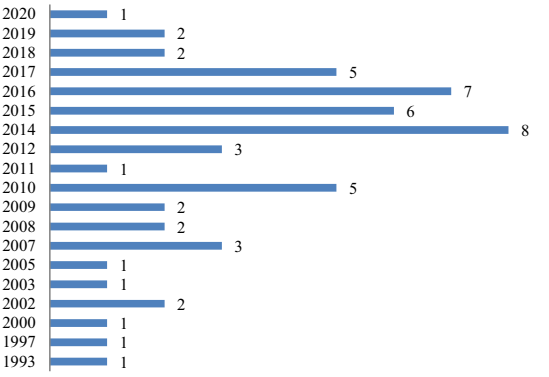
Q1. Why would conventional container terminal adopt the technology of ACT?

In this study, large amounts of literature will be reviewed in an attempt to find the answer to the formulated question. It would enable the understanding of the trending phenomenon that causing the popularity of ACT development. The literature collections will provide the scholar views on the trending phenomenon that will generate the outcome for a contribution towards the future study.

2. Review methodology

2.1 Systematic literature review

Systematic literature review (SLR) was used to review existing literature of scientific topic in a far more objective and organised way; it could be considered as a less biased evidence-



Source: Developed based on data from PEMA (2016), UNCTAD (2018)

Figure 1.
ACT built every year worldwide

based conclusions review methodology that would lead to the gradual adoption and acceptance of theoretical framework (Munn *et al.*, 2018). Conducting SLR is recommended before began research to study the previous research studies and briefly understand the advances made so far in global regarding a particular research topic; SLR could provide answers in more scientific secure conclusions based on large collections of literature (Schünemann *et al.*, 2017). By using SLR, existing literature could have been review more rigorously and transparently through the investigation of studies from various scientific sources; this type of review method is reliable and organised as it could reduce the risk of getting inaccurate conclusions that are too subjective or incomplete (Maynard *et al.*, 2018). One of the notable strength of SLR is that it could provide a summary of massive current literature that noted in detail and ready to be updated and amended based on current research needs; when combined with preferred reporting items for systematic reviews and meta-analyses (PRISMA) proposed by Moher *et al.* (2010), it could assist researchers to report the analyse outcome of reviews systematically through the steps of scoping, planning, identification, screening, eligibility assessment and interpretation of the result. After formulating a review question, SLR is required to seek for the answer through a series of actions such as identification, selections and critical appraisal where it would follow a clearly defined protocol before the review began; the searches of literature would be done comprehensively throughout multiple databases to identify all literature replicated or reproduced to generate a result that could specifically answer the formulated review question (Dewey and Drahota, 2016).

2.2 Setting review criteria

To perform SLR on collected literature, it is necessary to formulate a review question. The formulated question was available in Section 1 based on the problem statement that exists in the current trend of the maritime industry. However, merely the word of mouth and journal articles (UNCTAD, 2018; Wang *et al.*, 2019a; Zhao *et al.*, 2019) were genuinely insufficient to justify the necessity to carry out the study. Hence, it was decided then to identify the criteria that would function as a beacon to perform the review. In this study, the criteria would be originated from a scholar who is well experienced in the research field of maritime studies. After reading a series of literature, it was found that the publication in 2017 titled *The Future of Port Logistics: Meeting the Challenges of Supply Chain Integration* by *Professor Theo Notteboom* and *Kris Neyens* critically mentioned several criteria that would contribute to the answer of formulated review questions. Table 1 below shows the detail of the identified criteria within the publication.

Content identified as criteria	Page
. . . Companies will have no choice but to perform in the most **environmentally sustainable** way possible; one because the political and legislative will is inexorably driven that way; two because the consumers want it and three because reducing waste and fuel **reduces cost** . . .	26
. . . Differentiation and **cost optimisation** can be achieved through improved online customer experience and automation . . .	38
. . . To this extent companies must further invest and focus on **tackling** the most pressing **challenges** of port infrastructure such as spatial constraints and the pressure on **productivity** . . .	78

Source: Notteboom and Neyens (2017)

Table 1. Identified criteria to answer the review question

2.3 Systematic literature review framework design

Figure 2 shows the process steps of SLR with PRISMA integration to review the articles searched in this study. The framework contained the integration of the SLR review process (Dewey and Drahota, 2016; Maynard *et al.*, 2018; Munn *et al.*, 2018; Schünemann *et al.*, 2017) and the PRISMA framework proposed by Moher *et al.* (2010). The designed framework would provide a graphical view of how the review process was carried out towards the findings of results.

Based on Figure 2, the review started with the formulation of the review questions that serve as a primary focus within this study. A formulated question defined protocol or plan where the criteria are clearly stated before the review will be conducted (Dewey and Drahota, 2016). In this study, the question formulated attempts to find out why Conventional Container Terminal would adopt the technology of ACT.

The next process of the review methodology was begun by setting the review criteria for the upcoming articles searching process. The setting of selected search criteria will determine the inclusion and rejection of searched studies in literature searching to answer the formulated review question by minimizing selection bias as minimum as possible (Piper, 2013). In this study, the search criteria were based on the content retrieved from *The Future of Port Logistics: Meeting the Challenges of Supply Chain Integration* by *Theo Notteboom* and *Kris Neyens* that was published in 2017.

Upon the complete set of review criteria, the search of the literature was begun. The upcoming four stages will be regarded as the process of PRISMA that was mentioned in Section 2.1. PRISMA was regarded as an evidence-based minimum set of items to assist the researcher in reporting the systematic review and meta-analyses that had evaluated collected research studies and literature (Moher *et al.*, 2010).

The first stage of PRISMA was the identification of articles journals. At this stage, articles from various journals will be retrieved from the search database such as Science Direct, Springer Link, Taylor and Francis Online, Web of Science, SCOPUS and Emerald Insight. There were 1,819 articles journals in total that were retrieved from the mentioned databases.

The second stage of PRISMA was the screening of articles journals. The articles identified in stage one was examined thoroughly to exclude the duplicated articles of the same titles that were available in multiple search databases. Upon the finish exclusion of duplicate articles, the articles that were unrelated to the ACT research scope were removed as well. At the end of this stage, there were 1,303 articles in total were excluded and 516 articles in total were screened and remain.

The third stage of PRISMA would be the process of articles reviewing. In this stage, the article review would be reviewed in an attempt to retain those articles were eligible for further review later. The articles that were retained at this stage would be those which were discussed about the outcome of ACT technology adoption in container terminal such as productivity, cost and environmental. This stage would use the criteria that were mentioned in Section 2.2. The stage concluded with the exclusion of 293 articles and only 223 articles remained.

The fourth stage of PRISMA would the identification of findings. This stage would identify the articles that mentioned the findings of AC adoption in the container terminal. The articles that achieved the findings associated with the adoption of productivity, cost and environment would be valuable for further review later on. Like the previous, stage criteria of Section 2.2 were also used in this stage to narrow down the review. Towards the end of the PRISMA, there were 46 articles in total were removed and 177 articles in total were retained.

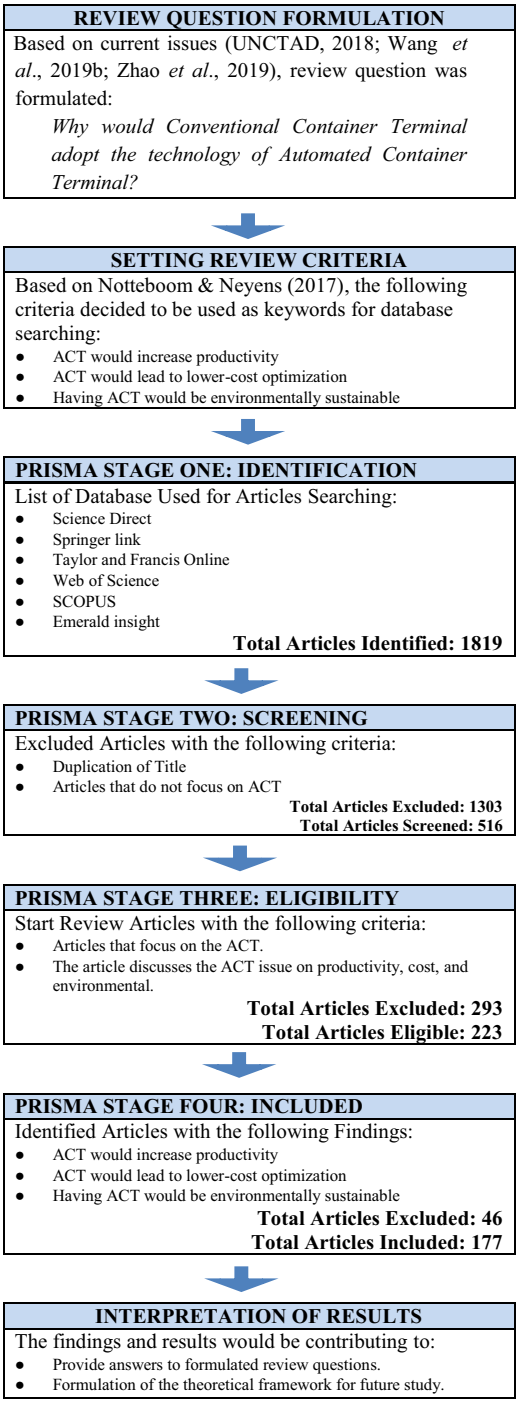


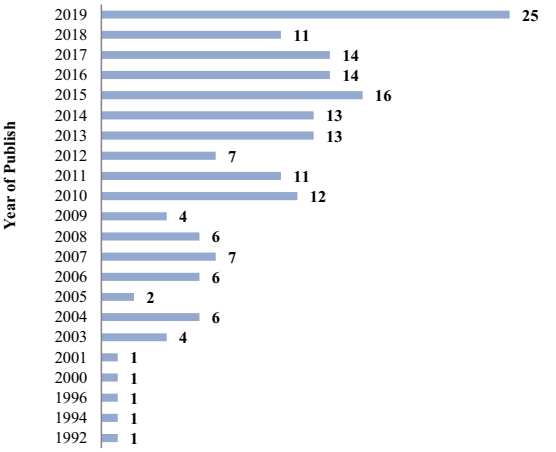
Figure 2.
SLR with PRISMA framework

Finally, the 177 articles that were retained after the stage of PRISMA would be reviewed comprehensively in an attempt to identify the findings within the articles. The accumulated findings in the articles would be recorded in statistical form to find out the trend that would provide answers for formulated review questions in Section 1. Also, the results would contribute to the formulation of the theoretical framework for future study.

