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Maritime logistics and digital transformation with big data: review and research trend

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Abstract

Purpose – This paper summarizes and synthesizes existing research while critically assessing findings for future studies to advance the scholarship of maritime logistics and digital transformation with big data.

Design/methodology/approach – A bibliometric analysis was conducted on 159 journal articles from the Scopus database with search keywords "maritime*" and "big data." This analysis helps identify research gaps by identifying themes via keyword co-occurrence, co-citation and bibliographic coupling analysis. The Theory-Context-Characteristics-Methodology (TCCM) framework was applied to understand the findings of bibliometric analysis and provide a research agenda.

Findings – The analyses identified emerging themes of the scholarship of maritime logistics and digital transformation with big data and their relationships to identify research clusters. Future research directions were provided by examining existing research's theory, context, characteristics and method.

Originality/value – This research is grounded in bibliometric analysis and the TCCM framework to understand the scholarly evolution, giving managers and academics retrospective and prospective insights.

Keywords Digital transformation, Big data, Maritime logistics, Innovation, Automatic identification system (AIS)

Paper type Research paper

1. Introduction

Maritime logistics is one of the oldest industries from a source to a destination, which connects global trade by providing transport with ports and shipping industry, warehousing and distribution and integrated logistics services (Song and Panayides, 2015; Nam and Song, 2011). Scholars have examined the automatic identification system (AIS) and the Internet of Things (IoT) for the smart port and smart port indicators with operation, environment and energy and safety and security (Makkawan and Muangpan, 2021; Rajabi *et al.*, 2018). A study investigated the shipping industry's technical initiatives for cost and environmental damage reduction with greater efficiency (Xiao *et al.*, 2022). Green logistics, including the port and its logistics service, have adopted the energy transition from fossil fuels to electric vehicles and equipment (Arena *et al.*, 2018).

Existing research has shown scholarly attention to smart and green logistics, where big data serves a crucial role for machine learning and artificial intelligence (AI) to make a digital transformation of maritime trade and supply chain management. Digital transformation refers to the integration of advanced digital technologies like IoT and cloud-based services into important aspects of a business (Brock and Wangenheim, 2019). Scholars have examined how digital transformation improves operations and provides better value to the maritime logistic ecosystem. A study has adopted digital transformation from a process innovation perspective to identify drivers, success factors and barriers to digitalization and digital transformation (Tijan *et al.*, 2021). Region-specific digital transformation in maritime logistics has received scholarly attention. Scholars have investigated how stakeholders interact with

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the adoption of digital platforms in the Taiwanese context (Yang and Lin, 2023) and how port connectivity affects maritime logistics capacities in the Indonesian context (Iman *et al.*, 2022).

Although big data is central to understanding digital transformation in maritime logistics, little attention has been dedicated to exploring the scholarship of maritime logistics and digital transformation with big data. This paper aims to provide knowledge that can be applied practically and academically to advance our understanding of the scholarship of big data and maritime logistics. The motivation of this paper is to conduct the *Envisioning, Explicating, Relating* and *Debating* method proposed by MacInnis (2011), where each phase helps understand the evolving scholarship. The contributions of this paper include conceptualizing and summarizing existing research and synthesizing different perspectives while critically assessing the findings from the scholarship for the future research agenda.

2. Theoretical background

The role of big data in maritime logistics and digital transformation can be viewed as disruptive innovation (Bălan, 2020). Big data for maritime logistics is the understanding of the flow of information and materials regarding ports and shipping. When big data with a greater scale, speed and scope than traditional data meets with AIS, the maritime system's productivity, efficiency and sustainability can be achieved (Yang *et al.*, 2019). Hussein and Song (2022) have conceptualized the application of big data in four domains of maritime logistics: security and safety, port connectivity, automation and operational efficiency.

