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Contextual Difference in the Drivers of Internet-of-Things-Adoption in Road, Rail, and Maritime Freight Transport

Binay Kumar Rajak, Swagato Chatterjee, Amit Upadhyay, and M Vimala Rani

***Abstract*— The Internet of Things (IoT) is widely considered an important infrastructure for enhancing the transparency of processes and the quality of business decisions in the era of Industry 4.0. Yet, little is known about the differential drivers of the adoption of IoT for different modes of freight transport. Since the modes of freight transport differ substantially, the purpose of this study is to compare the contextual differences among IoT adoption drivers in road, rail, and maritime freight transport and assess the suitability of different modes of freight transport for IoT adoption. The identified drivers for IoT adoption are classified under the TOE (Technology, Organization, and Environmental) framework, and the relative weight of drivers for road, rail, and maritime freight transport are compared using FANP (Fuzzy Analytic Network Process) method. The most important drivers for freight transport are Competitive Advantage, Management Support, and Security and Privacy. Comparatively, the most prioritized driver for road transport is investment cost, for rail transport is management support, and for maritime is the Ease of use. This study found the maritime transport as the best mode to adopt IoT using MULTIMOORA (Multi-objective optimization on the basis of a ratio analysis plus the full Multiplicative form) method. The results identify prospective customers for IoT adoption, help the government and policymakers develop transport policies, including freight modal share and National Rail Plan vision, and assist transport managers in developing strategies for Industry 4.0.**

***Index Terms*—FANP; MCDM; MULTIMOORA; Freight transport; Internet of things (IoT); Logistics Management; TOE framework.**

I. Introduction

INTERNATIONAL trade has expanded 40 times in the last six decades [1]. Freight transport is one of the crucial sectors that can help grow international trade through safer and easier distribution of freights. But the operations related to freight transport create some externalities, such as pollution, infrastructure degradation, and congestion, that affect sustainable growth. The externalities of freight transport have become a critical issue as global merchandise exports increased by 13.8% in 2022 [2]. Many of the externalities of freight transport can be monitored and controlled by implementing Industry 4.0 (I4.0), which emphasizes end-to-end digitization [3]. Sun et al. [4] highlighted several advanced technologies, such as the Internet of Things (IoT), cybersecurity, blockchain, and cloud computing, that can help achieve the objectives of I4.0.

The implementation of IoT in the transport system is the primary phase in the direction of implementing I4.0. Further, the implementation of IoT can play a vital role in the performance improvement and expansion of many industries, such as healthcare [5], manufacturing [6], and agriculture [7], including various contexts of the transport and logistics industry [8]. It helps the physical components to integrate smoothly into the digital network [9] and operate in real-time with the help of Radio Frequency Identification (RFID), Wireless sensor networks (WSN), Middleware, Cloud computing, and software of IoT applications [10].

The adoption of IoT can either reduce or eliminate the critical bottlenecks of the freight transport system. The potential benefits of IoT implementation in freight transports are increasing connectivity, providing real-time status, fleet and route monitoring, improving safety and security, improving the performance of operators, cutting shipping costs, and improving last-mile delivery [11], [12], [13], [14]. All these benefits improve the effectiveness of freight transport and reduce logistics costs.

However, there is no evidence in the literature on IoT implementation in freight transport, though few studies [15], [16], [17], [18] have focused on IoT implementation in the logistics and transport domain. This is a significant research gap in the field of IoT that needs to be addressed and explored since freight transport is often different from other forms of transport where, along with transportation, material handling plays an important role. Hence, this research focuses on recognizing the IoT implementation drivers for freight transport and determining the relative weights of drivers. Accordingly, this

(Corresponding author: Swagato Chatterjee)

Binay Kumar Rajak is with the Vinod Gupta School of Management, Indian Institute of Technology Kharagpur, West Bengal, 721302, India (e-mail: binay3285iitd@gmail.com)

