ORIGINAL ARTICLE

Literature review and comparative analysis of inland waterways transport: "Container on Barge"

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Abstract

Container on Barge (COB) facilitates intermodal transportation by transporting shipping containers on barge tows. COB has seen rapid expansion globally over the past 20 years, providing a cost-efficient, environmentally friendly, and congestion-reducing mode of container transportation. European countries have led COB transportation in both study and application over the past two decades. However, increasing interest is observed in both the USA and Asia. In this literature review and comparative analysis, 135 COB-focused peer-reviewed articles are reviewed and analyzed to systematically describe the development and current status of COB transportation research. The relevant literature is analyzed to reveal publication rates and titles, geographical regions of interest, research questions, applied methodologies, advantages of COB transportation, and key success factors. The aim of our effort is to provide information on various aspects of COB development among different regions in the world and to summarize the existing literature to support and guide future COB development.

Keywords Container on barge · Inland waterways transport (IWT) · Maritime transportation · Intermodal transportation · Literature review · Comparative analysis

1 Introduction

With the increasing growth in the global container shipping market, the inland waterways transport (IWT) of containers is garnering increasing interest as a reliable and low-cost alternative mode to roadway transportation (Konings 2007; Caris et al. 2011). Container on Barge (COB) transports containers between river ports and seaports via barge tows along accessible inland waterways (Shobayo and van Hassel 2019). Beginning in the 1990s, COB started to develop in

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Northwestern Europe (Netherlands, France, Germany, and Belgium). With the supportive regional government policies, COB transportation embraced a significant market growth, making a breakthrough to three million twenty-foot equivalent units (TEUs) by the end of 2000, three times the TEUs in 1990 (Konings and Priemus 2008). After 2000, with the enabling political arrangements of the container transportation channel between the seaports (Shanghai, Shenzhen, and other southern seaports) in China and European seaports, COB expanded well into the Serbia, Slovakia, Austria, and Poland where IWT shows strong connectivity with seaports (Grobarcikova and Sosedova 2016). In the last decade, China and the USA appear to be catching up, with interest in the development of COB transportation (Konings 2006; Notteboom et al. 2020).

Based on the existing literature, there are three widely accepted benefits of COB that make its development worthwhile. First, transporting containers by barge can significantly reduce shipping costs because of the high fuel efficiency of IWT (per ton per mile) compared with truck or rail transportation. According to the Oklahoma Department of Transportation (2019), on average, one gallon of fuel can move a ton of cargo 576 miles by barge, 413 miles by train, and only 155 miles by truck. The infrastructure cost for barge transportation is 12.6 EUR per thousand ton-kilometers, while it is 45.21 EUR for train and 48.42 for truck, indicating that barge transportation infrastructure cost is about four times less than train or truck (Gharehgozli and Zaerpour 2018). Second, COB is more environmentally friendly compared with other transportation modes. For example, the environmental cost for transporting containers by barge is 0.27 cents per ton per kilometer, while it is 2.01 cents by train and 0.80 cents by truck (Gharehgozli and Zaerpour 2018). Third, COB transportation can alleviate port congestion. According to a study conducted by Zweers et al. (2019), 40% of trucks in the Port of Rotterdam experience heavy delays, and the development of COB could enable the port to switch container transport from truck to barge, thus making the port area more accessible.

From our inquiry, it appears that this article is the first to present a comprehensive literature review and comparative analysis of COB research. The aim of our work is to describe the current status of COB research, summarize information related to key aspects of COB research among different regions in the world, and provide a literature database for future COB research and development. The article examines the similarities and differences of existing COB studies and classifies each reviewed article to enable future researchers to efficiently locate COB transportation information of interest.

A systematic search of the peer-reviewed literature related to Container on Barge (COB) was conducted. Nine keywords were identified: "container," "barge," "inland waterways," "IWT," "river transportation," "inland terminal," "Yangtze transportation," "Mississippi transportation," and "multimodal transportation." We used two search strategies: (1) search for keywords "container" and "barge" simultaneously and (2) individually search keyword combinations by combining each of the other eight keywords with the keyword "container." Using these search strategies, we identified 285 articles published from January 2000 to April 2021 from the following six databases: Compendex, TRID, Business Source Complete, ABI/INFORM Collection, INSPEC, and Web of Science. After

reviewing the content of these articles, 135 of them were retained for inclusion in our analysis, judging from their focus and high relevance to COB.

Our findings are organized in the seven sections that follow: (1) Annual publication count of COB articles, (2) Journals publishing COB research, (3) Geographic region of COB research, (4) Research questions studied in COB literature, (5) Methodological approaches employed in COB research, (6) Advantages of COB, and (7) COB success factors. Each section describes a key aspect found to be important in describing and understanding the COB literature. In each section, the selected 135 COB articles are further classified to provide detail into each key aspect of COB.

2 Annual publication count of COB articles

In this section, the selected 135 Container on Barge articles are counted per year to compute the annual publication count (the number of articles published per year). Figure 1 shows the number of COB articles published each year from January 2000 to April 2021. The annual publication count fluctuates between zero and 3 from 2000 to 2010 before it begins to increase gradually until reaching the peak in 2020 with 19 articles published. Four COB articles were published in the first 4 months of 2021.

Comparing the past decade with the one prior, the average annual publication count of COB articles has more than doubled. The year in the past decade with the lowest COB publication count (2012) has five COB publications, which is greater than that of any year between 2000 to 2010. Another observed trend is the rapid growth in annual publication count observed between 2011 and 2020, as shown in Fig. 1. These observations indicate that research on COB is receiving increasing attention from scholars.
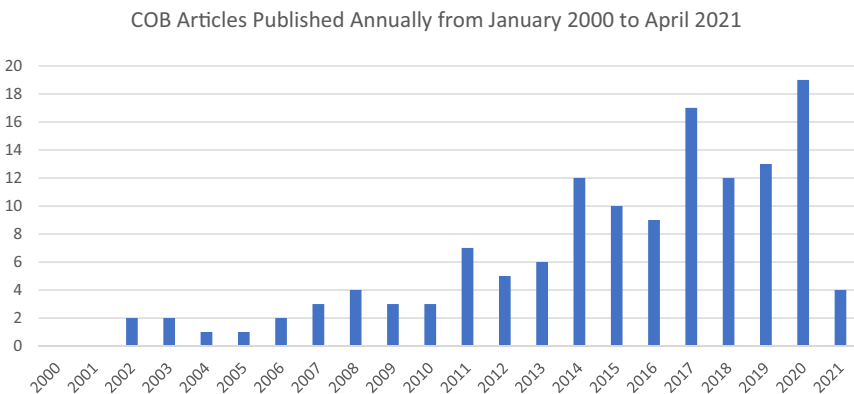

Fig. 1 COB articles published annually from January 2000 to April 2021

3 Journals publishing COB research

The journals that published the selected 135 COB articles between January 2000 and April 2021 are reported in this section. As presented in Table 1, the *Journal of Transport Geography* ranks in the top position with ten COB publications. This is closely followed by *European Journal of Operational Research* and *Transportation Research Part E: Logistics and Transportation Review*, each with nine COB publications, *Transportation Research Record* with eight COB publications, and *Maritime Economics & Logistics* with seven COB publications.

In general, the journals publishing COB research indicate a wide range of application areas. There are more than 60 journals across a wide variety of topical research areas that have published at least one COB article between January 2000 and April 2021. This indicates that COB is being studied not only by scholars in the transportation area but also in other areas, e.g., computer science, economics, and civil engineering.