Scholars have viewed digital transformation, integrating advanced digital technologies for big data, as disruptive innovation (Brock and Wangenheim, 2019). Understanding disruptive innovation is challenging in the maritime logistics context as stakeholders in maritime logistics are globally dispersed and grounded in widely diverse economic and environmental standing across the global value chain (Halkias *et al.*, 2023; MacCarthy *et al.*, 2022).

Blockchain and autonomous technologies have received scholarly attention for understanding digital transformation as disruptive innovation, leading to changing value configurations or business models across stakeholders (Liu *et al.*, 2023; Tsvetkova and Hellström, 2022; Li and Fung, 2019). Scholars have examined how maritime operators and autonomous systems can collaborate through teamwork, creativity and continuously evolving relationships (Shahbakhsh *et al.*, 2022). A study suggests that the lack of standardization in deploying blockchain has brought inefficiency in value configurations (Bavassano *et al.*, 2020).

Existing research is instructive but lacks an understanding of the evolving scholarship of digital transformation and maritime logistics with big data by integrating various theories, contexts, characteristics and methodologies. The following research questions will be investigated:

RQ1. What are the emerging themes of the scholarship of maritime logistics and digital transformation with big data?

RQ2. What are the clusters of themes to identify research clusters?

RQ3. What are the future research directions by examining the theory, context, characteristics and method of existing research?

3. Method

A systemic literature review allows the implementation of MacInnis's (2011) method to envision, explicate, relate to and debate the evolving scholarship. This method reveals knowledge gaps and outstanding research calls to advance knowledge by integrating existing knowledge. Scholars suggest that systemic literature review gains greater benefits when it is deployed when there is an outstanding research call to integrate fragmented knowledge across different disciplines and identify various forms of systemic literature review (Paul *et al.*, 2021). The meta-analytical review uses a statistical appraisal of the causal relationship between factors and consequences. A theory-based review investigates how a theory (e.g. a resource-based view) has been examined in the various research streams. The domain-based review includes a bibliometric review for thematic analysis and framework analysis to incorporate existing literature.

This paper conducted has conducted a domain-specific review with a mix of quantitative (e.g. bibliometric) and qualitative (e.g. the Theory-Context-Characteristics-Methodology [TCCM] framework) methods to provide a comprehensive picture of the scholarship of big data in the maritime landscape (Munim *et al.*, 2020; Paul and Criado, 2020). Bibliometric analysis is useful for exploring a research topic across various disciplines, which allows influential academic outlets and papers, emerging themes via keyword co-occurrence analysis and clustering analysis from the backward-looking (e.g. co-citation) and forward-looking (e.g. bibliographic coupling) views (Donthu *et al.*, 2021). The TCCM framework helps synthesize existing research from theory-discovery to theory-testing perspectives to provide a comprehensive summary of existing research and draw future directions for theoretical and empirical research (Palmatier *et al.*, 2018; Paul and Benito, 2018).

The empirical rigor of a systematic literature review was ensured by assembling, arranging and assessing the literature. The five-phase research process recommended by Zupic and Čater (2015) was implemented: study design, data collection, data analysis, data visualization and interpretation. Table 1 illustrates the research processes.

Phase I was conducted for assembly. In this phase, the study design was identified by selecting the keyword and the database for the keyword search to collect data, which was informed by the research questions. For keyword and database, the keywords "maritime*" and "big data" and the Scopus database were chosen for data collection. As big data is essential to a general-purpose technology with machine learning and artificial intelligence (Goldfarb *et al.*, 2023), the search keyword was selected with the combination of two words to limit our scope to the maritime-related domains. The Scopus database was selected over the Web of Science as the latter covers 40,000+ journals but the latter compiles 21,000+ journals (Scopus, 2023; Clarivate, 2023).