Swagato Chatterjee is with the School of Business and Management, Queen Mary University of London, London, E14NS, UK (e-mail: swagato.chatterjee@qmul.ac.uk)

Amit Upadhyay is with the Department of Management Studies, Indian Institute of Technology Roorkee, Uttarakhand, 247667, India (email: amit@ms.iitr.ac.in)

M Vimala Rani is with the Vinod Gupta School of Management, Indian Institute of Technology Kharagpur, West Bengal, 721302, India (e-mail: vimala@vgsom.iitkgp.ac.in)

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study framed the research questions: (RQ1) Which drivers motivate the implementation of IoT in freight transport? (RQ2) Which drivers are more important in the process of implementation?

Moreover, the nature of different freight transport modes differs from each other significantly and depends on many factors such as budget, distance travelled, features of goods, volume, transit time, risks, environmental impact, accessibility, and feasibility. For instance, road transport is used for any goods, any quantity, and in any place, but it is generally preferred for less quantity, short distance, and last-mile delivery. Rail transport is an attractive mode of transport with increasing distance and volume and is considered the most sustainable and safest. Maritime transport is used for a large volume of goods and is the most affordable mode of freight transport.

Despite the facts, the maritime mode has transported about 90% of global merchandise by volume [19], with an average growth of 3.3 % in the last three decades and an overall shipment of about 11 billion tons in 2021 [2]. The land (Road and Rail) and air modes have collectively transported less than 10% of global merchandise, but road and rail transport are the crucial modes for domestic freight transport and last-mile delivery. Such diverse variation also influences the drivers on the implementation of IoT in different modes of freight transport. There is no literature on such a comparative analysis of IoT adoption in freight transport. Considering that the transport managers and policymakers have diverse understanding and knowledge of IoT adoption, we have another research question: (RQ3) How to prioritize the drivers supporting IoT implementation considering the requirements of different modes of freight transport?

Further, it is also important to understand the suitability of freight modes for IoT adoption. In this paper, 'IoT adoption suitability' of a mode of freight transport refers to its ability of enabling smooth integration of physical components associated with freight transport into the digital network and operations in real time with the help of RFID, WSN, middleware, cloud computing, and software for IoT applications.

Each mode has different operating conditions and undergoes different infrastructures, and governments and policymakers have assigned different objectives for different modes. The extant literature does not identify the most suitable mode of freight transport and does not rank the modes of freight transport according to their suitability for adoption of IoT. However, such knowledge will help the IoT developers in the transport industry to target a specific segment or prioritize the transport segments based on suitability. This requirement in the research gap leads to a further research question: (RQ4) Which is the most appropriate mode of freight transport to implement IoT in the existing system?

This research study majorly contributes to (i) exploring the drivers supporting IoT adoption in freight transport, (ii) determining the most important drivers for freight transport, (iii) a comparative analysis of the drivers for road, rail, and maritime freight transport, and (iv) identifying the most suitable mode of freight transport for IoT adoption.

The remaining sections of the article are as follows. Section II demonstrates the literature review on IoT in the freight transport and logistics domain. Section III introduces each method, explains its suitability in the current study, and plans for data collection. Section IV discusses the results and findings of each of the methods. Section V identifies the theoretical contributions of the study and explains practical implications to the stakeholders. The last section, VI, concludes the article and explains future research directions.

II. Literature Review

IoT is a continuously growing network that connects the physical components with a network of digital devices to monitor real-time activities. The goal is to collect accurate data to recognize the concerns and intervene accordingly. IoT allows interaction between device-device and human-device. However, scalability is one of the vital factors in the implementation of IoT concerning the type and size of the industry. To get the desired output, the architectures of IoT must account for interoperability and compatibility in the system to integrate different levels of components in the current infrastructure. To achieve smooth integration, IoT needs to deploy four layers of IoT architecture in the freight transport system: Sensing, Networking, Service, and Interface [20], and these layers are monitored by several technologies, such as RFID, WSN, sensors, and operating platform [10].