4 Geographic region of COB research

In this section, the articles were classified according to their regional scope. We identify the country of interest emerging from each article and provide their reference number of publications in each classification, and share in total articles. In Table 2, it is observed that 33 articles (24%) do not have a specific geographical focus, while the remaining 102 articles (76%) focus on at least one country in Asia, Oceania, Europe, or North America. Our literature search did not yield any COB articles focusing on Africa or South America. Articles that study more than one country are classified under each country studied in order to present comprehensive geographic coverage. These articles appear more than once in Table 2.

Of the articles with a regional focus, the largest number are focused on the Netherlands (26%), followed by China (13%), Germany (10%), Belgium (10%), and the USA (8%). Articles that focus on European countries account for the majority of reviewed articles, indicating strong COB interest and/or activity within Europe. Konings et al. (2010) explain this phenomenon as the result of a continuous and strategic investment made by European countries over the past three decades to stimulate COB development in Northwestern Europe (including Netherlands, France, and Belgium), so as to accelerate a container transportation modal shift from truck to barge. Seventeen articles study COB transportation in China, making it the country with greatest COB interest and/or activities in Asia. Container on barge transport on Yangtze River has been in a rapid growth phase since the Chinese government issued the 2016 National Plan for the Yangtze River Economic Belt Development (Yang et al. 2021).

There are 15 articles that focus on more than one country. Konings (2006), Konings and Priemus (2008), and Konings and Maras (2011) all focus on the development of COB transportation along the Rhine River (France, Switzerland,

Table 1 Journals publishing COB research

Journal title	Reference(s)	Number of articles
Journal of Transport Geography	Fremont and Franc (2010), Konings et al. (2013), Caris et al. (2011), Konings (2007), Radmilovic et al. (2011), Caris et al. (2014), Ramaekers et al. (2017), Santos and Soares (2017), Kolar et al. (2018) and Yang et al. (2021)	10
European Journal of Operational Research	Gharehgozli and Zaerpour (2018), Zehendner and Feillet (2014), Vis and De Koster (2003), Ursavas and Zhu (2016), Macharis and Bontekoning (2004), Hansen et al. (2008), Zhang et al. (2017), Zhen et al. (2018) and Kumawat et al. (2021)	9
Transportation Research Part E: Logistics and Transportation Review	Zhang et al. (2016), Choong et al. (2002), Fazi (2019), Gumuskaya et al. (2020), Fazi et al. (2020), Schepler et al. (2017), Zhen (2014), Pant et al. (2011) and Tan et al. (2018)	9
Transportation Research Record	Konings and Maras (2011), Konings (2006), Konings et al. (2010), Li et al. (2014), Maras (2008), Konings and Priemus (2008), Bai et al. (2017) and Bomba and Harrison (2002)	8
Maritime Economics & Logistics	Gumuskaya et al. (2020a, b), Yahalom et al. (2020), Cochrane (2008), Infante et al. (2009), Veenstra et al. (2012), Lee et al. (2014a, b) and Musso and Sciomachen (2020)	7
Flexible Services and Manufacturing Journal	Douma et al. (2011a, b), Corman et al. (2017), Caris et al. (2012), Zweers et al. (2020), Heilig and Voss (2017) and Zehendner et al. (2015)	6
Decision Support Systems	Fazi et al. (2015), Guo et al. (2020), Douma et al. (2012) and van Riessen et al. (2016)	4
OR Spectrum	Lee et al. (2006), Kemme (2012), Lee et al. (2014a, b) and Duinkerken et al. (2006)	4
Research in Transportation Business & Management	Clott et al. (2015), Williamsson et al. (2020), de Langen et al. (2017) and Baccelli and Morino (2020)	4
Transportation Research Part A: Policy and Practice	Notteboom et al. (2020), Smid et al. (2016), Wiegmans et al. (2015) and Zhang et al. (2020)	4
Transportation Research Part C: Emerging Technologies	Douma et al. (2009), Li et al. (2015), Fazi and Roodbergen (2018) and Hu et al. (2018)	4
IEEE Transactions on Automation Science and Engineering	Boschian et al. (2011), Maione et al. (2016) and Fanti et al. (2017)	3

Table 1 (continued)

Journal title	Reference(s)	Number of articles
Maritime Policy & Management	Paixao Casaca and Marlow (2005), Van den Berg and De Langen (2015) and Fu et al. (2010)	3
Sustainability	Ypsilantis and Zuidwijk (2019), Roukouni et al. (2020) and Kotowska et al. (2018)	3
Transportation Science	Zuidwijk and Veenstra (2015), Mishra et al. (2017) and Bouchery et al. (2020)	3
Asian Journal of Shipping and Logistics	Wiegmans and Konings (2015) and Seo et al. (2017)	2
International Journal of Production Research	Gharehgozli et al. (2017) and Ambra et al. (2019)	2
International Journal of Shipping and Transport Logistics	Zhang et al. (2014) and Gracia et al. (2019)	2
Journal of Shipping and Trade	Shobayo and van Hassel (2019) and Castelein et al. (2019)	2
LogForum	Wagener (2014, 2017)	2
Polish Maritime Research	Abramowicz-Gerigk and Burciu (2019), Radonjic et al. (2020)	2
Asia Pacific Viewpoint	Notteboom (2007)	1
Business & Information Systems Engineering	Balster et al. (2020)	1
Computers & Industrial Engineering	Nur et al. (2020)	1
Computers & Operations Research	Lin et al. (2014)	1
Computers in Industry	Braekers et al. (2013)	1
Container Terminals and Cargo Systems	Duinkerken et al. (2006)	1
Environmental Research Letters	Kaack et al. (2018)	1
European Journal of Control	Larsen et al. (2021)	1
European Journal of Transport and Infrastructure Research	Jourquin et al. (2014)	1
Expert Systems with Applications	Douma et al. (2011a, b)	1
HKIE Transactions	Li (2016)	1
IEEE Transactions on Systems Man Cybernetics: Systems	Dotoli et al. (2017)	1
International Journal of Logistics Research and Applications	Meers et al. (2018)	1
International Journal of Production Economics	Kengpol et al. (2012)	1

Table 1 (continued)

Journal title	Reference(s)	Number of articles
Journal of Control Science and Engineering	Zhao et al. (2018)	1
Journal of Mechanical Engineering	Park et al. (2009)	1
Journal of Ocean Engineering and Science	Liu et al. (2017)	1
Logistics Information Management	Kelleher et al. (2003)	1
Management Review: An International Journal	Nasir et al. (2019)	1
Mathematical Problems in Engineering	Han et al. (2020)	1
Naval Research Logistics	Zweers et al. (2019)	1
Neural Computing & Applications	Zhu et al. (2021)	1
Omega-International Journal of Management Science	Alfandari et al. (2019)	1
Operations and Supply Chain Management: An International Journal	Roso et al. (2015)	1
Proceedings of the Institution of Civil Engineers: Maritime Engineering	Yu et al. (2018)	1
Proceedings of the Institution of Mechanical Engineers. Proceedings Part M, Journal of Engineering for the Maritime Environment	Ding and Tseng (2013)	1
Progress in Artificial Intelligence	Lopez-Plata et al. (2018)	1
Promet-Traffic & Transportation	Kos et al. (2017)	1
Prosperitas	Bojić et al. (2020)	1
Research in Transportation Economics	Wadhwa et al. (2019)	1
Scientific Journal of Silesian University of Technology	Scherbina et al. (2019)	1
Scientific Journals of the Maritime University of Szczecin	Hann et al. (2016)	1
Simulation Modelling Practice and Theory	Dulebenets et al. (2015)	1
Supply Chain Forum	Lendjel and Fischman (2014)	1
Symmetry-Basel	Dai and Yang (2020)	1
Technological Forecasting and Social Change	Lun et al. (2013)	1
Tehnički Vjesnik	Rajkovic et al. (2016)	1