Phases 2 and 3 were implemented for the arrangement. At Phase 2, 159 journal articles were gathered from the keyword search via the Scopus database. They were published in 2015–2023 and were used in the subsequent phases for further analysis with the VOSviewer and programming language R's Bibliometrix package (Ding and Yang, 2020; Sharma *et al.*,

Phase I Study design	Phase II Data collection	Phase III Data analysis	Phase IV Data visualization	Phase V Interpretation
• Research questions and search keywords ("maritime*" and "big data") • Database selection (Scopus database)	• Keyword search generated 159 papers (2015–2023)	• R with the Bibliometrix package was used for data retrieval and analysis • Publication trend • Most cited papers	• Visualization to map the relationships of the papers was conducted via VOS viewer • Keyword co-occurrence analysis • Co-citation • Bibliographic coupling	• Thematic analysis • Cluster interpretation • TCCM framework for research agenda

Source(s): Author's own creation

Table 1. Overview of data collection and analysis

2022). In Phase 3, publication trends and most-cited papers were analyzed to identify prominent outlets and papers.

Assessment was executed in Phases 4 and 5. In Phase 4, data visualization was conducted to map the relationships between the papers and create keyword co-occurrence, co-citation and bibliographic coupling analyses. Phase 5 is dedicated to interpreting themes and clusters from the results of visualization and providing the TCCM framework (Bhukya and Paul, 2023) to outline the research agenda.

4. Results

The publication count in scholarship of big data for maritime logistics has increased since the pandemic, as big data has gained attention to address challenges in maritime logistics, including climate change, port accidents and international maritime trade tensions (Hussein and Song, 2022). Table 2 shows the most cited papers in the scholarship. Yang *et al.* (2019) have recorded

Title	Author	Year	Total citations
How big data enriches maritime research – a critical review of automatic identification system (AIS) data applications	Yang *et al.*	2019	180
Big data and artificial intelligence in the maritime industry: A bibliometric review and future research directions	Munim *et al.*	2020	133
Spatio-temporal vessel trajectory clustering based on data mapping and density	Li *et al.*	2018	115
A big data analytics method for the evaluation of ship - ship collision risk reflecting hydrometeorological conditions	Zhang *et al.*	2021	96
Information systems in seaports: A categorization and overview	Heilig and Voß	2017	87
Data-driven based automatic maritime routing from massive AIS trajectories in the face of disparity	Zhang *et al.*	2018	86
Digitization in maritime logistics—what is there and what is missing?	Fruth and Teuteberg	2017	82
A decision support system for vessel speed decision in maritime logistics using weather archive big data	Lee *et al.*	2018	79
Industry 4.0 in the port and maritime industry: a literature review	de la Peña Zarzuelo *et al.*	2020	77
Modelling the competitiveness of the ports along the maritime Silk Road with big data	Peng *et al.*	2018	53
Are AIS-based trade volume estimates reliable? The case of crude oil exports	Adland *et al.*	2017	46
Mass processing of sentinel-1 images for maritime surveillance	Santamaria *et al.*	2017	44
Smart port: a platform for sensor data monitoring in a seaport based on fiware	Fernández *et al.*	2016	43
Big data analysis of port state control ship detention database	Tsou	2019	41
A machine learning method for the evaluation of ship grounding risk in real operational conditions	Zhang *et al.*	2022	39
A fuzzy Delphi-AHP-TOPSIS framework to identify barriers in big data analytics adoption: Case of maritime organizations	Zhang and lam	2019	38
An updated model-ready emission inventory for guangdong province by incorporating big data and mapping onto multiple chemical mechanisms	Huang *et al.*	2021	37
Norwegian port connectivity and its policy implications	Jia *et al.*	2017	35
Profiling Malaysian ship registration and seafarers for streamlining future Malaysian shipping governance	Chuah *et al.*	2021	34
Developing a predictive maintenance model for vessel machinery	Jimenez *et al.*	2020	33