The application of IoT also has multiple developments in accomplishing the vision of I4.0 and is expected to influence future performance significantly. The IoT-adopted freight transport industry can easily accomplish the primary purpose of the supply chain, that is to "supply the right products in the right amount and of the right quality at the right time to the right location for the right cost" [21]. Further, it provides several benefits, such as flexibility, transparency, adaptability, and agility [22]. It reduces the risks of security and privacy and enhances the visibility of the transport company through critical decision-making [23]. In addition to the above significant benefits, it also diagnoses the critical activities of the freight transport system, including understanding the abilities, synchronizing the components, assessing the effectiveness, resource planning, and attempting to overcome the challenges and limitations [24], [25].

IoT in freight transport mainly tracks the vehicle movements and conditions of the goods and automatically manages the system to monitor the goods. For example, Upadhyay [26] describes the opportunities to enhance the performance of container scheduling, which can easily cope with the implementation of IoT in freight transport. The extent literature has a handful of research studies that showed the adoption of IoT on various logistics and supply chain, as shown in Table I. Most articles have theories or frameworks to support them, such as the TOE framework, information processing theory, and grounded theory.

The outcomes of these articles have highlighted the benefits and challenges of IoT adoption through hierarchical and cause-and-effect relationships among factors. For instance, Hsu and Yeh [15] explored the cause-and-effect relationship for the logistics industry; Ali et al. [18] explored the sustainable supply chain; and Rajak et al. [27] explored the hierarchical relationship for port logistics. However, Kamble et al. [16] explored the hierarchical and cause-and-effect relationships in the food retail supply chain. Yu et al. [17] analyzed the weight of IoT adoption barriers for a sustainable supply chain, whereas Rajak et al. [27] examined the factors of port logistics.

TABLE I
SUMMARY OF EXTANT LITERATURE ON IOT ADOPTION IN LOGISTICS CONTEXT

Ref.	Objectives	Country	Theory/ Framework /Research method
[15]	Analyse the factors influencing the adoption of IoT in the logistics industry and determine the cause-and-effect relationship between these factors.	Taiwan	TOE, DEMATEL
[28]	Investigates the factors that influence the adoption of IoT in logistics and supply chain management (SCM).	Taiwan	GT, SEM
[16]	Explore the interrelationships among IoT adoption barriers that influence the food retail supply chain.	India	DEMATEL, ISM
[29]	Examine the impact of IoT on the SC risk management process, internal and external pathways, and SCRM outcomes.	Europe	IPT, GT, Case study
[13]	Created a cloud-based, modular IoT solution to enhance the efficiency, control, and surveillance of container transportation of port-based intermodal supply chains (SC).	Spain	FIWARE platform
[30]	Explore and test the determinants of adopting the IoT in the transport and logistics industry.	Italy	OLS Regression
[31]	Scrutinize the influence of IoT on the performance of vaccine supply chain distribution.	India	EFA, CFA, SEM
[17]	Identify, analyze, and model the IoT adoption barriers for sustainable SC.	-	SF_AHP
[18]	Identify the drivers for adopting IoT in the supply chain for sustainability and explore the causal relationship among drivers.	Bangladesh, USA, Canada, Australia	RSRA
[27]	Explore the IoT adoption factors for port logistics and discuss the adoption intention for inter-port and inter-domain executives of the port.	India	TOE, FANP, TISM

CFA: Confirmatory Factor Analysis; DEMATEL: Decision-making trial and evaluation laboratory; EFA: Exploratory Factor Analysis; FANP: Fuzzy Analytic Network Process; GT: Grounded Theory; IPT: Information Processing Theory; ISM: Interpretive Structural Modeling; OLS: Ordinary least squares; RSRA: Rough Strength Relation Analysis; SEM: Structural equation modeling; SF-AHP: Spherical Fuzzy Analytical Hierarchy Process; TISM: Total Interpretive Structural Modeling; TOE: Technology, organization, and environment

Further, Birkel and Hartmann [29] examine the impact of IoT adoption on supply chain risk management, while Kumar et al. [31] examine the performance of vaccine supply chain distribution. It is also interesting that most of the articles focused on one country, such as India, Italy, Spain, and Taiwan. However, Ali et al. [18] focused on the cross-country analysis among Australia, Bangladesh, Canada, and the USA, and Birkel and Hartmann [29] focused on Europe.