Table 1 (continued)

Journal title	Reference(s)	Number of articles
Transport Policy	Monios and Wilmsmeier (2013)	1
Transport Problems	Grobarcikova and Sosedova (2016)	1
Transportation Planning and Technology	van der Horst et al. (2019)	1
Transportation Research Part B: Methodological	Teye et al. (2017)	1
Advanced Engineering Informatics	Feng et al. (2015)	1
Applied Soft Computing	Maras et al. (2013)	1

Table 2 COB geographic regions and frequency of study

Focus	Continent	Country	Reference(s)	Number of articles	Percentage of articles
Regional focus	Asia	China	Li (2016), Lun et al. (2013), Konings et al. (2010), Zhang et al. (2020), Han et al. (2020), Tan et al. (2018), Zhu et al. (2021), Cochrane (2008), Dai and Yang (2020), Zhao et al. (2018), Ding and Tseng (2013), Feng et al. (2015), Fu et al. (2010), Zhen et al. (2018), Yang et al. (2021), Seo et al. (2017), and Bojić et al. (2020)	17	13
		Malaysia	Nasir et al. (2019)	1	1
		South Korea	Park et al. (2009)	1	1
		Thailand	Kengpol et al. (2012)	1	1
		Vietnam	Kengpol et al. (2012)	1	1
	Oceania	Australia	Teye et al. (2017)	1	1
	Europe	Netherlands	Fazi et al. (2015), Douma et al. (2009, 2011a, b), Mishra et al. (2017), Gharehgozli et al. (2017), Fazi and Roodbergen (2018), Duinkerken et al. (2006), Fazi (2019), Ypsilantis and Zuidwijk (2019), van der Horst et al. (2019), Castelein et al. (2019), Konings et al. (2013), Konings (2007), Konings and Maras (2011), Konings (2006), Konings et al. (2010), Konings and Priemus (2008), Guo et al. (2020), Gumuskaya et al. (2020a, b), Zweers et al. (2020), Gumuskaya et al. (2020a, b), Fazi et al. (2020), Jourquin et al. (2014), Kotowska et al. (2018), Seo et al. (2017), Wiegmans et al. (2015), van Riessen et al. (2016), Veenstra et al. (2012), Zhang et al. (2014), Douma et al. (2011a, b), Douma et al. (2012), Bouchery et al. (2020), Roukouni et al. (2020), Larsen et al. (2021), and Van den Berg and De Langen (2015)	35	26
		Belgium	Braekers et al. (2013), Caris et al. (2012), Shobayo and van Hassel (2019), Caris et al. (2011), Meers et al. (2018), Konings and Maras (2011), Konings (2006), Konings et al. (2010), Konings and Priemus (2008), Guo et al. (2020), Ramaekers et al. (2017), Jourquin et al. (2014), and Kotowska et al. (2018)	13	10

Table 2 (continued)

Focus	Continent	Country	Reference(s)	Number of articles	Percentage of articles
		Germany	Konings and Maras (2011), Konings (2006), Konings et al. (2010), Konings and Priemus (2008), Grobarcikova and Sosedova (2016), Notteboom et al. (2020), Notteboom (2007), Guo et al. (2020), Kotowska et al. (2018), Yang et al. (2021), Balster et al. (2020), Kemme (2012), and Wagener (2014)	13	10
		France	Zehendner and Feillet (2014), Lendjel and Fischman (2014), Fremont and Franc (2010), Konings and Maras (2011), Konings (2006), Konings et al. (2010), Konings and Priemus (2008), Kotowska et al. (2018), Zehendner et al. (2015), and Schepler et al. (2017)	10	7
		Italy	202, Boschian et al. (2011), Baccelli and Morino (2020), Dotoli et al. (2017), Infante et al. (2009), and Musso and Sciomachen (2020)	6	4
		Serbia	Rajkovic et al. (2016), Radonjic et al. (2020), Maras et al. (2013), and Bojić et al. (2020)	4	3
		Switzerland	Konings and Maras (2011), Konings (2006), Konings et al. (2010), and Konings and Priemus (2008)	4	3
		Poland	Hann et al. (2016), Abramowicz-Gerigk and Burciu (2019), and Wagener (2014)	3	2
		Portugal	Schepler et al. (2017) and Santos and Soares (2017)	2	1
		Spain	Lopez-Plata et al. (2018) and Santos and Soares (2017)	2	1
		Sweden	Roso et al. (2015) and Williamsson et al. (2020)	2	1
		Austria	Grobarcikova and Sosedova (2016)	1	1
		Croatia	Kos et al. (2017)	1	1
		Czech Republic	Kolar et al. (2018)	1	1
		Slovakia	Grobarcikova and Sosedova (2016)	1	1
		Turkey	Ursavas and Zhu (2016)	1	1

Table 2 (continued)

Focus	Continent	Country	Reference(s)	Number of articles	Percentage of articles
		Ukraine	Scherbina et al. (2019)	1	1
	North America	USA	Bomba and Harrison (2002), Choong et al. (2002), Liu et al. (2017), Clott et al. (2015), Konings et al. (2010), Yahalom et al. (2020), Nur et al. (2020, p. 201), Pant et al. (2011), Wadhwa et al. (2019), and Bai et al. (2017)	11	8
		Canada	Maione et al. (2016)	1	1
		Mexico	Gracia et al. (2019)	1	1
	South America	N/A	N/A	0	0
	Africa	N/A	N/A	0	0
No geographic regional focus			Gharehgozli & Zaerpour (2018), Zuidwijk and Veenstra (2015), Li et al. (2014), Dulebenets et al. (2015), Vis and De Koster (2003), Corman et al. (2017), Li et al. (2015), Alfandari et al. (2019), Zhang et al. (2016), Maras (2008), Kelleher et al. (2003), Zweers et al. (2019), Kaack et al. (2018), Lin et al. (2014), Caris et al. (2014), Wagener (2017), Heilig & Voss (2017), Smid et al. (2016), Macharis and Bontekoning (2004), Paixao Casaca & Marlow (2005), Ambra et al. (2019), Hu et al. (2018), Lee et al. (2006), Lee et al. (2014), Zhang et al. (2017), Yu et al. (2018), Zhen (2014), de Langen et al. (2017), Wiegmans & Konings (2015), Radmilovic et al. (2011), Kumawat et al. (2021), Monios and Wilmsmeier (2013), and Hansen et al. (2008)	33	24

and Germany), the port areas of Rotterdam (Netherlands), and the port area of Antwerp (Belgium). Konings et al. (2010) compare COB development in Texas (USA) and the Port of Rotterdam (Netherlands) to conclude that COB is a mature mode of transportation in the Netherlands while it is still in an early phase in the USA. Notteboom (2007) and Notteboom et al. (2020) explore a general pattern of COB business development, by comparing COB development conditions between the Rhine River (Germany, Belgium, France, Netherlands, and Switzerland) and the Yangtze River (China). They suggest that COB development in single-river systems seems to follow a similar path, although heavily influenced by geographic conditions, local supportive policies, development strategies, and other factors. Grobarcikova and Sosedova (2016) focus on the upper area of the Rhine River, specifically the Danube Canal (Germany, Austria, and Slovakia). They conclude that current COB research studying the Danube Canal does not consider the major challenge of unstable water level and how this limits COB development and submit this challenge should not be omitted in future research.