3. Systematic literature review descriptive analysis

The first ACT that started the operation was the Europe Container Terminals (ECT) Delta Terminal in Port of Rotterdam in the year 1993 (Evers and Koppers, 1996). Due to this, it was decided that the literature timeline search began from the year 1993 onwards. The search was made through databases such as Science Direct, Springer Link, Taylor and Francis Online, Web of Science, SCOPUS and Emerald insight. The retrieved articles from these databases were 1,819 in total at the beginning during the PRISMA Stage One (Section 2.3). At the end of the process, only 177 articles remained after the extensive review process.

Figure 3 shows the number of articles published from 1992 until 2019 that were reviewed in this study. It appears that the papers that discussed the potential of ACT were quite low in numbers before the year 2010, there only less than 10 articles published globally during the time. Probably the ACT technology at the time was still at the infancy stage, a lot of technical problems persist; stakeholders and investors were still lack of confident to implement in such an advanced technology due to engineers were still experiencing with trial and error design in the technology (Hoshino *et al.*, 2007). However, starting 2010 saw a notable increment in the articles published regarding the ACT; more than 10 articles were published every year until recently, except for 2012 which only 7 articles were published. The trend of increase in publishing could be because of the increase of ACT construction that happened at the same time that accompanies by the increment in research demand to improve the productivity of the container terminal (PEMA, 2016; Sauri Marchán *et al.*, 2014; UNCTAD, 2018). By the year 2019, 177 articles discuss ACT were published in total



Source: Developed Based on Systematic Reviewed Literatures

Figure 3.
Yearly ACT themed article published

It is very essential to identify the source of articles in terms of the journals where it was published; the identification of journal sources would determine the impact factor of the articles where it was published based on their relevant disciplines (Garcia *et al.*, 2011). Furthermore, the reputation of journals would also determine the quality of the research produced to ensure the reliability of the findings discussed (González-Pereira *et al.*, 2010). In Table 2, the journals that published articles regarding ACT were shown to determine the favourable journal towards the title. The journal of *OR Spectrum* had the highest frequency of articles published that discussed ACT; it published 23 articles in total from the year 1992 until 2019. The next journal that favours ACT articles publication is the *European Journal of Operational Research* which published 13 articles in the same period. Also, the journal *of Computers and Operations Research* already published 12 articles that discussed ACT in the findings from the same time frame as well. The rest of the articles were published in small numbers across the various journals in different disciplines. The journals which have a high frequency of publishing the ACT related articles would enable the researcher to consider the subscription for the latest research issues to get the latest update for the contribution in the future research of the same discipline.

4. Findings and discussions

4.1 Automated container terminal improved productivity of the port

The adoption of ACT technology in container terminal would minimise the inefficiency problem that caused the delay in container handling processes by reducing the total travel time of vehicles within the container terminal to increase productivity; ACT could improve the efficiency of the port through the integration of vehicle scheduling and container yard storage plan to minimise the turnover time of vessel that also contributed to the productivity of container terminal (Luo *et al.*, 2016). The adoption of ACT technology in a container terminal is increasing due to the rapid development of global trade that requires the terminal operator to seek technology that could offer higher productivity (Yang *et al.*, 2018). Furthermore, the introduction of automated container operations had proven the solution to be effective and efficient in addressing the problem of space limitation within the container yard (Abdul Rahman *et al.*, 2016).

Figure 4 shows the numbers of articles that supported ACT have higher productivity compare to the conventional container terminal. Before the year 2010, the research about ACT remains very low in numbers; hence, the articles with the related findings that ACT improved productivity of port also very limited. However, there is a significant increase in publishing starting from the year 2010 and beyond. As of 2019, the number of articles with the related findings that ACT improved productivity of port reached 18 articles in the same year. The trend of increase in article publishing was also in line with the trend of increase in ACT construction that happened since 2010 as shown in Figure 1. Hence, it is sufficed to say that the adoption of ACT technology by conventional container terminal is necessary to increase their productivity to remain competitive within the port industry; the container terminal that reluctant to do so would face the grave challenges in competing with other advanced port around the globe to survive.

4.2 Automated container terminal lowered the operation cost

The terminal operators constantly improve the technology to reduce the operating cost that would generate considerable profits; ACT greatly reduces the labour dependency and labour cost that resulted from the epoch effect of automation technology development in container terminal (Li and Lu, 2019). The increasing trend of adoption of ACT technology also resulted from the rapid development of global trade that requires terminal operators to

Journal title	Quantity	Quartile ranking
Advanced Engineering Informatics	3	Q1
Advanced Robotics	1	Q1
Annals of Operations Research	1	Q1
Applied Mathematical Modelling	2	Q1
Applied Soft Computing	2	Q1
Automation in Construction	1	Q1
Computational Management Science	1	Q1
Computers and Industrial Engineering	12	Q1
Computers and Operations Research	1	Q1
Control Engineering Practice	1	Q1
Engineering Optimisation	1	Q1
European journal of operational research	13	Q1
Expert Systems with Applications	4	Q1
Flexible Services and Manufacturing Journal	9	Q1
Industrial Management and Data System	1	Q1
International Journal of Control	1	Q1
International Journal of Flexible Manufacturing Systems	1	Q1
International Journal of Physical Distribution and Logistics Management	1	Q1
International Journal of Production Economics	9	Q1
ISA Transactions	1	Q1
Journal of Cleaner Production	2	Q1
Journal of Intelligent and Robotic Systems	1	Q1
Journal of Intelligent Manufacturing	3	Q1
Journal of Optimisation Theory and Applications	1	Q1
Journal of the Operational research Society	3	Q1
Journal of Zhejiang University-Science	2	Q1
Maritime Economics and Logistic	5	Q1
Maritime Policy and Management	2	Q1
Ocean Engineering	1	Q1
OR Spectrum	23	Q1
Research in Engineering Design	1	Q1
Research in Transportation Business and Management	2	Q1
Research in Transportation Economic	2	Q1
Robotics and Autonomous System	2	Q1
Simulation Modelling Practice and Theory	1	Q1
Transport Policy	3	Q1
Transportation Research Part A: Policy and Practice	2	Q1
Transportation Research Part B: Methodological	1	Q1
Transportation Research Part C: Emerging Technologies	7	Q1
Transportation Research Part E: Logistics and Transportation Review	5	Q1
World Development	1	Q1
Information Technology and Management	1	Q2
Journal of mechanical science and technology	1	Q2
Journal of Simulation	1	Q2
Mathematical Problems in Engineering	4	Q2
Periodica Polytechnica Transportation Engineering	1	Q2
Polish Maritime Research	1	Q2
Procedia Manufacturing	1	Q2
Sustainability	1	Q2
WMU Journal of Maritime Affairs	2	Q2
IFAC Proceedings Volumes	8	Q3
IFAC-Papers On-Line	1	Q3

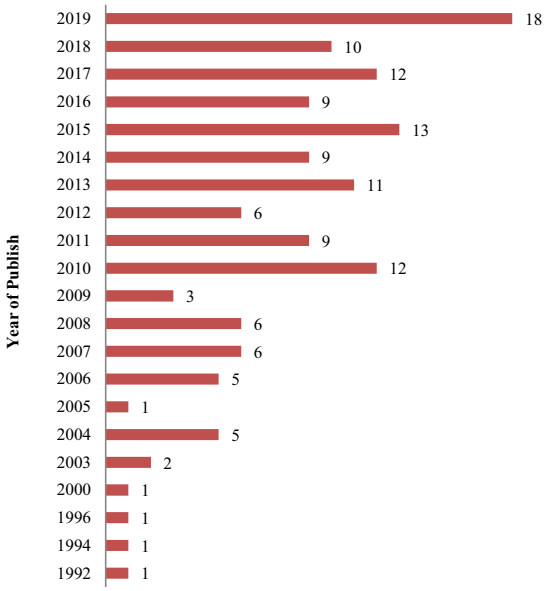
Table 2. Quantity of articles included in the review

(*continued*)

Journal title	Quantity	Quartile ranking
Natural Computing	1	Q3
NETNOMICS: Economic Research and Electronic Networking	1	Q3
The International Journal of Advanced Manufacturing Technology	1	Q3
Open Automation and Control Systems Journal	1	Q4
Journal of Innovation in Digital Ecosystems	1	Unranked
Procedia CIRP	2	Unranked
Procedia-Social and Behavioural Sciences	1	Unranked
Transportation Research Procedia	4	Unranked
Total Journal reviewed	**177**	

Source: Developed based on systematically reviewed literature

Table 2.