Although Table I shows some evidence of successful IoT adoption, the literature focusing on the freight transport industry is scarce. Specifically, there is an absence of literature that conducts a comparative analysis of the drivers supporting IoT adoption in various modes of freight transport despite its tremendous potential for reducing logistics costs and promoting international trade. This study identifies IoT adoption drivers for freight transport from the literature of I4.0 and IoT adoption and validates the practical usability of these drivers from the experts of road, rail, and maritime freight transport.

Although Table I shows some evidence of successful IoT adoption, there is a paucity of literature on the freight transport industry. Specifically, there is no literature on IoT adoption drivers in freight transport as a comparative analysis of different modes of freight transport, despite its tremendous potential for reducing logistics costs and promoting international trade and globalization. This study identifies IoT adoption drivers for freight transport from the literature of I4.0 and IoT adoption and validates the usability of these drivers from the experts of road, rail, and maritime freight transport.

III. RESEARCH METHOD

IoT adoption in freight transport study includes many conflicting drivers, and no alternative dominates all drivers. Decision-makers are required to choose an appropriate alternative considering the trade-off between those drivers and maintaining the subjectivity of the freight transport problems. Therefore, this study uses multi-criteria decision-making (MCDM) methods to comprehend the IoT adoption drivers and their implications in freight transport.

As depicted in Fig. 1, this study uses an integrated TOE-FANP-MULTIMOORA research methods for a comparative analysis of different modes of freight transport. The TOE (Technology, Organization, and Environment) framework provides a theoretical context to classify the IoT adoption drivers. The FANP (Fuzzy Analytic Network Process)

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determines the relative weight among drivers and dimensions, and MULTIMOORA (Multi-objective optimization on the basis of a ratio analysis plus the full Multiplicative form) method ranks the modes of freight transport. The following subsections elaborate on the appropriateness of the TOE framework, FANP, and MULTIMOORA methods and explain the details of the data-collection process and background of the experts.

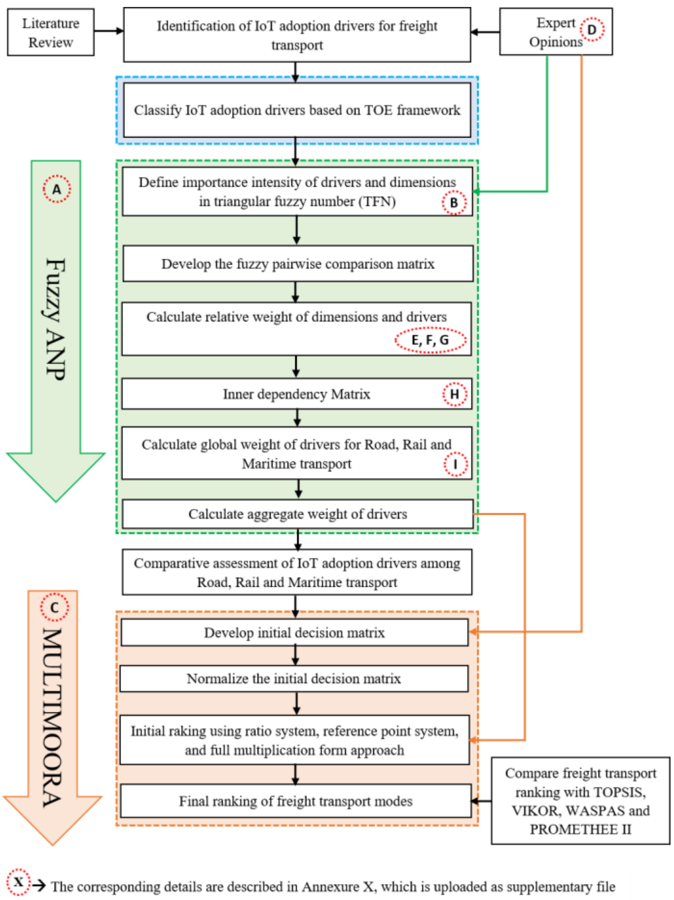

Fig. 1. Integrated TOE-FANP-MULTIMOORA research methods for comparative analysis of IoT adoption in freight transport modes.