The observations from Table 2 show that (1) COB studies are concentrated within a limited number of developed or rapidly developing countries with favorable inland waterway resources, i.e., Germany, Belgium, France, the Netherlands, China, and the USA, and (2) regional characteristics of COB are of obvious interest since the vast majority of COB articles (76%) have a regional focus.

5 Research questions studied in COB literature

In this section, the COB-related research questions studied in the 135 selected articles are reviewed. Our review indicates that the COB research questions studied globally are quite diversified. In Table 3, there are five classifications and 23 distinct research questions listed with their corresponding author information, number of articles, and share in total articles. Among the five classifications, almost one-third of the selected articles (32%) are categorized as intermodal transportation, followed by 21% of articles classified as terminal operations and 18% articles classified as COB performance. Furthermore, at a more detailed level, the most frequently researched topic is intermodal transportation network design (16%), followed by the ship routing problem (14%), barge container terminal operations (13%), and comparative strategies for COB development (12%). In addition, barge handling efficiency is studied in 14 papers (10%), and empty container repositioning by barge is studied in 8 articles (6%). The remaining COB research topics are studied less than 5% among the reviewed articles.

Twenty-two of the reviewed 135 articles (16%) study intermodal transportation network designed for or integrated with COB transportation. This involves carriers (barges, trains, and trucks), producers, customers, and terminal operators who ship cargo between deep-sea ports and inland ports. More than one decade earlier, Kelleher et al. (2003) discussed the possibility of developing a more efficient and environmentally friendly intermodal transportation system that utilizes inland waterway resources. As shown in Fig. 1, COB-related transportation has gained increasing attention since 2014, showing increasing support for Kelleher's vision. Li et al.

Table 3 Research questions studied in COB literature

Classification	Research question	Reference(s)	Number of articles	Percentage of articles
Intermodal transportation	Intermodal transportation network design	Li et al. (2015), Zehendner and Feillet (2014), Rajkovic et al. (2016), Li et al. (2014), Corman et al. (2017), Grobarcikova and Sosedova (2016), Hann et al. (2016), Kelleher et al. (2003), Fremont and Franc (2010), Liu et al. (2017), Clott et al. (2015), Caris et al. (2012), Guo et al. (2020), Yahalom et al. (2020), Bouchery et al. (2020), Wagener (2014), Radmilovic et al. (2011), Bai et al. (2017), Nasir et al. (2019), Tan et al. (2018), Veenstra et al. (2012), and Ambra et al. (2019)	22	16
	Empty container repositioning by barge	Choong et al. (2002), Braekers et al. (2013), Roso et al. (2015), Alfandari et al. (2019), Maras (2008), Kolar et al. (2018), Zhang et al. (2020), and Wadhwa et al. (2019)	8	6
	Intermodal facility location	Teye et al. (2017), Lin et al. (2014), Dotoli et al. (2017), and Monios and Wilmsmeier (2013)	4	3
	Inter-terminal container movement	Mishra et al. (2017), Gharehgozli et al. (2017), Hu et al. (2018), and Heilig and Voss (2017)	4	3
	Port congestion management	Meers et al. (2018), Gumuskaya et al. (2020a, b), and Zweers et al. (2020)	3	2
	Intermodal transportation policy	Baccelli and Morino (2020) and Kotowska et al. (2018)	2	1
	Demurrage and detention reduction	Fazi and Roodbergen (2018)	1	1

Table 3 (continued)

Classification	Research question	Reference(s)	Number of articles	Percentage of articles
Terminal operations	Barge container terminal operation	Vis and De Koster (2003), Dulebenets et al. (2015), Konings and Priemus (2008), Nur et al. (2020), Smid et al. (2016), Cochrane (2008), Lopez-Plata et al. (2018), Schepler et al. (2017), Zhao et al. (2018), Yu et al. (2018), Park et al. (2009), Zhang et al. (2017), Zehendner et al. (2015), Lee et al. (2006), Musso and Sciomachen (2020), Kumawat et al. (2021), and Zhen (2014)	17	13
	Barge information sharing	Zuidwijk and Veenstra (2015), Zhang et al. (2016), and Fanti et al. (2017)	3	2
	Berth allocation problem	Li (2016), Ursavas and Zhu (2016), and Hansen et al. (2008)	3	2
	Inter-organizational relationships	Duinkerken et al. (2006), Castelein et al. (2019) and van der Horst et al. (2019),	3	2
	Container stacking problem	Gharehgozli and Zaerpour (2018) and Fazi (2019)	2	1
	Barge rotation planning and quay scheduling	Douma et al. (2009)	1	1
Barge management	Barge handling efficiency	Shobayo and van Hassel (2019), Douma et al. (2011a, b), Konings and Maras (2011), Konings (2006), Konings et al. (2013), Caris et al. (2011), Konings (2007), Gracia et al. (2019), Douma et al. (2011a, b), Douma et al. (2012), Feng et al. (2015), Fu et al. (2010), Lee et al. (2014a, b), and Kemme (2012)	14	10
	Barge capacity optimization	Zweers et al. (2019), Scherbina et al. (2019), and Ramaekers et al. (2017)	3	2
	Push-boat assignment	Radonjic et al. (2020) and Zhen et al. (2018)	2	1
	Transportation disruption	Ding and Tseng (2013) and Pant et al. (2011)	2	1
	Barge fleet size standardization	Ypsilantis and Zuidwijk (2019)	1	1

Table 3 (continued)

Classification	Research question	Reference(s)	Number of articles	Percentage of articles
COB performance	Comparative strategies for COB development	Notteboom et al. (2020), Notteboom (2007), Konings et al. (2010), Williamson et al. (2020), Caris et al. (2014), de Langen et al. (2017), Roukouni et al. (2020), Wiegmans & Konings (2015), Maione et al. (2016), Yang et al. (2021), Wiegmans et al. (2015), Wagener (2017), Jourquin (2014), Han et al. (2020), Santos and Soares (2017), and Paixao Casaca and Marlow (2005)	16	12
	Environmental impact assessment	Lun et al. (2013), Dai and Yang (2020), Zhang et al. (2014), Kos et al. (2017), and Kaack et al. (2018)	5	4
	Facility and equipment performance	Lendjel and Fischman (2014) and Abramowicz-Gerigk and Burciu (2019)	2	1
	Feasibility study	Bomba and Harrison (2002)	1	1
Ship routing problem	Ship routing problem	Zweers et al. (2019), Ypsilantis & Zuidwijk (2019), Fazi et al. (2015), Alfandari et al. (2019), Maras (2008), Gumuskaya et al. (2020a, b), Fazi et al. (2020), Maras et al. (2013), Boschian et al. (2011), Macharis and Bontekoning (2004), Balster et al. (2020), Larsen et al. (2021), Lee et al. (2014a, b), Zhu et al. (2021), Seo et al. (2017), Kengpol et al. (2012), Bojić et al. (2020), van Riessen et al. (2016), and Infante et al. (2009)	19	14