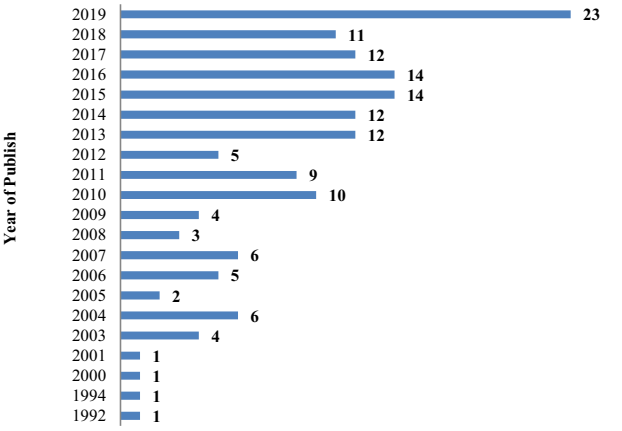


Source: Developed Based on Systematic Reviewed Literatures

Figure 4.
Yearly published articles that supported ACT improved productivity

constantly seeking for technology that could generate more profit by reducing cost (Yang *et al.*, 2018). ACT is necessary to provide cost-effective cargo handling services; cargo transporter, terminal operators shipping companies and port authorities are willing to adopt the cutting edge technology to achieve maximum cost savings (Gharehgozli *et al.*, 2019). Furthermore, ACT could reduce the overhead cost for ports and terminals by using the energy at a more efficient level; energy efficiency utilisation in ACT means the same quality of services still can be retained by using less energy at a lower cost (Iris and Lam, 2019).

The articles that supported that ACT lowered the operation cost that was published yearly were presented in Figure 5. The numbers of research regarding ACT remain low



Source: Developed Based on Systematic Reviewed Literatures

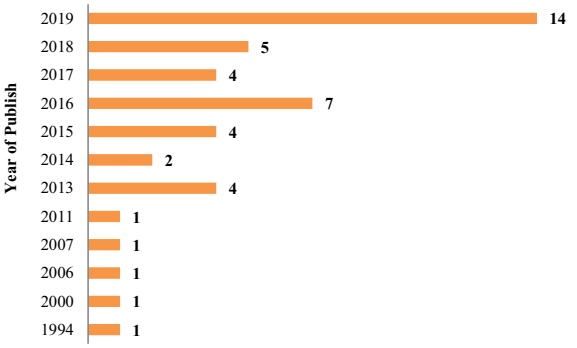
Figure 5.
Yearly published articles that supported ACT lowered the operation cost

before the year 2010; this is also the reason why the articles with the findings of ACT lowering the operation cost were limited as well. Starting from 2010, the numbers of articles publishing in related topics were increased significantly. By 2019, the number of articles with the findings of ACT lowered the operation cost reached 23 publications in the same year. The increasing trend of publication could be highly associated with the trend of increase in ACT construction that started in 2010 that could be referring to Figure 1. Hence, it was sufficient to claim that the adoption of ACT technology by conventional container terminal is essential to lower the operation cost of the terminal so that the competitiveness can be sustained in the long term.

4.3 Automated container terminal is environmentally sustainable

The rapid development of global trade and continuous construction of the green port is spearheading the direction of existing container terminal towards the adoption ACT technology; considering the high pollution carbon emission from the diesel engine, the replacement of diesel engine vehicles with electric-powered equipment could realise the minimise the effect of climate change and environmental sustainability of green port (Wang *et al.*, 2019a). The adoption of ACT applied the usage of advanced automated and environmentally friendly technologies had demonstrated the effectiveness of ecologically friendly container terminal such as ACT; the success of the first ACT in Port of Rotterdam had proven that ACT is a highly efficient and ecologically friendly container terminal that was recognised and widely accepted in the maritime industry and global port community (Shi *et al.*, 2019).

Figure 6 shows the numbers of research that were done with the findings of ACT are environmentally sustainable. Before the year 2013, the number of articles that were published remains very low with only one publication once in a few years. Beginning from the year 2013, there was a noticeable increase in articles published in relevant subjects but the numbers remained low with less than 10 publications within every year. The year 2019 saw a significant increase in the publication in the discussed matter as much as 14 publications. The trend of publication could be associated with the increasing environmental concerns of global warming due to carbon emission from diesel vehicles that



Source: Developed Based on Systematic Reviewed Literatures

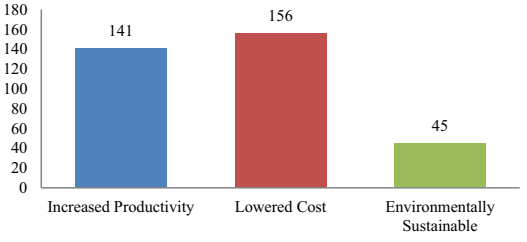
Figure 6.
Yearly published articles that supported ACT is environmentally friendly

were mentioned by Wang *et al.* (2019b) that received lots of attention from scholars and industrial players. Thus, the collections of reviewed literature show that the ACT technology application in a container terminal is necessary to sustain environmental and the practice of green port; the sustainable green container terminal is necessary to reduce the negative impact of industrial waste into the natural environment that sustains the living of the human.

4.4 Overall journal articles distributions

Figure 7 shows the distribution of journal articles that were based on different findings that supported the adoption of ACT technology. There were 177 articles retrieved in total. However, each article may contain more than one finding. Hence, the number of articles distribution will base on the findings that were identified in each article.

Amongst the 177 articles reviewed, 141 articles mentioned about ACT technology could increase the productivity of the container terminal as shown in Figure 7. As the container vessel becoming bigger, the handling volume of the container also increased, the containers have to be processed as fast as possible; the demand for such kind of service quality requires the enormous productivity level of container terminals and only ACT could offer services at such velocity (Briskorn *et al.*, 2019). Hence, it is no surprise that the majority of container



Source: Developed Based on Systematic Reviewed Literatures

Figure 7.
Distribution of journal articles based on findings

terminal stakeholders agreed that ACT could provide higher productivity levels compared to conventional container terminal that was still largely in practice at present.

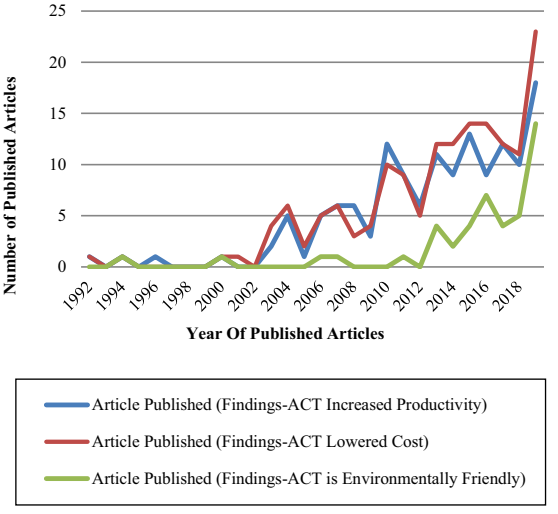
In terms of articles that mentioned the findings that ACT technology lowered the operation cost, there were 156 articles in total were identified during the review as shown in Figure 7. Bjerkan and Seter (2019) found that ACT could reduce the waiting time for the incoming and outgoing ship at Shanghai Port and Port of Gothenburg; by using the simulation model, they also confirmed that the ACT technology indeed improved the operational cost of the port. Hence, it is sufficient to say that the investor of the container terminal will always favour the new technologies that are more cost saving in the exchange for a higher profit margin.

The research of environmental concerns at the port surrounding area also received attention in recent years; this is proven by 45 publications of articles that found ACT is environmentally sustainable as presented in Figure 7. The increasing concern of the environmental impact of port activities and expansion due to climate change and energy conservation is becoming critical in recent year; the adoption of ACT technology based on the concept of Green Port is receiving a lot of acceptance amongst the port industrial players to ensure the environmental sustainability around the container terminal (Lam and Li, 2019).

4.5 The trend of findings in automated container terminal research

The research about the ACT saw its dusk begun in the year of 1992. Some of the noticeable pioneer researchers are Wan *et al.* (1992), Vepsalainen (1994) and Evers and Koppers (1996). These researchers open the path in the field of research about ACT; their research studies are still cited and benefitted the present researchers. The roles of these trailblazers in ACT research marks the beginning era of technology innovation in the port automation; as then, various institutions around the globe started to look deeper into the more specific findings in ACT research.

Figure 8 summarises the trend of ACT research remains low in the early 1990s until the early 2000s. Starting from the year 2003 and beyond, the ACT research started to show



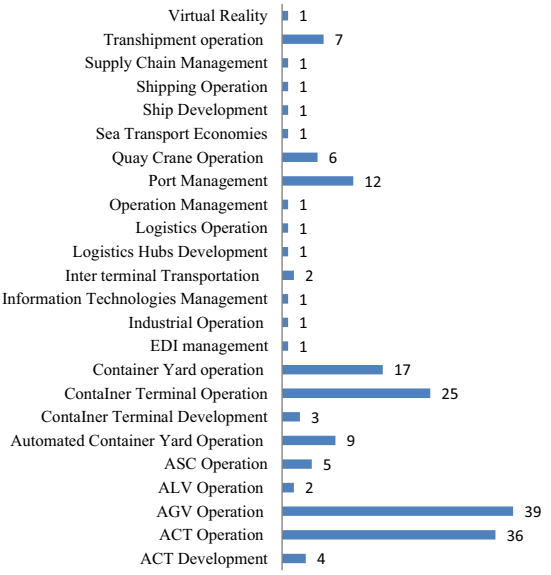
Source: Developed Based on Systematic Reviewed Literatures

Figure 8.
Trend comparison of articles published

some promising trend and reach the highest peak in the year between 2004 until 2006. The noticeable researchers that active in ACT research studies during the year 2000s are IFA Vis, Koo PH, Gunther, Grunow and Lau HY. These researchers focus on different aspects of ACT according to their research area. For example, IFA Vis done the research of ACT that focusses on operational management, Koo PH focusses on AGV fleet sizing, Gunther focusses on container terminal cargo handling, Grunow focusses on AGV despatching and Lau HY focusses on the scheduling of container handling equipment in the ACT. The publication's information on these research studies is available in the Appendix section.