Source(s): Author's own creation

Table 2.
Most cited papers

the highest citation count as they critically examine how AIS data can be used for data mining, measurement, causality and operational research, improving ship/port, trade, safety and environmental performance analyses. Munim *et al.* (2020), the paper with the second highest citation count, also examined the application of AIS, energy efficiency and predictive modeling. Other scholars have also investigated the use of AIS with big data in various fields, including informed decision-making on routing (Zhang *et al.*, 2018) and crude oil export volume (Adland *et al.*, 2017). In addition to AIS, smart port development and policy were the most popular themes among the top-cited papers (Heilig and Voß, 2017; de la Peña Zarzuelo *et al.*, 2020; Peng *et al.*, 2018; Fernández *et al.*, 2016; Tsou, 2019; Jia *et al.*, 2017). In addition, the relationship between vessels and big data has received scholarly attention. Scholars have examined spatiotemporal trajectory clustering (Li *et al.*, 2018), vessel speed decisions with weather big data (Lee *et al.*, 2018) and predictive maintenance decision support on vessels (2020).

Keyword co-occurrence analysis (Figure 1) identified five clusters: Smart port, Industry 4.0, machine learning, navigation safety and AIS. Co-citation analysis (Figure 2) and bibliographic coupling analysis (Figure 3) complement each other by examining established and emerging research clusters, respectively. Four clusters were detected in the co-citation analysis: Traffic conflict and accidents, optimal routing for vessels, trajectory discovery for vessels and dynamic simulation. Bibliographic coupling analysis revealed four clusters: Accident control, AIS and time series analysis, maritime risk assessment and safety assessment.

5. Discussion

5.1 Theoretical implications

The findings from the systemic literature review provide the importance of holistic insights from different domains. The use of big data in maritime logistic addresses long-standing

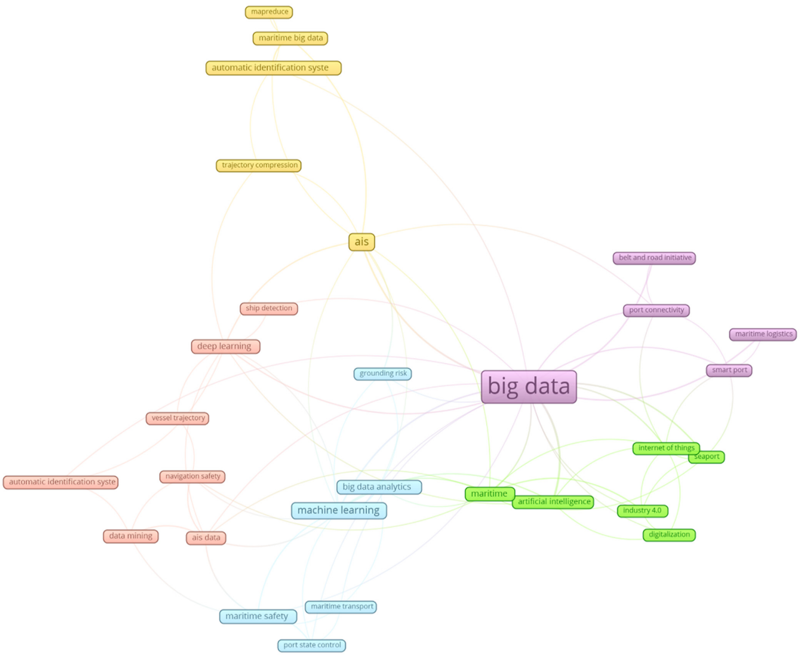

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Figure 1.
Keyword co-occurrence analysis