(2015) present a multilevel container flow planning model to study characteristics of an intermodal transportation network, including mode changes, capacity constraints, and scheduling time. The model successfully lowers the intermodal container transportation cost in different simulation scenarios. Ocean shipping is connected to inland transport by combining truck, rail, and barge transportation. Li et al. (2014) point out that, by implementing COB transportation as a mode to transport containers between deep-sea terminals and inland waterway terminals, container distribution efficiency at seaports can be increased and the operational pressure can be reduced on terminals when faced with highly increasing cargo transport demand. Corman et al. (2017) apply a presumed consumer equilibrium principle that includes both single and multiple container units to be transported by multiple modes. Their model indicates that COB can compete with truck and train under certain conditions with appropriate policy support, accessibility to waterway, and time-insensitive cargoes. Grobarcikova and Sosedova (2016) attempt to design and merge a COB transportation chain into the existing Rhine–Danube intermodal transportation system but fail, due to unstable water level and insufficient infrastructure. Hann et al. (2016) analyze the effects of main transportation parameters of the river–land intermodal transportation on the Oder Waterway in Poland. Nasir et al. (2019) interviewed container transportation professionals in Malaysia and found COB can be crucial to building an improved intermodal transportation network in future.

There are 19 articles (14%) that study the COB ship-routing problem. The ship-routing problem is receiving attention from researchers who seek to manage the increasing requirement from seaport terminals to distribute containers more efficiently to inland ports (Zweers et al. 2019). Maras (2008) develop an inland waterway COB shipping route model that accommodates port calls for empty containers. Ypsilantis and Zuidwijk (2019) build a mixed-integer linear programming (MILP) model to optimize barge fleet size and barge routes on inland waterways and investigate the suitability of COB transportation, while considering cost savings and transportation sustainability. Fazi et al. (2020) optimize container IWT between dry ports and seaports in the Port of Rotterdam area aiming to achieve economies of scale and diversion of traffic from road transport.

Seventeen papers (13%) study the barge container terminal operations to increase operational efficiency in terms of operational time and/or cost. Dulebenets et al. (2015) evaluate if terminal operation efficiency can be improved if containers are stacked on a barge for next transshipment instead of being moved internally to the storage yard. Smid et al. (2016) analyze the operation cost sensitivity of different size container terminal and show that larger terminals generally have a greater container flow throughput to generate economies of scale. Lopez-Plata et al. (2018) optimize the internal delivery vehicle scheduling with a customized heuristic algorithm that considers real-world scenarios and disruptive events.

Sixteen papers (12%) compare the strategies for COB development. Notteboom et al. (2020) conduct a comparison study between the Rhine and Yangtze rivers and identify that the traffic distribution, regional economies, and terminal ownerships are the main factors caused different COB development path between them. Wiegmans and Konings (2015) compare barge container transportation with truck-only mode to conclude that, with the exception of handling large flow of containers in

small inland waterway terminals, COB-integrated intermodal transportation would gain obvious competitiveness over truck-only mode. Williamsson et al. (2020) compare two attempted COB development cases from Sweden to unveil that policy support from local government can significantly boost COB development.

Interestingly, eight studies (6%) focus on the empty container repositioning by barge. The efficient transport of empty containers by barge is getting more attention in recent years since it may significantly enhance a shipping company's profitability by reducing empty container storage and/or leasing costs (Maras 2008; Alfandari et al. 2019). Roso et al. (2015) draw comparisons between empty container transportation by barge and by truck in terms of economic effects, transportation time efficiency, and environmental sustainability. Braekers et al. (2013) build a case study of the Port of Antwerp and design a decision support tool of COB transportation that takes empty container barge transportation into consideration.

The research questions studied in COB literature vary widely. It appears that COB development relies heavily on the natural geographical waterway conditions and infrastructure investment. These unique functional and structural characteristics drive a variety of challenges encountered during COB development and motivate investigations in the success factors and paths for COB development. In addition, COB transportation seldom operates on its own but connects to an existing intermodal transportation network where multiple parties involved in development and operations. Therefore, a multitude of complex COB research challenges are derived from complicated real-world applications, reflecting the need for enhancing operation and coordination efficiency.

6 Methodological approaches employed in COB research

The methodological approaches employed in the articles of our sample are categorized in this section and in Table 4. Sixteen distinct methodological approaches are identified and are presented along with the article reference, number of articles, and share in total articles of each category. Based on our review, the most frequently applied methodological approach to COB research is simulation (23%), followed by case study analysis (19%) network optimization (11%), economic analysis (10%), and mixed-integer programming (10%). Studies that apply more than one methodology appear multiple times in Table 4.

Among the methodologies, 31 out of the 135 articles (23%) implement a simulation approach. Zehendner and Feillet (2014) combine simulation with mixed-integer programming model to minimize the overall delay time at an intermodal container terminal by finding optimal solutions to allocate truck and straddle carries for internal container movement between yard and different transportation modes (train or barge). Li et al. (2015) propose a linear programming model to control and reassign container flows in an intermodal transportation network with multiple objectives, to minimize transportation time and costs. The simulation results from their predesigned scenarios show that the model works well under different levels of market demand, with a certain allowed level of demand prediction errors. Caris et al. (2011) conduct a discrete event simulation to study the cooperation between

Table 4 Methodological approaches employed in COB research

Methodology	Reference(s)	Number of articles	Percentage of articles
Simulation	Zehendner and Feillet (2014), Li et al. (2015), Li et al. (2014), Shobayo and van Hassel (2019), Caris et al. (2012), Grobarcikova and Sosedova (2016), Gharehgozli et al. (2017), Duinkerken et al. (2006), Dulebenets et al. (2015), Caris et al. (2011), Meers et al. (2018), Douma et al. (2011), Douma et al. (2009), Yahalom et al. (2020), Gumuskaya et al. (2020a, b), Fu et al. (2010), Bouchery et al. (2020), Gracia et al. (2019), Douma et al. (2012), Larsen et al. (2021), Yu et al. (2018), Park et al. (2009), Kemme (2012), Musso and Sciomachen (2020), Zhang et al. (2014), Roukouni et al. (2020), Maione et al. (2016), Boschian et al. (2011), Pant et al. (2011), Zehendner et al. (2015), and Kumawat et al. (2021)	31	23
Case study analysis	Castelein et al. (2019), van der Horst et al. (2019), Clott et al. (2015), Roso et al. (2015), Liu et al. (2017), Liu et al. (2017), Braekers et al. (2013), Gumuskaya et al. (2020a, b), Williamsson et al. (2020), Ramaekers et al. (2017), Bojić et al. (2020), Kotowska et al. (2018), Baccelli and Morino (2020), Dotoli et al. (2017), Fanti et al. (2017), Kengpol et al. (2012), van Riessen et al. (2016), Bai et al. (2017), Feng et al. (2015), Dai and Yang (2020), Wadhwa et al. (2019), Zhang et al. (2014), Roukouni et al. (2020), Maione et al. (2016), Boschian et al. (2011), and Pant et al. (2011)	25	19
Network optimization	Liu et al. (2017), Fazi and Roodbergen (2018), Braekers et al. (2013), Rajkovic et al. (2016), Kelleher et al. (2003), Fazi et al. (2015), Corman et al. (2017), Li et al. (2015), Li et al. (2014), Clott et al. (2015), Nur et al. (2020), Dotoli et al. (2017), Feng et al. (2015), Dai and Yang (2020), and Wadhwa et al. (2019)	15	11
Economic analysis	Abramowicz-Gerigk and Burciu (2019), Konings (2006), Hann et al. (2016), Lendjel and Fischman (2014), Konings and Maras (2011), Fremont and Franc (2010), Konings et al. (2013), Jourquin et al. (2014), Seo et al. (2017), Smid et al. (2016), Wiegmans and Konings (2015), Radmilovic et al. (2011), and Bai et al. (2017)	13	10
Mixed-integer programming	Ypsilantis and Zuidwijk (2019), Teye et al. (2017), Alfandari et al. (2019), Maras (2008), Zehendner and Feillet (2014), Gumuskaya et al. (2020a, b), Zhen et al. (2018), Maras et al. (2013), Schepler et al. (2017), Lin et al. (2014), Lee et al. (2006), and Zehendner et al. (2015)	13	10
Empirical analysis	de Langen et al. (2017), Cochrane (2008), Wagener (2014, 2017), Van den Berg and De Langen (2015), Han et al. (2020), Ding and Tseng (2013), Paixao Casaca and Marlow (2005), Veenstra et al. (2012), Fu et al. (2010), and Wiegmans et al. (2015)	11	8