4.6 The trend of focusses on automated container terminal research

The research of ACT reaches another threshold between 2014 and 2017 with more focusses on AGV as shown in Figure 9. The trigger of the research trends could be associated with the constructions of ACT around the globe that were so frequent at during the time, there was more than 20 ACT were built between 2014 and 2017, the numbers make up 30% of available of global ACT in total as of present. Overall the trend of research about ACT is gaining a lot of attention after the year 2017. There was a slight decrease in research studies in the year 2018; the numbers quickly increased in the year 2019 with more than 20 publications. The most obvious increase in the ACT research trend is the environmental sustainable focussed research papers, the possible reasons are that environmental concern and natural resources depletion is becoming a serious issue in recent years (Lam and Li, 2019). This research trend is also in line with the Sustainable Goals Development Policy that was proposed by the United Nations that was signed in 2015; this initiative aims to protect and restores the environment through continuous advancing economic and social development (Alexander and Delabre, 2019).

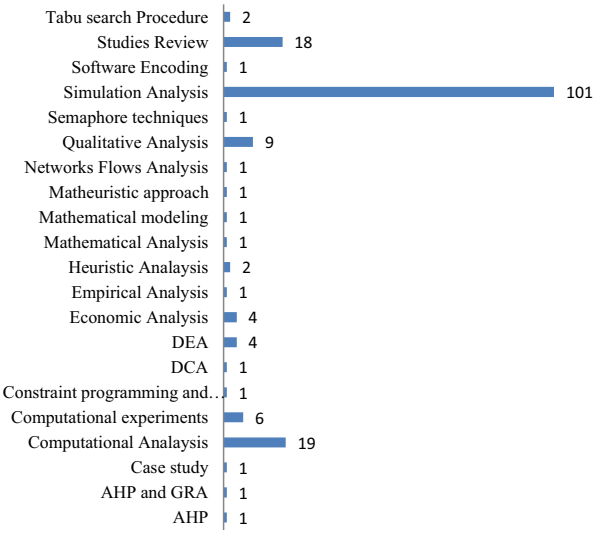


Source: Developed Based on Systematic Reviewed Literatures

Figure 9.
Research focus of articles published

4.7 The trend of innovations breakthrough in automated container terminal research

As the trade volumes expand, the demand for technologies with greater efficiency and productivity would be required. Such a demand spark light the motivation of the researcher to keep on improvises the current technologies with unique innovations every year. Figure 10 shows the innovations that were achieved by some scholars from the year 2016 until the year 2019. The *Intelligent Autonomous Vehicles Cooperative Model* that was developed by Bahnes *et al.* (2016) aimed to enhance the operational efficiency of the container terminal. In the same year, Chandrakumar *et al.* (2016) successfully incorporated *LEAN and Green Concepts* in transshipment terminal operations that ended up with productivity enhancement; a model based on this innovation was also developed. As the container vessels become bigger, the industrial players need to assess the necessity for technological upgrades; hence, Meng *et al.* (2017) developed the *Mega Vessels Impact Analysis Model* that specifically tailored for container terminal operations. Gattuso and Cassone *(*2018) were trying to develop a model that could reduce the operation costs of Automated Guided Wagon in container yard; their research outcome manages to introduce the *AGW Efficient Transport Model* that could level up the efficiency of freight transport in the container yard. As electric-powered vehicles become the norm in the industry, the battery life of the vehicles becomes one of the benchmark performances in the ACT; to improve the battery utilisation of electric-powered vehicles, Zhan *et al.* (2019) developed the model that could improvise the battery charging in the ACT. These mentioned innovations above are just tips of the iceberg that were being developed in recent years, more innovations reviewed results are available in the Appendix section in this article (Table 3).



Notes: DCA = Difference of Convex Algorithm; DEA = Data envelopment analysis; AHP = analytical hierarchy process; ALV = automated lifting vehicle
Source: Developed Based on Systematic Reviewed Literatures

Figure 10.
Research methodologies of articles published

Articles published	Innovations
Bahnes, N., Kechar, B., and Haffaf, H. (2016). Cooperation Between Intelligent Autonomous Vehicles To Enhance Container Terminal Operations. Journal Of Innovation In Digital Ecosystems, 3(1), 22–29	Intelligent autonomous vehicles cooperative model
Chandrakumar, C., Gowrynathan, J., Kulatunga, A. K., and Sanjeevan, N. (2016). Incorporate LEAN And Green Concepts To Enhance The Productivity Of Transhipment Terminal Operations. Procedia CIRP, 40, 301–306	Productivity enhancement model through incorporate LEAN and green concepts
Meng, Q., Weng, J., and Suyi, L. (2017). Impact Analysis Of Mega Vessels On Container Terminal Operations. Transportation Research Procedia, 25, 187-204	Mega vessels impact analysis model
Gattuso, D., and Cassone, G. C. (2018). AGW For Efficient Freight Transport In Container Yard: Models And Costs. Transportation Research Procedia, 31, 108–120	AGW efficient transport model
Zhan, X., Xu, L., Zhang, J., and Li, A. (2019). Study On AGV Battery Charging Strategy For Improving Utilisation. Procedia CIRP, 81, 558–563	Battery charging utilisation model

Source: Developed based on systematically reviewed literature

Table 3.
Research innovations of articles published

4.8 The trend of methodologies application in automated container terminal research

Various research methodologies were observed in articles published in the period from 1992 to 2019. The popularity of methodologies applied also correlates with the research focus of the researcher. Figure 11 shows the trend of methodologies that were applied in the research in the past until recently. In Figure 9 of Section 4.6, it was shown that the maritime operation remains one of the most popular topics for the research. The nature of the research that focusses on maritime operation requires the researcher to keep on looking for innovation to improve the productivity of the container terminal (Chandrakumar *et al.*, 2016). Using the data that were extracted from the real-world terminal operation, scholars such as Meng *et al.* (2017) would attempt to run the data in the virtual simulation to predict the different scenarios that were developed. This method of simulation analysis remains the popular technique until today due to its infinite possibility and opportunities for technological improvement. The simulation analysis methodology could be applied to the research that focusses on container terminal operations such as AGV Operation (Zhan *et al.*, 2019), Quay crane operation (Zhan *et al.*, 2019) and container yard operation (He *et al.*, 2019). Research method such as studies review that was applied in this paper may not seem popular amongst the researcher in the field of ACT, but it is still outstanding compare to other methods that were applied in the same field, a scholar such as Heilig *et al.* (2019) reviewed the IT application in the terminal management, while Doumbia-Henry (2016) reviewed the sustainability of the port terminal.

4.9 The trend of contributions in automated container terminal research

From 1992 until 2019, a lot of research studies had been completed with successful innovations and their contributions. Throughout the years, various simulation models had been developed to assist the terminal in the productivity improvement such as *Strategic Battery Charging* (Zhan *et al.*, 2019), *AGV Efficient Transportation (*Gattuso and Cassone, 2018) and *Productivity Enhancement Through Incorporate LEAN And Green Concep*ts by Chandrakumar *et al.* (2016). Besides simulation models, many researchers also developed the

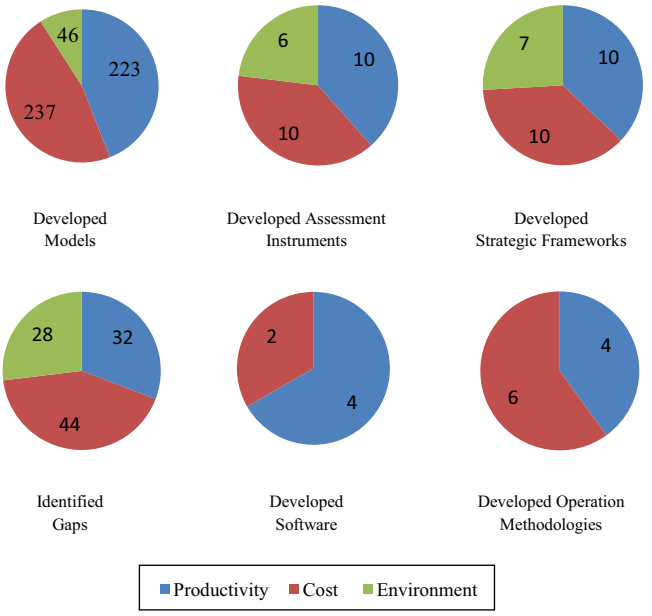


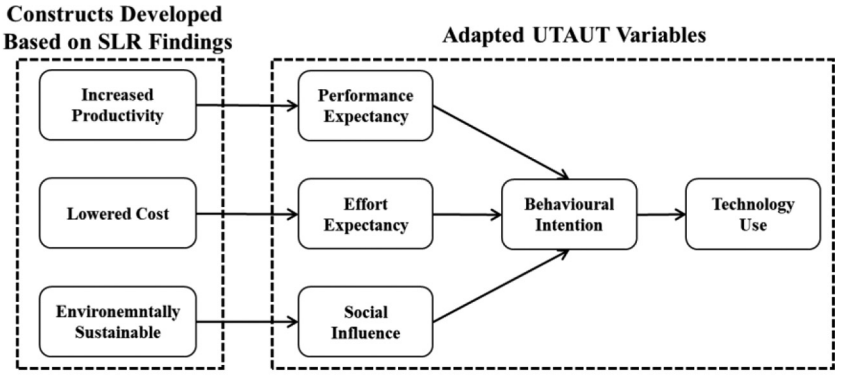
Figure 11. Research contributions of articles published

Source: Developed Based on Systematic Reviewed Literatures

assessment instruments for container terminal; scholars such as Meng *et al.* (2017) developed *Impact Analysis For Mega Vessel*, Gil Ropero *et al.* (2019) developed *BootStrap Application for Port Efficiency* and Jun *et al.* (2018) developed *Input-Output Analysis for Smart Port*. Besides innovations, some researchers perform studies reviews such as this article to identify the research gaps amongst the existing studies; scholars such as Heilig *et al.* (2017) identified the gap of IT application in the seaport, Doumbia-Henry (2016) identified the gap of sustainability in port development and Iris and Lam (2019) who identified the gap of operation strategy in the container port. Figure 12 shows the total distributed numbers of innovations and output of the research studies in the ACT field from the year 1992 until 2019. For detail innovations produced by every scholar can refer to the Appendix section within this article.