A. TOE Framework

TOE is a theoretical framework that helps to explore the firm's implementation decision and adoption processes in technology, organization, and external environmental contexts. This framework familiarized the essential features of implementing IoT [32] and how these contexts influenced the various stages of IoT adoption in freight transport. The TOE framework is frequently used in research on innovation and technology implementation. For example, Orji et al. [33] used the TOE framework to adopt blockchain technology.

In the technological context, the drivers are related to IoT's technical aspects in different freight transport modes. Generally, the technological contexts of freight transport are the perceived benefits derived from the existing technology in the use and integration of IoT. In the organizational context, the drivers are concentrated on the features and resources of the freight transport system, which influence IoT adoption. Generally, freight transport's organizational contexts include the transport system's background and scale-based drivers of transport sectors. In the environmental context, the drivers are concentrated on the external freight transport system and significantly influence the firm's IoT adoption decisions. Broadly, environmental contexts of freight transport encompass the characteristics of the freight transport industry, support from government laws, market structure, and external drivers of transport sectors.

B. Fuzzy Analytic Network Process (FANP) Method

The Analytic Network Process (ANP) is an MCDM method that establishes a complex network structure among different levels of decisions and factors such as goals, criteria, and sub-criteria. It is an advanced form of the Analytic Hierarchy Process (AHP) method, which creates a unidirectional hierarchal framework of criteria and sub-criteria developed by Saaty [34]. ANP resolves the interdependency issues of AHP and establishes the complex network structure, which is more practical and rational for today's complex environment.

IoT adoption drivers' estimation and prioritization is a strategic, multi-criteria, conflicting choice that demands MCDM models. ANP has been effectively executed in similar contexts, such as Orji et al. [33] used to evaluate the weight of blockchain adoption factors for the freight logistics industry, and Rajak et al. [27] used to calculate the weight of IoT adoption factors for port logistics. A comparison of ANP method with some other related MCDM methods have been shown in Appendix A1 of supplementary file.

In the ANP method, a pairwise comparison matrix needs to be developed among factors, dimensions, and goals from the experts. Sometimes, the experts' judgment create bias during pairwise comparison as making decisions in current dynamic and complex freight transport networks is highly challenging. This limitation of human judgment and vagueness can be effectively overcome by adding fuzzy logic in the ANP model [35]. The fuzzy logic concept in the ANP has been used in several applications [36].

The ANP method prefers fuzzy logic to other soft computing techniques because it needs to solve the pairwise comparison matrix to determine the relative weight. Fuzzy logic provides a suitable mathematical and methodological base for capturing the uncertainty of human judgment and vagueness, such as factor comparison, causal links, thinking, and reasoning.

In this study, triangular fuzzy number (TFN) is used to estimate the relative weight of the drivers, and the intensity of the relative importance of drivers is defined in linguistic attributes using TFNs, as shown in Appendix B. The FANP method has three main steps to calculate the local and global weights of drivers and dimensions, explained in Appendix A.

C. MULTIMOORA Method

MULTIMOORA is an MCDM technique used for ranking the multiple criteria alternatives. MULTIMOORA is an improved version of the MOORA method. MOORA method optimizes two or more objectives with various criteria and identifies the best option. The outcome of the MOORA method

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is the combination of two ranking systems: a ratio system and a reference point system [37]. MULTIMOORA is one step further than the MOORA approach. The final ranking aggregates three ranking methods: a full multiplicative form, a ratio system, and a reference point system. The ultimate integrative ranking is based on the theory of dominance [38]. The ratio system and full multiplication form are ranked the freight transport based on value measurement approach whereas the reference point system is ranked-on goal or distance-based approach.