Table 4 (continued)

Methodology	Reference(s)	Number of articles	Percentage of articles
Heuristic optimization	Gharehgozli and Zaerpour (2018), Fazi and Roodbergen (2018), Guo et al. (2020), Fazi et al. (2020), Hansen et al. (2008), Lopez-Plata et al. (2018), Zhang et al. (2017), Infante et al. (2009), Zhen (2014), and Lee et al. (2014a, b)	10	7
Comparative analysis	Notteboom et al. (2020), Notteboom (2007), Konings (2007), Bomba and Harrison (2002), Konings et al. (2010), Yang et al. (2021), Santos and Soares (2017), and Kaack et al. (2018)	8	6
Literature review	Vis and De Koster (2003), Konings and Priemus (2008), Kolar et al. (2018), Macharis and Bontekoning (2004), Heilig and Voss (2017), Monios and Wilmsmeier (2013), and Ambra et al. (2019)	7	5
Non-optimization mathematical modeling	Lun et al. (2013), Zuidwijk & Veenstra (2015), Zhang et al. (2016), Fazi (2019), Tan et al. (2018), and Kos et al. (2017)	6	4
Stochastic modeling	Ursavas and Zhu (2016), Mishra et al. (2017), Zweers et al. (2020), Gumuskaya et al. (2020a, b), Lee et al. (2014a, b), and Kumawat et al. (2021)	6	4
Decision model	Baccelli and Morino (2020), Dotoli et al. (2017), Douma et al. (2011a, b), Fanti et al. (2017), Kengpol et al. (2012), and van Riessen et al. (2016)	6	4
Integer programming	Li (2016), Choong et al. (2002), Hu et al. (2018), and Zhao et al. (2018)	4	3
Machine learning	Balster et al. (2020), Bouchery et al. (2020), and Radonjic et al. (2020)	3	2
Linear programming	Zweers et al. (2019) and Scherbina et al. (2019)	2	1%
Interview	Nasir et al. (2019)	1	1

inland waterway terminals, to bundle container flows in intermodal barge transportation. The authors argue that, through cooperation, inland waterway terminals could generate economies of scale while reducing average barge waiting time at terminals. However, a set of bundling measures is required in future research to improve transportation efficiency. Furthermore, Caris et al. (2012) study the application of bundling strategies on interterminal container transportation that moves containers between terminals with truck, barge, and/or automated guided vehicle. By using game theory combined with simulation experiments, the authors argue that bundling strategies can bring economic benefits only when high demand occurs at terminals.

Case study analysis is the second most frequently employed methodological approach found in COB research, comprising 19% of our sample. Castelein et al. (2019) conduct a case study of the Port of Rotterdam to identify the underlying problems caused by interorganizational cooperation and competition under pressure. Their case study reveals the significance of mutual trust, value sharing, and unity among intermodal transportation parties, to maintain a healthy balance between cooperation and competition. Van der Horst et al. (2019) also conduct a case study on the COB transportation in the Port of Rotterdam and conclude that the different ownership of port or terminal properties and the lack of decision-making authority from COB parties are the two main drawbacks that limit further COB development, even with supportive government policies. Clott et al. (2015) explore the operational and political challenges of containerized soybean transportation based on a case study. They argue that a main factor causing an increased total cost in containerized soybean export in the USA is barge delay, which could be improved by employing suitable optimization tools from private businesses and streamlined government decision-making processes.

In addition to simulation and case study analysis, more than a third of our sample (36%) apply an optimization-based approach. To specify the type of optimization used in each study, optimization is further divided into network optimization (11%), mixed-integer programming (10%), heuristic optimization (7%), stochastic modeling (4%), integer programming (3%), and linear programming (1%), as presented in Table 4.

Network optimization (11%) is the most commonly applied optimization method applied in reviewed COB studies. Liu et al. (2017) formulate a (national) intermodal network model of barge, truck, and train container transport to optimize the total transportation costs of the USA's containerized soybean flows. Fazi and Roodbergen (2018) build a network model for transporting containers between seaports and inland ports, aiming to minimize transportation costs, demurrage, and detention time while using on-time delivery as the main constraint. Braekers et al. (2013) utilize a network model to determine shipping routes for roundtrips between seaports and multiple inland ports in Northwestern Europe (primarily, Netherlands and Belgium). The objective of their network optimization model is to maximize transportation profitability while considering the empty container repositioning problem. Rajkovic et al. (2016) use network optimization to minimize container transportation costs and time from the Port of Shanghai (China) to Serbia based on a simplified intermodal transportation network that includes COB. Fazi et al. (2015) minimize the penalty of barge docking and underutilization along with transportation costs. In

addition, network optimization is observed to be a popular method for studying the decision-making process for selecting routes and controlling container flows in COB-involved intermodal transportation (Corman et al. 2017; Li et al. 2014, 2015).

Other optimization approaches [mixed-integer programming (10%), heuristic optimization (7%), stochastic modeling (4%), integer programming (3%), and linear programming (1%)] are implemented among researchers, due to the various aspects of their COB research questions and/or applications described in Table 3. In general, the majority of these articles seek to minimize transportation costs, time, or distance or maximize profit under a given decision scenario. In addition to these optimization approaches, nonmathematical methodological approaches employed less frequently in the COB literature are empirical analysis (8%), comparative analysis (6%), and literature review (5%).

Observing Table 4, we identify a pattern where earlier papers (published before 2011) favor optimization methods more than recently published papers (after 2011). The more recent research is more likely to implement case study analysis, simulation, and empirical analysis. Due to the increasing complexity of competitors and collaborators relations among COB parties (i.e., shippers, operators, customers, port authorities, government, other stakeholders), these complex interrelationships may require simulation, case study, and/or empirical approaches to achieve robust representation. Moreover, we observe that new and innovative trending approaches are used in recent publications. For instance, four articles implement game theory and Nash equilibrium to study the behavior of market players in COB-involved intermodal transportation networks (Douma et al. 2012; Bouchery et al. 2020; Roukouni et al. 2020; Caris et al. 2012). Three papers published in 2020 apply machine learning to predict estimated time of arrival and market demands in COB transportation (Balster et al. 2020; Bouchery et al. 2020; Radonjic et al. 2020).