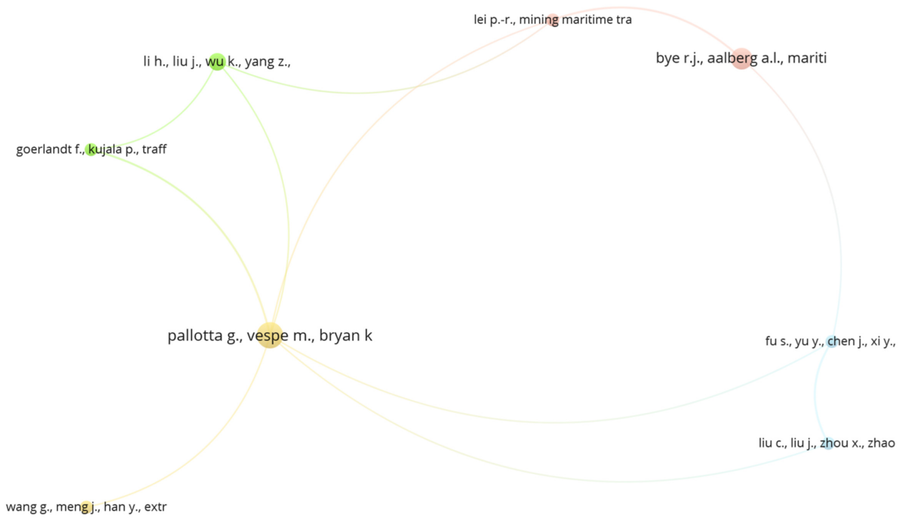

Figure 2.
Co-citation analysis

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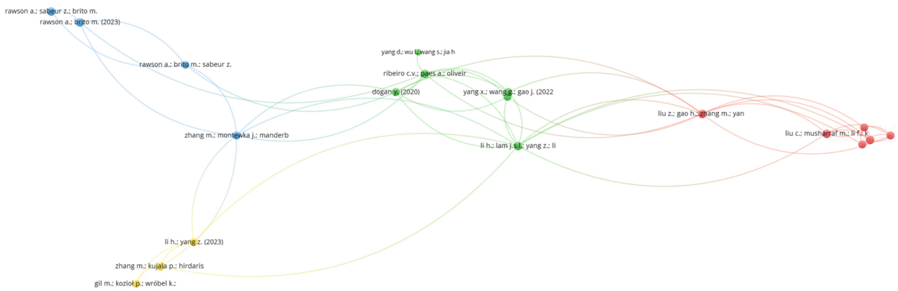

Figure 3.
Bibliographic coupling analysis

Source(s): Author's own creation

concerns about capacity utilization, fleet capacity and planning routing in the shipping industry (Wu, 2012). Big data can help with prediction, classification, optimization, clustering and monitoring with digital transformation on the drivers (e.g. price of fuel, labor, capital stock, current affairs and weather) of capacity utilization, leading to providing solutions to engineering, environment, economy, politics and logistics.

The TCCM framework (Bhukya and Paul, 2023) has been applied to understand the scholarship of big data for maritime logistics and provide future research directions (Figure 4). Theories guide existing scholarships and the advancement of future scholarship by interacting with the characteristics, contexts and methods of the research streams. The author suggests that current and developing theories may explain how big data affects the digital transformation of maritime logistics. The context in which most popular studies occur has also been examined and discussed. Scholars have examined how the digital transformation of maritime logistics interacts with the characteristics of big data. Finally, the methodologies used in the scholarship, such as data acquisition and analysis techniques, have been discussed.

For theories, the scholarship has adopted semantic integration of big mobility data, port service efficiency computation and the Discrete Global Grid System (DGGS). Big mobility data

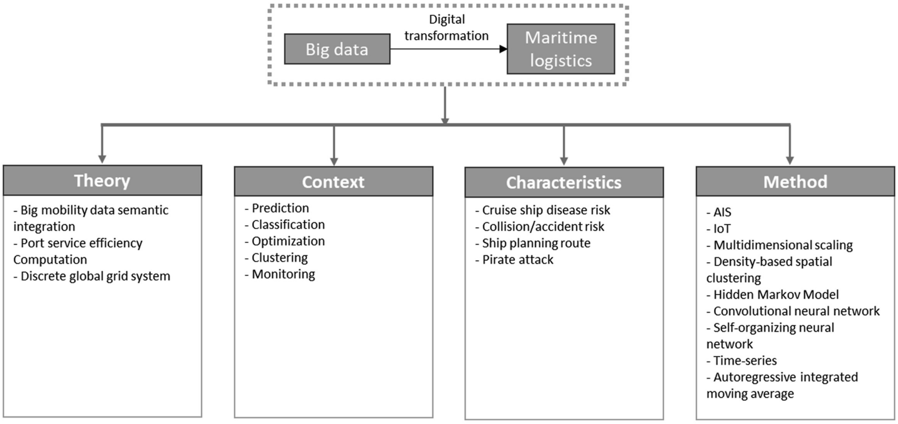

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Figure 4.
Future research directions based on the TCCM framework