5. Conceptual framework for future study

There was various research that was done before that attempt to find out the main reasons behind the adoption of automation technology by the maritime industry such as Bjerkan and Seter (2019), Iris and Lam (2019), Li and Fung (2019) and Zhang *et al.* (2019). The current SLR research paper found out that the adoption of ACT technology would increase the productivity of the container terminal, this is supported by the cumulative findings of 141 research articles that were reviewed systematically in this paper. Secondly, the adoption of ACT technology would lower the cost of the container terminal, cumulative findings of 156 systematically reviewed articles supported this. Finally, SLR analysis within this paper shows that the adoption of ACT technology would render the container terminal environmentally sustainable; there were 45 articles in total that supported this idea.



Source: Developed Based on Systematic Reviewed Literature and adaption of the UTAUT model by Venkatesh *et al.* (2016)

Figure 12. Conceptual framework for future research

Future research will require a framework or model for describing, explaining and predicting the acceptance, adoption and use of ACT technologies in the container terminal industry. The conceptual framework will be based on constructs that were developed using the results that were obtained in this SLR study. As the target of ACT will be technology users, the conceptual framework will adapt UTAUT (Unified theory of acceptance and use of technology) variables from Venkatesh *et al.* (2016). Performance expectancy refers to the degree of using technology to help users in performing chosen activities. Effort expectancy refers to the degree of freedom to use technologies. Social Influence refers to perceptions that support the use of technologies. The conceptual framework will have constructs that suit the context and users of the container terminal industry. Finally, the purpose of identifying the drivers for adoption, adaption and use of ACT technologies will be investigated in detail. Figure 12 shows the developed conceptual framework formulated based on the results of the current SLR study and the adaption of the UTAUT model.

6. Conclusion

The volume of shipments will keep on increasing because of the convenience of global trade in recent years. Hence, the need for ACT in the port sector is inevitable. The ECT Delta Terminal at Rotterdam Port marks the new era of automation in the port industry. As time goes by, the ACT technologies will become more matured and reliable. Hence, the mass ACT technology adoption by the major container terminals around the world is just a matter of time. However, finding out the real factors ACT technology adoption is more relevant at the moment because it could assist the current container terminals that were not automated yet in deciding on the investment in automated technology.

The main purpose of this research is to verify the factors of ACT technology adoption by container terminal operators. The methodology used in this paper was SLR that systematically reviewed the existing literature. The collectively reviewed literature was analysed that generated statistical results after that. These results were significant in developing the conceptual framework that would benefit the future study of ACT research. Given the fact that ACT technology is not widely used around the world yet, this research would serve as a part of the contribution in collective literature for future researchers.

The literature reviewed in this paper mainly focusses on research about ACT and the outcome of its application in the maritime industry. The statistical results show that the research publications were rather slow at the beginning era of ACT introduction in the industry, probably due to limited locations of available ACT during the time. However, as time goes by, ACT numbers were increasing significantly and provide opportunities for scholars to initiate the study more conveniently. Additionally, the findings of the reviewed literature showed that the factors for container terminal operators to invest in the ACT were limited to production increment and cost reduction during the early days; however, the environmental concerns factor were taken into accounts at present.

Many works of the literature suggested that container terminal operators would benefit from the adoption of ACT technology in long term. The analysis results also show that quantitative methods were common in the literature with empirical statistics and only limited research studies that used qualitative methods in their studies previously. The used literature analysis technique in this study allowed the researcher to find out the pattern and trends of research findings that will generate clearer insights for future study. The ACT research topic could be considered a relatively fresh topic in the maritime industry because there are only limited numbers of ACT available around the world.

The research in the ACT could apply various methodologies ranging from operational research, case studies, economics modelling, simulation and software engineering due to the freshness of the topic. However, this literature review only assesses the trends of ACT research outcomes throughout the timeline. A broader review in the future probably could allow the expansion of a more detailed research area under the same topic. The conceptual framework that was generated at the end of the research aims to provide future research opportunities to conduct the study in the way of empirical.

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Appendix

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
Vis *et al.* (2001). Determination of the number of automated guided vehicles required at a semi-automated container terminal	AGV planning	AGV determination model	Networks flow analysis	Developed model that benefits: – cost optimisation
Wan *et al.* (1992). The use of information technology by the port of Singapore authority	Information technologies management	IT management framework	Qualitative analysis	Developed framework that benefits: – better productivity – cost optimisation
Laine and Vepsäläinen (1994). Economies of speed in sea transportation	Sea transport economies	Sea transport framework	Economic analysis	Developed framework that benefits: – better productivity – cost optimisation – environmental friendly
Evers and Koppers (1996). Automated guided vehicle traffic control at a container terminal	AGV operation	AGV traffic control model	Semaphore techniques	Developed model that benefits: – better productivity
Lee *et al.* (2000). A new efficient EDI system for container cargo logistics	EDI management	Efficient EDI framework	Qualitative analysis	Developed framework that benefits: – better productivity – cost optimisation – environmental friendly
Bish (2003). A multiple-crane-constrained scheduling problem in a container terminal	Quay crane operation	Multiple-crane-constrained scheduling model	Simulation analysis	Developed model that benefits: – cost optimisation
Kim *et al.* (2003). Sequencing delivery and receiving operations for yard cranes in port container terminals	Container yard operation	Yard crane delivery and receiving model	Simulation analysis	Developed model that benefits: – cost optimisation
Moorthy *et al.* (2003). Cyclic deadlock prediction and avoidance for a zone-controlled AGV system	AGV operation	AGV cyclic deadlock prediction and avoidance model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Vis and De Koster (2003). Transshipment of containers at a container terminal: an overview	Transhipment operation	Container transshipment model	Studies review	Developed model that benefits: – better productivity – cost optimisation

(*continued*)

Table A1. Research publications and its contribution to the ACT study

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
Koo *et al.* (2004). Estimation of part waiting for time and fleet sizing in AGV systems	AGV operation	AGV waiting time estimation model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Koo *et al.* (2004). Fleet sizing and vehicle routing for container transportation in a static environment	ACT operation	Fleet sizing and vehicle routing model	Tabu search procedure	Developed model that benefits: – better productivity – cost optimisation
Liu *et al.* (2004). Automated guided vehicle system for two container yard layouts	AGV operation	AGV system layout model	Simulation analysis	Developed model that benefits: – cost optimisation
Steenken *et al.* (2004). Container terminal operation and operations research-a classification and literature review	Operation management		Studies review	Identified gaps that benefits: – better productivity – cost optimisation
Vis and Harika (2004). Comparison of vehicle types at an automated container terminal	ACT operation	Vehicle performance assessment model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Yang *et al.* (2004). Simulation-based performance evaluation of transport vehicles at automated container terminals	ACT operation	Transport vehicle assessment model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Grunow *et al.* (2005). Despatching multi-load AGV in highly automated seaport container terminals	AGV operation	Model development	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Chen *et al.* (2006). An integrated approach for modelling and solving the scheduling problem of container handling systems	ACT operation	Integrated scheduling model	Simulation analysis	Developed model that benefits: – better productivity
Günther and Kim (2006). Container terminals and terminal operations	ACT operation		Studies review	Identified gaps that benefits: – better productivity – cost optimisation
Le-Anh and De Koster (2006). A review of design and control of automated guided vehicle systems	AGV operation		Studies review	Identified gaps that benefits: – better productivity – cost optimisation

Table A1.

(*continued*)

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
Veeke *et al.* (2006). Conceptual design of industrial systems: an approach to support collaboration	Industrial operation		Studies review	Identified gaps that benefits: – better productivity – cost optimisation – environmental friendly
Vis (2006a). A comparative analysis of storage and retrieval equipment at a container terminal	Automated container yard operation	Storage and retrieval equipment analysis model	Simulation analysis	Developed model that benefits: – cost optimisation
Vis (2006b). Survey of research in the design and control of automated guided vehicle systems	AGV operation		Studies review	Identified gaps that benefits: – better productivity – cost optimisation
Briskorn *et al.* (2007). Inventory-based despatching of automated guided vehicles on container terminals. In container terminals and cargo systems	AGV operation	AGV despatching model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Chen *et al.* (2007). A Tabu search algorithm for the integrated scheduling problem of container handling systems in a maritime terminal	ACT operation	Integrated scheduling model	Tabu search procedure	Developed model that benefits: – better productivity – cost optimisation
Dekker *et al.* (2007). Advanced methods for container stacking. in container terminals and cargo systems	ACT operation	Advanced container stacking model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Duinkerken *et al.* (2007). Comparing transportation systems for inter-terminal transport at the Maasvlakte container terminals	Inter terminal operation	Inter terminal transportation model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Grunow *et al.* (2007). Strategies for despatching AGVs at automated seaport container terminals	AGV operation	AGV despatching model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Kim *et al.* (2007). Deadlock prevention for automated guided	AGV operation	AGV deadlock prevention model	Simulation analysis	Developed model that benefits: – better productivity

(*continued*)

Table A1.