7 Advantages of COB

In this section, the 135 articles are reviewed to identify the advantages of COB. As presented in Table 5, 35 (26%) articles mention one or more advantages of COB, while the remaining articles (74%) do not specifically discuss any COB advantages. Twenty-five out of 135 articles (19%) discuss the low cost of COB transportation. Environmentally friendly is the second-most frequently mentioned advantage, with 15 out of 135 articles (11%), followed by 7 articles (5%) that debate the advantage of reducing road congestion by promoting COB. In addition, seven articles (5%) address how COB could help in achieving economies of scale, and six articles (7%) discuss the reliability of COB as an important advantage. The remaining advantages are discussed in three or fewer articles.

Low cost appears to be the most significant advantage of COB transportation, with 19% of the articles addressing it. Some of the researchers were able to identify reasons why this is the case. As Zweers et al. (2019) argue, barge transportation can significantly reduce the total transportation costs owing to the following two reasons: (1) economies of scale: by loading as many containers as possible onto the barge, shipping costs could be decreased between 20% and

Table 5 Advantages of COB

Advantages	Reference(s)	Number of articles	Percentage of articles
Lower transportation cost	Lendjel and Fischman (2014), Zweers et al. (2019), Shobayo and van Hassel (2019), Ypsilantis and Zuidwijk (2019), Konings and Maras (2011), Gharehgozli & Zaerpour (2018), Fazi et al. (2015), Konings et al. (2010), Li (2016), Lun et al. (2013), Konings & Priemus (2008), Clott et al. (2015), Roso et al. (2015), Konings et al. (2013), Konings (2007), Yahalom et al. (2020), Maras et al. (2013), Feng et al. (2015), Caris et al. (2014), Van den Berg and De Langen (2015), Kaack et al. (2018), Kotowska et al. (2018), Ramaekers et al. (2017), Wiegmans & Konings (2015), and Zhen et al. (2018)	25	19
Environmentally friendly	Zweers et al. (2019), Shobayo and van Hassel (2019), Ypsilantis and Zuidwijk (2019), Bomba and Harrison (2002), Fazi et al. (2015), Lun et al. (2013), Roso et al. (2015), Zhang et al. (2014, 2020), Kos et al. (2017), Kotowska et al. (2018), Roukouni et al. (2020), Fu et al. (2010), Caris et al. (2014), and Zhen et al. (2018)	15	11
Road congestion mitigation	Lendjel and Fischman (2014), Zweers et al. (2019), Bomba and Harrison (2002), Choong et al. (2002), Fazi et al. (2015), Caris et al. (2014), and Zhen et al. (2018)	7	5
Economies of scale	Lendjel and Fischman (2014), Braekers et al. (2013), Caris et al. (2012), Ypsilantis and Zuidwijk (2019), Van den Berg and De Langen (2015), Ramaekers et al. (2017), and Wiegmans and Konings (2015)	7	5
Reliable transport mode	Konings and Maras (2011), Konings et al. (2010), Konings et al. (2013), Konings (2007), Maras et al. (2013), and Feng et al. (2015)	6	4
Alternative to road transportation	Konings (2006), Bomba and Harrison (2002), and Konings et al. (2013)	3	2
River resource utilization	Choong et al. (2002), Zhang et al. (2020), and Caris et al. (2014)	3	2
Fuel efficiency	Bomba and Harrison (2002) and Gharehgozli and Zaerpour (2018)	2	1
Empty container repositioning	Alfandari et al. (2019) and Fu et al. (2010)	2	1
Low infrastructure investment	Gharehgozli and Zaerpour (2018) and Zhang et al. (2020)	2	1
Smaller port network expansion	Bomba and Harrison (2002)	1	1
High cargo volume	Gharehgozli and Zaerpour (2018)	1	1
Low maintenance cost	Gharehgozli and Zaerpour (2018)	1	1
Multimodal transport development	Fazi et al. (2015)	1	1
Flexible terminal dwell time	Fazi et al. (2015)	1	1
No advantages discussed		100	74

50% compared to truck or rail; and (2) an estimated 40–80% of truck container transportation costs are generated while transporting between inland destinations. Therefore, increasing the market share and distance covered by COB could significantly reduce this share of costs in containerized intermodal transportation. Shobayo and van Hassel (2019) present similar findings showing that COB provides seaports with an alternative to directly move containers through inland waterways without wasting time on congested roads; thus, the cost per TEU declines, especially when transporting larger quantities of cargo. Maras et al. (2013) find several conditions of COB cost advantage in intermodal transportation: (1) containers should be transported by large-sized barges to generate economies of scale; (2) when shipping regular containers, empty container repositioning should also be scheduled to utilize all capacity left on the barge to reduce the cost of purely shipping empty containers; and (3) berth allocation and route planning should be optimized to avoid port penalty costs as much as possible. Gharehgozli and Zaerpour (2018) provide an external costs comparison chart (measured in cents per ton-kilometers) and argue that barge container transportation (0.27) has the lowest fuel consumption when compared with truck (0.8) and train (2.01), and in addition, barge infrastructure costs are approximately 25% of the other two modes. Konings et al. (2010) indicate that container stacking height and terminal size also contribute to the comparatively low cost of barge transport. Furthermore, Lun et al. (2013) consider that barge transportation produces less environmental pollution, which can lead to a lower external cost.

There are 15 articles (11%) that describe *environmentally friendly* as another major advantage of COB transportation. Although most nations have their own standards to measure the sustainability of different transportation modes, "external costs" is recommended by the European Commission to evaluate the environmental sustainability of transportation modes. In general, most researchers only mention the environmentally friendly benefit of COB without going into depth. However, Lun et al. (2013) study the external costs of barge container transportation and conclude that the external cost of barge container transportation is much lower than that of regular containership in Hong Kong. Roso et al. (2015) indicate that using COB instead of trucks to transfer empty containers would further reduce fuel consumption; thus, environmental damage would be further decreased. Fu et al. (2010) argue that COB has a low fuel efficiency and pollutes less harmful particles into the air. Kotowska et al. (2018) promote COB as the best choice for modal shift from truck container transportation to decrease negative impacts on environment by reducing emission, noise, and land utilization.

Reducing road congestion is also well debated among seven articles (5%). Road congestion is a major problem in seaport areas that creates container vehicles delay, but intermodal transportation including COB can mitigate this situation (Zweers et al., 2019). Earlier, Bomba and Harrison (2002) advise that COB services launched in the Port of Rotterdam provide a great example for moderating road congestion in the port areas of New York and New Jersey in the USA. More recently, Lendjel and Fischman (2014) attempt to design a congestion-free container transportation network with the combined modal of truck and barge transportation for cities with high density of population in France. The situation here is quite the same; most articles

simply mention that COB reduces road congestion without in-depth explanation or data to confirm this advantage.

We make three general observations from Table 5: (1) low cost is identified as the top advantage of COB transportation (it may be of interest to note that most papers omit discussing the disadvantage that time-sensitive cargo is not commonly transported by COB); (2) although barges appear to be fuel efficient and eco-friendly, environmental issues of the other modes (truck, rail, automated guided vehicles, etc.) involved in COB intermodal transportation need further consideration, to quantify COB external costs advantages; and (3) empty container repositioning by COB appears to be effective in further reducing road congestion in port areas, in addition to COB transport of loaded containers.