is central to transitioning from descriptive to predictive analytics on trajectories, implementing geography-based transfer learning on crash prediction and monitoring fleets with event forecasting and contextual data from the environment and entities in motion (Sakr *et al.*, 2022). Semantic integration of big mobility data allows spatio-temporal trajectory discovery and online recommendations on big streaming mobility data (Santipantakis *et al.*, 2020). Port service efficiency assessment is fundamental to optimizing logistics planning and resource management (Wang and Peng, 2023). DGGS is the spatial data structure of big data for digital transformation. It accommodates AIS and other big data to understand better incidents, vessel traffic, topographic information, infrastructure risk and maritime environment data (e.g. wind speed, wave height, ice characteristics and tidal flow) (Rawson *et al.*, 2022).

For contexts and characteristics, cruise ship disease risk, collision/accident risk, ship planning route and pirate attacks were focal domains for value creation by using prediction, classification, optimization, clustering and monitoring with digital transformation. For method, AIS and IoT data were popular data in the scholarship. Stochastic modeling techniques were popular analysis methods (He *et al.*, 2018; Nguyen *et al.*, 2023). Multidimensional scaling for dimension reduction and density-based clustering were analyzed using trajectory analysis with AIS data (Li *et al.*, 2018). The Hidden Markov Model was used for inferring the ship encounter intention to assess collision accidents (Ma *et al.*, 2022). Neural network algorithms were adopted for ship detection and autonomous navigation (Shi and Liu, 2020; Li *et al.*, 2020). Time-series modeling (Gao and Shi, 2020) and autoregressive integrative moving averages (Doğan, 2020) were used to continuously improve algorithms with statistical methods.

This research is not without limitations. As bibliometric analysis is quantitatively oriented, it fails to capture the nuances of citation behavior and their roles in scholarship. Scholars argue that citations serve various purposes: legitimation, micropolitics and influence (Vogel and Güttel, 2013). A nuanced understanding of content using natural language processing (e.g. topic modeling) may remedy this drawback at scale (Yu and Xiang, 2023). Unlike the citation-driven bibliometric analysis, a meta-analysis may help advance our understanding of how big data interacts with maritime stakeholders by mediating and moderating relationships with various effect sizes (Krishen *et al.*, 2021). Future research may expand the scope of data collection by including other databases (e.g. Web of Science, Business Source Complete and ProQuest).

Knowledge flow analysis can be conducted to advance the scholarship of maritime logistics and big data to complement the findings from this research. Tijssen (2001) emphasizes the importance of knowledge flow and research policy to understand the evolution of the digital transformation of maritime logistics. Scholars have used cross-citation and path analyses on patents regarding autonomous driving technology (Cho *et al.*, 2021). They found that the ecosystem of autonomous driving technology has grown with three types of players: technology developers, technology integrators and technology implementers. Using knowledge flow analysis with patent data can be helpful as technological advancements require complexities with various emerging technologies and collaboration over an extended period. Expert interviews with scholars in different domains (e.g. conceptual vs empirical) may augment the findings of the TCCM framework with different vantage points (Akartuna *et al.*, 2022). From this perspective, inviting organizations and stakeholders for community-based participatory research may give us emic perspectives, complementing the etic perspectives from existing mainstream research (McKemmish *et al.*, 2012).