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
vehicles in automated container terminals				
Cao *et al.* (2008). Deployment strategies of double-rail-mounted gantry crane systems for loading outbound containers in container terminal	Automated container yard operation	Double-rail-mounted gantry crane deployment model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Hu *et al.* (2008). AS/RS based yard and yard planning	Container yard operation	Yard planning software	Simulation analysis	Developed software that benefits: – better productivity – cost optimisation
Lau and Zhao (2008a). Integrated scheduling of handling equipment at automated container terminals	ACT operation	Integrated schedule model	Simulation analysis	Developed model that benefits: – better productivity
Stahlbock and Voß (2008). Operations research at container terminals: a literature update	ACT operation		Studies review	Identified gaps in – better productivity – cost optimisation
Zeng and Hsu (2008). Conflict-free container routing in mesh yard layouts	ACT operation	Conflict-free routing development	Simulation analysis	Developed model that benefits: – better productivity
Alessandri *et al.* (2009). Management of logistics operations in intermodal terminals by using dynamic modelling and nonlinear programming	ACT operation	Dynamic logistics operation model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Huang *et al.* (2009). The optimum route problem by genetic algorithm for loading/unloading of yard crane	ACT operation	Yard crane optimum routing model	Simulation analysis	Developed model that benefits: – cost optimisation
Nguyen and Kim (2009). A despatching method for automated lifting vehicles in automated port container terminals	ALV operation	ALV despatching model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Tavakkoli-Moghaddam *et al.* (2009). an efficient algorithm for solving a new mathematical model for a quay crane	Quay crane operation	Quay crane scheduling model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation

Table A1.

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Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
scheduling problem in container ports				
Angeloudis and Bell (2010). An uncertainty-aware AGV assignment algorithm for automated container terminals	AGV operation	AGV assignment model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Borgman *et al.* (2010). Online rules for container stacking	Container yard operation	Container stacking rules model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Chew *et al.* (2010). IT-based planning and control of seaport container terminals and freight transportation systems	ACT operation		Studies review	Identified gaps that benefits: – better productivity – cost optimisation
Dorndorf and Schneider (2010). Scheduling automated triple cross-over stacking cranes in a container yard	ASC operation	Automated triple cross-over stacking cranes scheduling model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Ku *et al.* (2010). An optimisation framework for yard planning in a container terminal: the case with automated rail-mounted gantry cranes	Container yard operation	Optimisation framework for yard planning	Simulation analysis	Developed framework that benefits: – better productivity – cost optimisation
Lee and Kim (2010). Comparison and evaluation of various cycle-time models for yard cranes in container terminals	Container yard operation	Cycle-time models for yard cranes	Simulation analysis	Developed model that benefits: – better productivity
Lee *et al.* (2010). Vehicle despatching algorithms for container transshipment hubs	Transshipment operation	Vehicle despatching algorithms	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Longo (2010). Design and integration of the containers inspection activities in the container terminal operations	Container terminal operation	Integrated model for container inspection	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Lu and Xi (2010). A proactive approach for the simultaneous berth and quay crane scheduling problem	Quay crane operation	Quay crane scheduling model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation

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Table A1.

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
with stochastic arrival and handling time				
Park *et al.* (2010). Real-time scheduling for twin RMGs in an automated container yard	Automated container yard operation	RMG scheduling model	Simulation analysis	Developed model that benefits: – better productivity
Petering (2010). Development and simulation analysis of real-time, dual-load yard truck control systems for seaport container transshipment terminals	Container transshipment operation	Dynamic vehicles routing model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Wiese *et al.* (2010). Mathematical models and solution methods for optimal container terminal yard layouts	Automated container yard operation	Container yard layout mathematical model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Bae *et al.* (2011). Comparison of operations of AGVs and ALVs in an automated container terminal	AGV operation	AGV and ALV traffic control scheme model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Chang *et al.* (2011). Developing a dynamic rolling-horizon decision strategy for yard crane scheduling	Container yard operation	Yard crane scheduling model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Choe *et al.* (2011). Generating a rehandling-free intra-block remarshaling plan for an automated container yard	Automated container yard operation	Intra-block re-marshal model	Simulation analysis	Developed model that benefits: – better productivity
Fumarola and Poelman (2011). Generating virtual environments of real-world facilities: discussing four different approaches	Virtual reality	Virtual environments software	Simulation analysis	Developed software that benefits: – cost optimisation
Geerlings and Van Duin (2011). A new method for assessing CO_2-emissions from container terminals: a promising approach applied in Rotterdam	ACT development	CO_2 emission assessment methodology	AHP	Developed methodology that benefits: – better productivity – cost optimisation – environmental friendly

Table A1.

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Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
Klerides and Hadjiconstantinou (2011). Modelling and solution approaches to the multi-load AGV despatching problem in container terminals	AGV Operation	AGV despatching model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Park *et al.* (2011). Dynamic adjustment of container stacking policy in an automated container terminal	Container yard operation	Container stacking optimisation model	Simulation analysis	Developed model that benefits: – better productivity
Salido *et al.* (2011). Integrated intelligent techniques for remarshaling and berthing in maritime terminals	ACT operation	Berth allocation and container stacking optimisation model	Simulation analysis	Developed models that benefits: – better productivity – cost optimisation
Sauri and Martin (2011). Space allocating strategies for improving import yard performance at marine terminals	Container yard operation	Strategic storage model for containers	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Choe *et al.* (2012). Queue-based local scheduling and global coordination for real-time operation control in a container terminal	Container terminal operation	Scheduling and coordination model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Kemme (2012). Effects of storage block layout and automated yard crane systems on the performance of seaport container terminals	Automated container yard operation	Strategic container stacking model	Simulation analysis	Developed models that benefits: – better productivity – cost optimisation
Ku *et al.* (2012). A novel approach to yard planning under vessel arrival uncertainty	Automated container yard operation	Container yard planning strategic model	Simulation analysis	Developed model that benefits: – cost optimisation
Le *et al.* (2012). DCA for solving the scheduling of lifting vehicle in an automated port container terminal	ALV operation	ALV scheduling model	DCA	Developed model that benefits: – better productivity – cost optimisation
Rodriguez-Molins *et al.* (2012). Intelligent planning for allocating containers in maritime terminals	Container yard operation	Intelligent planner for container stacking	Software encoding	Developed software that benefits: – better productivity
Bichou (2013). An empirical study of the		Benchmarking model for	DEA	Developed model that benefits:

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Table A1.

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
impacts of operating and market conditions on container-port efficiency and benchmarking	Container terminal development	container terminal marketing and operation		– better productivity – cost optimisation
Chen *et al.* (2013). Integrated scheduling of crane handling and truck transportation in a maritime container terminal	Container terminal operation	Integrated model for crane handling and truck transportation	Constraint programming Disjunctive graph	Developed model that benefits: – better productivity – cost optimisation
Dekker *et al.* (2013). A chassis exchange terminal to reduce truck congestion at container terminals	Container terminal operation	Chassis exchange terminal	Simulation analysis	Developed methodology that benefits: – cost optimisation – environmental friendly
Gelareh *et al.* (2013). Scheduling of intelligent and autonomous vehicles under pairing/unpairing collaboration strategy in container terminals	AGV operation	IAV scheduling model	Simulation analysis	Developed model that benefits: – cost optimisation
Kulak *et al.* (2013). Strategies for improving a long-established terminal's performance: a simulation study of a Turkish container terminal	Container terminal operation	Strategic model for terminal	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Lee and (2013). Optimizing the yard layout in container terminals	Container yard operation	Container yard layout optimisation model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Rashidi and Tsang (2013). Novel constraints satisfaction models for optimisation problems in container terminals	Container terminal operation	Constraint satisfaction and optimisation problems	Studies review	Identified gaps that benefits: – better productivity – cost optimisation
Skinner *et al.* (2013). Optimisation for job scheduling at automated container terminals using a genetic algorithm	Container terminal operation	Optimised job scheduling mathematical model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
van Asperen *et al.* (2013). Evaluating the impact of truck announcements on	Container yard operation	Container stacking evaluation model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation

Table A1. (*continued*)

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
container stacking efficiency				– environmental friendly
Wu *et al.* (2013). An integrated programming model for storage management and vehicle scheduling at container terminals	Container yard operation	Integrated model for storage and vehicle scheduling	Simulation analysis	Developed model that benefits: – better productivity
Yang and Chang (2013). Impacts of electric rubber-tired gantries on green port performance	Container yard operation	RTG and ERTG performance comparison	Economic analysis	Proposed framework that benefits: – better productivity – cost optimisation – environmental friendly
Zhen (2014). Storage allocation in transshipment hubs under uncertainties	Transshipment operation	Storage allocation decision support system	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Cai *et al.* (2014). Rescheduling policies for large-scale task allocation of autonomous straddle carriers under uncertainty at automated container terminals.	ASC operation	Rescheduling policies for ASC uncertainty task allocation	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Carlo *et al.* (2014). Transport operations in container terminals: literature overview, trends, research directions and classification scheme.	Container terminal operation	Future research gap of container terminal operation	Studies review	Identified gaps that benefits: – better productivity – cost optimisation
Hu *et al.* (2014). A Decomposition method to analyse the performance of the frame bridge based automated container terminal	ACT operation	Frame bridge ACT evaluation model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Taner *et al.* (2014). Layout analysis affecting strategic decisions in artificial container terminals	Automated container terminal operation	ACT strategic decision model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Tang *et al.* (2014). Modelling and solution of the joint quay crane	Quay crane operation	Particle swarm optimisation model	Computational experiments	Developed model that benefits: – better productivity

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Table A1.

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
and truck scheduling problem				
Carlo and Martínez-Acevedo (2015). Priority rules for twin automated stacking cranes that collaborate	ASC operation	ASC priority rules	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Choe *et al.* (2015). Crane scheduling for opportunistic remarshaling of containers in an automated stacking yard	ACT operation	Opportunistic re-marshal model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Dulebenets *et al.* (2015). Evaluation of the floater concept at marine container terminals via simulation	Container terminal operation	Floater concept evaluation model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation – environmental friendly
Fazlollahtabar and Saidi-Mehrabad (2015). Methodologies to optimise automated guided vehicle scheduling and routing problems: a review study	AGV operation		Studies review	Review methodologies that benefits: – better productivity – cost optimisation
He *et al.* (2015). Integrated internal truck, yard crane and quay crane scheduling in a container terminal considering energy consumption	Container terminal operation	Mixed-integer programming model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation – environmental friendly
Ji *et al.* (2015). Optimisation of loading sequence and rehandling strategy for multi-quay crane operations in container terminals	Quay crane operation	Multi-quay crane operations optimisation strategy	Computational experiments	Developed model that benefits: – better productivity – cost optimisation
Kavakeb *et al.* (2015). Green vehicle technology to enhance the performance of a European port: a simulation model with a cost-benefit approach	AGV operation	Simulation model with a cost-benefit approach	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Kaveshgar and Huynh (2015). Integrated quay crane and yard truck	Container terminal operation	Integrated optimisation model	Mathematical modelling	Developed model that benefits: – better productivity

Table A1.