The MULTIMOORA method is much more robust than the other MCDM raking techniques, combining three different methods [39]. Also, researchers have given more importance to the MULTIMOORA method, as various domains have utilized it extensively, including logistics and transportation, manufacturing, automobile, sustainable development, policymaking, and healthcare [40]. Therefore, the MULTIMOORA method is also suitable for IoT adoption in freight transport. A comparison of MULTIMOORA method with some other related MCDM ranking methods have been shown in Appendix C1. The steps of the MULTIMOORA method are discussed in Appendix C.

D. Data collection

An integrated TOE-FANP-MULTIMOORA method is used to comprehend IoT's influence on freight transport modes. 36 professionals from 14 different freight transport companies participated in data collection through their experts' opinions on pre-design questionnaires. Appendix D provides a comprehensive overview of the experts and background of the company. Two sets of data have been collected from each expert. The first data set is for the FANP method, and the second is for the MULTIMOORA method. The sample of questionnaires is provided in Appendix J. All 14 companies are visited to assure them of confidentiality about the experts' information and the opinions exclusively utilized for academic research.

IV. Results and Discussions

This section shows the results and findings of a comparative analysis of IoT adoption in freight transport modes. This study first identifies the IoT adoption drivers for freight transport and classifies them under the TOE framework. Next, the weight of IoT adoption drivers is calculated using the FANP method. Then, this study compares the IoT adoption dimensions and drivers in three modes of freight transport: Road, Rail, and Maritime. Finally, the freight modes are ranked to scrutinize the suitability for IoT adoption among road, rail, and maritime transport. All these steps are discussed in the following subsections.

A. Identification and classification of drivers adopting IoT

The IoT adoption drivers influencing freight transport are identified from IoT and I4.0 literature, which the professionals confirm from different modes of freight transport, as shown in Fig. 2. Accordingly, this study identifies 18 drivers in total, and are classified in the context of technology, organization, and environment.

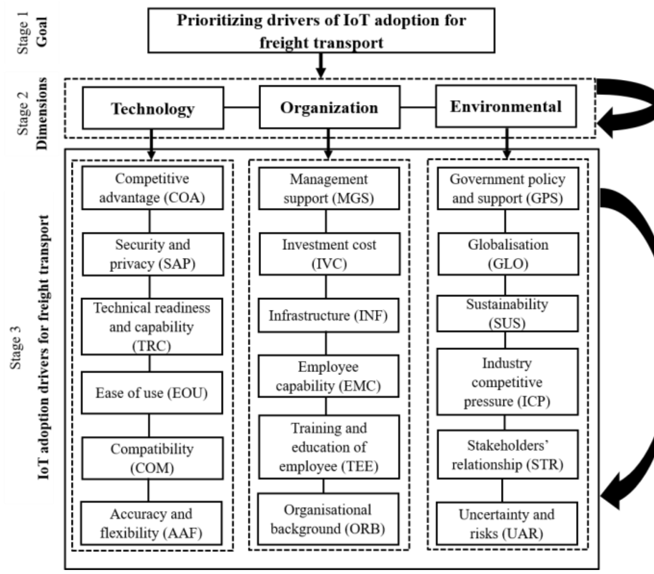

Fig. 2. FANP model for IoT adoption drivers for freight transport modes.

1) *Technological context drivers*

As depicted in Fig. 2, six drivers under technological context influence the adoption of IoT in freight transport: COA, SAP, TRC, EOU, COM, and AAF. 'Compatibility' is a vital driver in the technological dimension, as it shows the ease of integrating IoT devices with the existing infrastructure for adopting IoT in freight transport [16], [41], [42]. Another vital driver under the technological dimension is 'security and privacy.' This driver helps to protect the privacy and security of clients, data, and information, which ensures authentication and access control [15], [16], [43]. 'Technical readiness and capability' is an essential driver providing some level of readiness regarding digital infrastructure and the capacity to adopt IoT in freight transport [44], [45], [46]. This driver shows the positive stimulus for implementing IoT and ensuring existing infrastructure can easily integrate with the new development.