8 COB success factors

The key success factors of COB are discussed in this section. Our literature review identifies 11 COB success factors as listed in Table 6, along with their corresponding reference and the number and percentage of articles. Based on the findings observed in Table 6, infrastructure investment is the most notable factor, with 11 articles (8%) discussing this success factor. This factor is followed by container market growth (nine articles, 7%), navigability of inland waterways (seven articles, 5%), availability of inland waterways (six articles, 4%), and terminal operations efficiency (six articles, 4%). Moreover, hinterland access of major seaports and enabling government policies are COB success factors that appear in five (4%) articles. Other COB success factors are mentioned in two or fewer articles.

Although the availability and navigability of inland waterways are not the most frequently mentioned COB success factors, these two factors are clearly a necessary factor of successful COB development. Like Notteboom et al. (2020, p. 2) states, "the potential role and spatial configuration of a container barge network is also strongly entwined with the availability and navigability of the inland waterways and canals." In addition, availability of inland waterways with access to major cities with large scale of economy will gain more competitive advantages for COB service (Notteboom 2007).

Infrastructure is the most frequently mentioned key factor in COB success. Without the support of good inland waterways infrastructure capacity, COB transportation is not able to handle enough TEUs in a required time (Fremont and Franc 2010). Van der Horst et al. (2019) illustrate that European countries have been working collaboratively with port authorities and private organizations to increase the effectiveness of seaport and inland waterway port infrastructure usage, indicating that more investment in COB infrastructure would maintain high levels of transportation safety, reliability, material handling efficiency, and sustainable COB services. These benefits could generate a positive loop to reduce future infrastructure maintenance and investment costs, preserve good waterway accessibility, and reduce government burden. The recent, continuously increasing investment made by the private sector and provinces alongside the Yangtze River have resulted in updated container barge infrastructure and increased waterway accessibility that have boosted COB

Table 6 COB success factors

COB success factors	Reference(s)	Number of articles	Percentage of articles
Infrastructure	Notteboom et al. (2020), Braekers et al. (2013), Caris et al. (2012), van der Horst et al. (2019), Fazi (2019), Caris et al. (2011), Fremont & Franc (2010), Notteboom (2007), Fu et al. (2010), Radmilovic et al. (2011), and Larsen et al. (2021)	11	8
Container market growth	Braekers et al. (2013), Notteboom et al. (2020), Shobayo and van Hassel (2019), Mishra et al. (2017), Notteboom et al. (2020), van der Horst et al. (2019), Konings et al. (2010), Fu et al. (2010), and Kotowska et al. (2018)	9	7
Navigability of inland waterways	Notteboom et al. (2020), Braekers et al. (2013), Caris et al. (2012), Fazi (2019), Caris et al. (2011), Notteboom (2007), and Radmilovic et al. (2011)	7	5
Availability of inland waterways	Notteboom et al. (2020), van der Horst et al. (2019), Notteboom (2007), Konings et al. (2013), Konings (2007), and Kotowska et al. (2018)	6	4
Terminal operations efficiency	Konings and Priemus (2008), Konings (2007), Konings et al. (2010), Gracia et al. (2019), Wiegmans et al. (2015), and Fu et al. (2010)	6	4
Hinterland access of major seaports	Braekers et al. (2013), Caris et al. (2012), Caris et al. (2011), Williamsson et al. (2020), and Wiegmans et al. (2015)	5	4
Enabling government policies	Notteboom et al. (2020), van der Horst et al. (2019), Fazi (2019), Konings et al. (2010), and Konings (2006)	5	4
Competition between transportation modes	Caris et al. (2012) and Notteboom et al. (2020)	2	1
Barge utilization	Notteboom et al. (2020)	1	1
Operational collaboration among barge operators	Konings et al. (2010)	1	1
Information sharing/communication	Konings et al. (2010)	1	1

development in this region, making the Yangtze one of the top river systems with COB services (Notteboom et al. 2020).

Rapid COB development benefits from the growth of container market demand and the growth of intermodal transportation. Barge transportation in Northwestern Europe has experienced an average steady growth of 15% during the past two decades (Braekers et al. 2013). As a result, the total TEU handled by European inland waterway barge transportation increased 37% in 10 years (2007–2017) (Shobayo and van Hassel 2019). Driven by the rapid international trading growth, the Yangtze River handles more than two billion tons of freight every year, which makes fundamental changes to the development of the COB transportation in the inland waterway in China (Notteboom et al. 2020). In addition, the significant increasing in trading between China and the European Union has motivated both European nations and China to make investments and implement policies to launch intermodal transportation including truck, rail, and barge to handle the massive number of containers arriving daily at seaports (Konings et al. 2010). In support of handling the significantly increasing container flow at seaports, barge transport on inland waterways can provide direct accessibility to hinterland ports and a safe, low-cost, and reliable container shipping alternative (Kotowska et al. 2018). As a result, we observe a steady and rapid development of COB transportation in the large seaport area where the inland waterway accessibility and navigability conditions are favorable.

Another key factor in COB success is enabling government policies. As a component of regional economic systems, local policies can have a positive impact on the development of inland waterway transportation including COB services (Li et al. 2014). The European shift from traditional container transportation to intermodal transport since the 1990s is credited to the increasing existence of enabling policies in both public and private sectors (Konings et al. 2010). Since 2010, European policies have increased the percentage of total container transported by inland waterway, which further motivated the development of container barge transportation (van der Horst et al. 2019). In another example, China straightforwardly pushed through the supportive policies for COB development in the Yangtze River Delta area in 2016, which generated the "window of opportunity" and resulted in one of the largest COB transportation markets in the world (Notteboom et al. 2020).

9 Conclusions and future work

This literature review and comparative analysis is based on 135 peer-reviewed journal articles with a research focus of Container on Barge (COB) that were selected from maritime and intermodal container transportation studies published between January 2000 and April 2021. This article summarizes and compares these 135 COB studies to help maritime practitioners and researchers understand the current global COB status and provide a comprehensive literature review for future COB research. Important aspects of the reviewed articles are organized into seven categories of interest: (1) annual publication count of COB articles, (2) journals publishing COB research, (3) geographic region of COB research, (4) research questions studied in COB literature, (5) methodological approaches employed in COB Research, (6) advantages of COB,

and (7) COB success factors. Container on Barge research has seen an upward trend over the past decade globally, especially in the last 5 years. The *Journal of Transport Geography* has published the most COB articles to date. We find that the most prevalent geographic region studied in the reviewed literature is the Netherlands, with 26% of the articles studying COB in this country. In fact, 53% of all reviewed articles focus on Northwestern Europe (Belgium, Netherlands, France, and Germany), indicating this region is leading the world in COB transportation. This literature survey identifies intermodal transportation (32%) and terminal operations (21%) as the top two research topics among COB researchers worldwide. In terms of methodological approach, the most commonly applied method supporting COB research is simulation, which is employed in 23% of the reviewed articles, followed by case study analysis with a 19% employment rate. This review identifies the top three advantages of COB transportation as lower transportation cost, environmentally friendly, and road congestion mitigation. Furthermore, this literature review distinguishes the top two success factors for developing COB transportation, that is, existing infrastructure and container market growth.

The findings in this article will help inform and motivate future growth in research and development of COB transportation. There are clear advantages and paths to success towards COB implementation, and research in this area can help to support positive change towards COB as a mechanism for reduced emissions, maintenance, and congestion in transportation networks throughout the world. The outcomes of this review are supporting ongoing work towards the development of a decision analysis tool that will assess the readiness for COB implementation at port terminals in the USA.

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