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Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
scheduling for unloading inbound containers				
Luo and Wu (2015). Modelling of dual-cycle strategy for container storage and vehicle scheduling problems at automated container terminals	Automated container yard operation	Strategy for container and vehicle scheduling	Computational experiments	Developed model that benefits: – better productivity – cost optimisation
Petering (2015). Real-time container storage location assignment at an RTG-based seaport container transshipment terminal: problem description, control system, simulation model and penalty scheme experimentation	Transshipment operation	Real-time container storage location assignment model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Tao and Qiu (2015). A simulation optimisation method for vehicles despatching amongst multiple container terminals	Container terminal operation	Vehicles despatching optimisation method	Simulation analysis	Developed model that benefits: – cost optimisation
Xin *et al.* (2015a). Energy-efficient container handling using hybrid model predictive control	ACT operation	Energy-efficient model with predictive control	Simulation analysis	Developed model that benefits: – cost optimisation – environmental friendly
Xin *et al.* (2015b). Event-driven receding horizon control for energy-efficient container handling	ACT operation	Energy-efficient event-driven receding horizon control	Simulation analysis	Developed model that benefits: – cost optimisation – environmental friendly
Xin *et al.* (2015c). Control of interacting machines in automated container terminals using a sequential planning approach for collision avoidance	ACT operation	Sequential planning approach for collision avoidance.	Simulation analysis	Developed model that benefits: – cost optimisation – environmental friendly
Choe *et al.* (2016). Online preference learning for adaptive despatching of AGVs in an automated container terminal	AGV operation	Online preference learning for adaptive AGV despatching	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation – environmental friendly

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Table A1.

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
Gharehgozli *et al.* (2016). Sea container terminals: new technologies and or models	ACT development		Studies review	Identified gaps that benefits: – better productivity – cost optimisation – environmental friendly
Hu *et al.* (2016). Sequencing twin automated stacking cranes in a block at the automated container terminal	Automated container yard operation	ASC sequencing model	Simulation analysis	Developed model that benefits: – cost optimisation
Li *et al.* (2019). Integrated scheduling of a container handling system with simultaneous loading and discharging operations	Container terminal operation	Integrated scheduling model	Computational experiments	Developed model that benefits: – better productivity – cost optimisation
Luo *et al.* (2016). Modelling of integrated vehicle scheduling and container storage problems in the unloading process at an automated container terminal	ACT operation	Integrated scheduling and storage modelling	Computational experiments	Developed model that benefits: – better productivity – cost optimisation – environmental friendly
Yang and Chen (2016). Determinants of global logistics hub ports: comparison of the port development policies of Taiwan, Korea and Japan	Logistics hubs development	Logistics hub port assessment instrument	AHP GRA	Developed instrument that measures: – productivity – cost optimisation – environmental friendly
Zhen (2016). Modelling of yard congestion and optimisation of yard template in container ports	Container yard operation	Yard congestion optimisation model	Simulation analysis	Developed instrument that benefits: – productivity – cost optimisation
Zheng *et al.* (2016). Predictive path following with arrival time awareness for waterborne AGVs	ACT development	Predictive control model for WAGV	Simulation analysis	Developed model that benefits: – cost optimisation
Bechtsis *et al.* (2017). Sustainable supply chain management in the digitalisation era: the impact of automated guided vehicles	Supply chain management	Sustainable supply chain management framework	Qualitative analysis	Developed framework that benefits: – better productivity – cost optimisation – environmental friendly

Table A1.

(*continued*)

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
Dhingra *et al.* (2017). A cooperative quay crane-based stochastic model to estimate vessel handling time	Quay crane operation	Cooperative quay crane stochastic model	Computational experiments	Developed model that benefits: – better productivity – cost optimisation
Espinouse *et al.* (2017). Complexity of scheduling problem in a single-machine flexible manufacturing system with cyclic transportation and unlimited buffers	AGV operation	AGV flexible transportation model	Heuristic analysis	Developed model that benefits: – better productivity
Gharehgozli *et al.* (2017a). A simulation study of the performance of twin automated stacking cranes at a seaport container terminal	ASC operation	ASC performance measuring instrument	Simulation analysis	Developed instrument that measures: – productivity – cost optimisation
Gharehgozli *et al.* (2017b). Heuristic estimation of container stacking and reshuffling operations under the containership delay factor and mega-ship challenge	Container terminal operation	Heuristic estimation model	Heuristic analysis	Developed model that benefits: – cost optimisation
Heilig and Voß (2017a). Inter-terminal transportation: an annotated bibliography and research agenda	Inter terminal transportation	Research gaps	Studies review	Identified gaps that benefits: – better productivity – cost optimisation – environmental friendly
Huang and Li (2017). Yard crane scheduling to minimise total weighted vessel loading time in container terminals	Container terminal operation	Yard crane scheduling model	Simulation analysis	Developed model that benefits: – better productivity
Irawan *et al.* (2017). Layout optimisation for an installation port of an offshore wind farm	Port development	Port layout optimisation model	Metaheuristic approach	Developed model that benefits: – better productivity – cost optimisation
Pjevcevic *et al.* (2017). Data envelopment analysis of AGV fleet sizing at a port container terminal	AGV operation	AGV fleet sizing model	DEA	Developed model that benefits: – better productivity – cost optimisation
Saini *et al.* (2017). A stochastic model for the	Container yard operation	Yard crane stochastic model	Simulation analysis	

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Table A1.

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
throughput analysis of passing dual yard cranes				Developed model that benefits: – cost optimisation
Wang *et al.* (2017). Key influencing factors on improving the waterway through the capacity of coastal ports	Port management	Simulation model for ship navigation	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Dhingra *et al.* (2018). Solving semi-open queuing networks with time-varying arrivals: an application in container terminal landside operations	ACT operation	MGM based stochastic model	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation – environmental friendly
Dkhil *et al.* (2018). Multi-objective optimisation of the integrated problem of location assignment and straddle carrier scheduling in a maritime container terminal at import	Straddle carrier operation	Straddle carrier optimisation integrated modelling	Simulation analysis	Developed model that benefits: – better productivity – cost optimisation
Jun *et al.* (2018). Impact of the smart port industry on the Korean national economy using input-output analysis	Port development	Hybrid method: Delphi surveys and input-output analysis	Economic analysis	Develop instrument to measures: – productivity – cost optimisation – environmental friendly
Knatz (2018). Port mergers: why not Los Angeles and long beach?	Port development	Research gaps in port merging	Qualitative analysis	Identified gaps that benefits: – productivity – cost optimisation – environmental friendly
Małopolski (2018). Sustainable and conflict-free operation of AGVs in a square topology	AGV operation	Conflict-free AGV operation simulation model	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation
Yongsheng *et al.* (2018) An integrated scheduling method for AGV routing in automated container terminals	AGV operation	Integrated scheduling model for AGV routing	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation – environmental friendly
Zhan *et al.* (2018). Cranes scheduling in frame bridges based	ACT operation	Scheduling model frame bridges crane	Mathematical analysis	Developed the model that benefits: – increased

Table A1. (*continued*)

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
automated container terminals				productivity – cost optimisation – environmental friendly
Bjerkan *et al.* (2019). Reviewing tools and technologies for sustainable ports: does research enable decision-making in ports?	Port development		Studies review	Identified gaps that benefits: – cost optimisation – environmental friendly
Briskorn *et al.* (2019). A generator for test instances of scheduling problems concerning cranes in transshipment terminals	Transshipment operation	Test data generator	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation – environmental friendly
Danyluk (2019). Fungible space: competition and volatility in the global logistics network	Ship development		Qualitative analysis	Developed the model that benefits: – increased productivity – cost optimisation – environmental friendly
Gharehgozli *et al.* (2019). Container terminal layout design: transition and future	Container terminal development	Novel layout design for container terminal	Studies review	Identified gaps that benefits: – cost optimisation – environmental friendly
Gil Ropero *et al.* (2019). Bootstrapped operating efficiency in container ports: a case study in Spain and Portugal	Container terminal operation	Bootstrap application to measure port efficiency	DEA	Develop instrument to measures: – productivity – cost optimisation – environmental friendly
Han *et al.* (2019). Scheduling cooperative twin automated stacking cranes in automated container terminals	ASC operation	Twin ASC cooperative scheduling model	Computational analysis	Developed the model that benefits: – increased productivity – environmental friendly
He *et al.* (2019). Yard crane scheduling problem in a container terminal considering risk caused by uncertainty	Container yard operation	Yard crane scheduling model	Computational analysis	Developed the model that benefits: – cost optimisation
Hu *et al.* (2019). A Three-stage decomposition method	ACT operation	Joint vehicle despatching and	Computational analysis	Developed the model that benefits: – increased

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Table A1.