5.2 Practical implications

For maritime logistics, big data drives business model innovation and reconfiguration of value to redefine practices, structures and governance for greater value across various stakeholders (Foss and Saebi, 2017), rather than mere product or service innovation. Big data-driven autonomous shipping would provide enhanced ship intelligence and crew reduction, which would provide cost savings, safety and greater earning potential at the micro-, meso- and macro-levels in the maritime logistic ecosystem (Tsvetkova and Hellström, 2022).

Practitioners may develop business model innovation strategies competing with the evolution of emerging technology in the maritime logistic ecosystem. Using synthetic or natural data will have benefits for the ecosystem. Scholars have investigated how synthetic data can augment collected maritime data (Baressi Šegota *et al.*, 2023). This approach produces the generation of synthetic data points that contain the same statistical parameters as the original data used to generate them, which makes more data accessible for training and validation with a fraction of the cost compared to the traditional method. Scholars suggest that aerial images with AIS can be more powerful, allowing various features like position, scale, heading and speed to match real-time images (Xiu *et al.*, 2019). The matching algorithm is divided into point matching and trajectory matching to ensure accurate identification of surface vessels based on their spatiotemporal characteristics.

Scholars have suggested that practitioners critically evaluate big data-driven business model innovation from various perspectives: external and internal drivers, change/resistance processes, scale, speed and scope of organizational changes (Loon and Quan, 2021). A rise of public benefit corporations (BC) may shape how big data influences maritime logistics beyond the regional or national level. Scholars have documented the potential impacts of BCs on transnational biosphere stewardship (Österblom *et al.*, 2022). SeaAhead (2023) has manifested its initiatives as an ocean-specific Boston-based BC to connect startups, investors, partners and mentors through engaging with startup programs, the bluetech ecosystem and investments.

This new wave of BCs can be a change agent to propose a novel value equation of big data practices for maritime logistics by developing business model innovation over product/service innovation. Business model innovation requires perspectives beyond an individual organization to include meso and macroperspectives for value creation. Evolving innovation strategies may call attention to switching their research focus for transitioning from technology development to technology implementation. In this context, forging a strong connection between practice and research, future research may investigate the human–machine teaming perspective and design thinking to facilitate stakeholder engagement in maritime logistics. This approach may broaden our understanding of the context and characteristics of the intersection of big data and digital transformation in maritime logistics.

6. Conclusion

This paper examines the scholarship of maritime logistics and digital transformation with big data. This paper aims to advance our understanding of big data and maritime logistics. The purpose of this paper is to utilize MacInnis' (2011) Envisioning, Explicating, Relating and Debating method to comprehend the developing scholarship. The bibliometric analysis and TCCM framework of this paper summarized the forward-looking and backward-looking literature and the characteristics, contexts and methods of the research streams. This approach was helpful to delineate research trends and differentiate the roles of big data for various stakeholders.

Future research may conduct knowledge flow analysis, innovative implementation models and emerging technology influence to understand the scholarship of maritime logistics and digital transformation. Big data-driven business model innovation in maritime logistics may gain better insights from digital transformation and design thinking perspectives. Scholars suggest how the potential innovation effects of big data may arise from service design routines, including exploration, ideation, reflection and implementation practices (Solem *et al.*, 2022). This perspective provides implications for how maritime logistics can collaborate and compete with the evolving role of big data as new knowledge and innovation are built upon existing knowledge and ecosystems.

Examining various applications of big data in maritime logistics may require multi-level perspectives as it needs to investigate the relationships between big data and micro/meso/macro-level actors in maritime logistics. Further research can be inspired by various analytical lenses of organizational theory, marketing strategy and open innovation to view various acceptance levels of innovation with big data (Kovacs *et al.*, 2019). Future research may examine how organizations approach challenges beyond their scope (e.g. the climate change challenge) in maritime logistics. As big data in maritime logistic innovation matters in this matter, analyzing different competencies and priorities of the Global South and North may generate practical insights. This approach may help design incentives and governance to collaborate and compete to establish benefits from the latest advancements in big data analytics at a greater scale, scope and speed, increasing the efficiency and safety of maritime logistics fighting against climate change globally.

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