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
for the joint vehicle despatching and storage allocation problem in automated container terminals		storage allocation model		productivity – cost optimisation – environmental friendly
Iris and Lam (2019). A review of energy efficiency in ports: operational strategies, technologies and energy management systems	Port development		Studies review	Identified gaps that benefits: – increased productivity – cost optimisation – environmental friendly
Lam *et al.* (2019). Green port marketing for sustainable growth and development. Transport policy	Port development		Qualitative analysis	Identified gaps that benefits: – cost optimisation – environmental friendly
Liu *et al.* (2019). Product packing and stacking under uncertainty: a robust approach	Logistics operation	Stacking decision-making model	Computational analysis	Developed the model that benefits: – increased productivity – cost optimisation
Lu and Wang (2019). A study on multi-ASC scheduling method of automated container terminals based on graph theory	ACT operation	Multi ASC scheduling model	Computational analysis	Developed the model that benefits: – increased productivity – cost optimisation
Mohammadi and Shirazi (2019). Towards high degree flexible routing in collision-free FMSS through automated guided vehicles' dynamic strategy: a simulation metamodel	AGV operation	AGV dynamic routing model	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation
Shi *et al.* (2019). Upgrading port-originated maritime clusters: insights from Shanghai's experience	Port development		Qualitative analysis	Identified gaps that benefits: – increased productivity – cost optimisation – environmental friendly
Thanos *et al.* (2019). Despatch and conflict-free routing of capacitated vehicles with storage stack allocation	AGV operation	AGV despatch and conflict-free routing model	Computational analysis	Developed the model that benefits: – increased productivity – cost optimisation
Wang *et al.* (2019b). Alignments between		Terminal service process	Empirical analysis	Identified gaps that benefits:

Table A1.

(*continued*)

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
strategic content and process structure: the case of container terminal service process automation	Container terminal development	automation evaluator		– increased productivity – cost optimisation
Zhang *et al.* (2019). Modelling the productivity and stability of a terminal operating system with quay crane double cycling	Container terminal operation	Double cycling quay crane productivity modelling	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation
Zhan *et al.* (2019). Scheduling quay cranes and yard trucks for unloading operations in container ports	Container terminal operation	Quay cranes and trucks for unloading modelling	Computational analysis	Developed the model that benefits: – increased productivity – cost optimisation
Zhu *et al.* (2019). The two-stage search algorithm for the inbound container unloading and stacking problem	ACT operation	Inbound unloading and stacking model	Computational analysis	Developed the model that benefits: – increased productivity
Kim and Hong (2015). A tracking algorithm for autonomous navigation of AGVs in an automated container terminal	AGV operation	AGV Navigation tracking algorithm	Simulation analysis	Developed the model that benefits: – cost optimisation
Hoshino *et al.* (2007). Improved design methodology for an existing automated transportation system with automated guided vehicles in a seaport container terminal	AGV operation	Improved AGV operation design	Simulation analysis	Developed the model that benefits: – cost optimisation – environmental friendly
Hu *et al.* (2013). Performance analysis on transfer platforms in based automated container terminals	ACT operation	Frame bridge ACT evaluation model	Computational analysis	Developed the model that benefits: – increased productivity – cost optimisation – environmental friendly
Homayouni *et al.* (2014). A genetic algorithm for optimisation of integrated scheduling of cranes, vehicles and storage platforms at	ACT operation	Genetic algorithm for integrated scheduling	Computational analysis	Developed the model that benefits: – cost optimisation

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Table A1.

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
automated container terminals				
Rizaldi *et al.* (2015). Yard cranes coordination schemes for automated container terminals: an agent-based approach	ACT yard operation	Yard cranes coordination schemes	Simulation analysis	Developed the model that benefits: – cost optimisation
Zhao *et al.* (2015). Simulation-based optimisation for storage allocation problem of outbound containers in automated container terminals	ACT operation	Optimisation model for storage allocation	Simulation analysis	Developed the model that benefits: – increased productivity
Corman *et al.* (2016). Optimal scheduling and routing of free-range AGVs at large scale automated container terminals	AGV operation	Optimal scheduling model for AGV	Computational analysis	Developed the model that benefits: – increased productivity – cost optimisation
Doumbia-Henry (2016). Maritime, oceans and sustainability-a way forward	Port development		Studies review	Identified gaps that benefits: – cost optimisation – environmental friendly
Homayouni and Tang (2016). Optimisation of integrated scheduling of handling and storage operations at automated container terminals	ACT operation	Integrated scheduling model	Computational analysis	Developed the model that benefits: – cost optimisation
Mengjue *et al.* (2016). Storage allocation in automated container terminals: the upper level	ACT operation	Storage optimisation model	Computational analysis	Developed the model that benefits: – cost optimisation
Heilig and Voß (2017b). Information systems in seaports: a categoriation and overview	Port management		Studies review	Identified gaps that benefits: – increased productivity – cost optimisation – environmental friendly
Li *et al.* (2018a). Impact analysis of travel time uncertainty on AGV catch-up conflict and	AGV operation	Travel time uncertainty impact analysis model for AGV	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation

Table A1. (*continued*)

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
the associated dynamic adjustment				
Ribino *et al.* (2018). Agent-based simulation study for improving logistic warehouse performance	AGV operation	Agent-based simulation model for AGV	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation
Wang *et al.* (2019b). Analysis and design of typical automated container terminals layout considering carbon emissions	ACT development	CO_2 emission model in ACT	Computational analysis	Developed the model that benefits: – increased productivity – cost optimisation – environmental friendly
Zhao *et al.* (2019). Research on cooperative scheduling of automated quayside cranes and automatic guided vehicles in an automated container terminal	ACT operation	AQC and AGV cooperative scheduling model	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation
Lau and Lee (2008b). Traffic control of internal tractors in port container terminal using simulation	Container terminal operation	Traffic control simulation model	Simulation analysis	Developed the model that benefits: – increased productivity
Li *et al.* (2011). Design and control of automated guided vehicle systems: a case study	AGV operation		Case study	Identified gaps that benefits: – environmental friendly
Hamdi *et al.* (2012). A heuristic for the container stacking problem in automated maritime ports	ACT operation	Stacking heuristic model	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation
Zaghdoud *et al.* (2012). Optimisation problem of assignment containers to AIVs in a container terminal	AGV operation	Assignment optimisation model	Computational analysis	Developed the model that benefits: – increased productivity
Zhang *et al.* (2013). Parameters' optimization of resources in a container terminal	Container terminal operation	Resources optimisation model	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation
Anghinolfi *et al.* (2014). Optimizing train loading operations in	ACT operation	Loading operations	Computational analyses	Developed the model that benefits: – cost optimisation

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Table A1.

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
innovative and automated container terminals		optimisation model		– environmental friendly
Xin *et al.* (2014a). Rescheduling of interacting machines in automated container terminals	ACT operation	Interacting rescheduling model	Simulation analysis	Developed the model that benefits: – cost optimisation
Xin *et al.* (2014b). Trajectory planning for AGVs in automated container terminals using avoidance constraints: a case study	AGV operation	Trajectory planning model	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation
Rekik *et al.* (2015). Real-time stacking system for dangerous containers in seaport terminals	Container terminal operation	Real-time stacking model	Simulation analysis	Developed the model that benefits: – increased productivity
Umar *et al.* (2015). Hybrid multiobjective genetic algorithms for integrated dynamic scheduling and routing of jobs and automated-guided vehicle (AGV) in flexible manufacturing systems (FMS) environment	AGV operation	Integrated dynamic Scheduling and routing for AGV	Computational analysis	Developed the model that benefits: – increased productivity – cost optimisation
Heilig *et al.* (2017). Digital transformation in maritime ports: analysis and a game-theoretic framework	Port development	Game-theoretic framework for maritime port	Economic analysis	Developed the model that benefits: – increased productivity – cost optimisation – environmental friendly
Li *et al.* (2018b). Quantum ant colony optimization algorithm for AGVs path planning based on Bloch coordinates of pheromones	AGV operation	Optimization algorithm for AGV path planning		Developed the model that benefits: – cost optimisation
Shen *et al.* (2014). Study on shuttle scheduling problem in automated container terminal	ACT operation	Shuttle scheduling model	Simulation analysis	Developed the model that benefits: – cost optimisation – environmental friendly
Pjevčević *et al.* (2011). Application of DEA to	AGV operation		DEA	Developed the model that benefits:

Table A1. (*continued*)

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
the analysis of AGV fleet operations in a port container terminal		AGV efficiency measurement model		– increased productivity – cost optimisation
Acciaro and Lee (2014). Strategic determinants of terminal operating system choice: an empirical approach using multinomial analysis	Container terminal operation	Terminal operation strategic determinants	Computational analysis	Developed the model that benefits: – increased productivity – cost optimisation
Güven and Eliiyi (2014). Trip allocation and stacking policies at a container terminal	Container terminal operation	Stacking optimization model	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation
Bahnes *et al.* (2016). Cooperation between intelligent autonomous vehicles to enhance container terminal operations	AGV operation	IAV cooperative model	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation – environmental friendly
Chandrakumar *et al.* (2016). Incorporate LEAN and green concepts to enhance the productivity of transshipment terminal operations	Transshipment operation	Productivity enhancement through LEAN and GREEN	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation – environmental friendly
Meng *et al.* (2017). Impact analysis of mega vessels on container terminal operations	Container terminal operation	Mega vessels impact analysis model	Simulation analysis	Developed the instrument that benefits: – increased productivity – cost optimisation
Gattuso and Cassone (2018). AGW for efficient freight transport in container yard: models and costs	AGV operation	AGW efficient transport model	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation
Castelein *et al.* (2019). The ostensible tension between competition and cooperation in ports: a case study on intra-port competition and inter-organizational relations in the Rotterdam container handling sector	Port development		Qualitative analysis	Identified gaps that benefits: – cost optimisation – environmental friendly

(*continued*)

Table A1.

Research study	Research focus	Innovation achieved	Methodologies applied	Research contribution
Li and Lu (2019). Maritime autonomous surface ships (MASS): implementation and legal issues	Shipping operation		Qualitative analysis	Identified gaps that benefits: – cost optimisation – environmental friendly
Zhan *et al.* (2019). Study on AGVs battery charging strategy for improving utilization	AGV operation	Battery utilisation model	Simulation analysis	Developed the model that benefits: – increased productivity – cost optimisation

Table A1.

Note: IAV = Intelligent autonomous vehicle

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