Apart from the above crucial drivers, one of the most important features of IoT adoption is the 'ease of use' during technical operations in freight transport [47], [48]. As IoT adoption creates an error-free digital network with the physical infrastructure of the transport system, the system can be technically 'flexible and accurate' at different stages of the operation, such as route and fleet monitoring, safety, and security [49], [50]. IoT's technological features and benefits in freight transport can help get a 'competitive advantage' in the transport community [45], [47], [50].

2) *Organizational context drivers*

As depicted in Fig. 2, there are six drivers under the organizational context that influence the adoption of IoT in freight transport: MGS, IVC, INF, EMC, TEE, and ORB. 'Employee capability' is a significant driver for the successful implementation of IoT in freight transport, as it requires skilled professionals to operate in the system to ensure the efficiency and effectiveness of IoT adoption [42], [47], [51]. The 'training and education of employee' is another significant driver in

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implementing IoT, as appropriate training for the employee helps to develop the essential capabilities, such as installation, interface, and monitoring of IoT networks to ensure the adaptability of IoT in freight transport [45], [46], [49]. The type of 'organizational background' provides the set of unique characteristics of a transport system in terms of culture, readiness, attitude, teamwork, and flexibility that help to understand the adaptability issues in the systems and accordingly plan the business decisions [44], [49], [52].

'Management support' is an influential driver within the organizational context and describes the level of assistance received from top management in terms of resources during and after the implementation of IoT, as IoT adoption is not possible without constructive support from top management [15], [43], [44]. In addition, the extent of 'infrastructure' and 'investment cost' available and required for the adoption of IoT substantially influence decisions, as these drivers support the development of contemporary infrastructure for freight transport [41], [46], [50]. The most challenging infrastructure for freight transport is the internet and electricity for getting real-time updates from IoT.

3) Environmental context drivers

As depicted in Fig. 2, six drivers under environmental context influence the adoption of IoT in freight transport: GPS, GLO, SUS, ICP, STR, and UAR. Globalization and sustainability are significant drivers external to the freight transport system due to the continuous internationalization of the economy [52], [53]. 'Globalization' is the compulsion driver for the transport system to compete in the international community. 'Sustainability' is the enforcement driver to achieve human, social, economic, and environmental sustainability in the transport system. 'Stakeholders' relationship' is also an external environmental driver in freight transport and deals with the continuous requirements of several stakeholders [45], [50]. The transporters respond differently to various needs of the stakeholders concerning IoT adoption. 'Industry competitive pressure' is the drive that relates to the transport system and demonstrates the level of competitiveness from transport industries for the adoption of IoT [42], [44], [49]. The competitiveness and opportunities in the I4.0 era have helped transport companies improve efficiency and effectiveness.

In addition, 'Government policy and support' is an influential driver in the transport system and provides aid to freight transport from the government and related agencies in terms of policies and standard legal regulations to adopt new technology like IoT in freight transport systems [43], [51]. The firm, government, and policymaking institutions can work concurrently to encourage the technology initiatives and expected issues in changing the dynamics of different modes of freight transport. The last driver, 'uncertainty and risks', is always a concern for the developer and user in adopting new technology like IoT, which deals with the dynamics of the modernized infrastructure [41]. The risks associated with IoT implementation are vulnerable to the scale of the freight transport company, such as client privacy, data security, and access control.

B. Calculation of global weight of IoT adoption drivers

The global weight of IoT adoption drivers in freight transport is determined using the FANP method, as shown in Fig. 3. The procedure to determine the weight is discussed in Appendix A. Initially, we consolidate the pairwise comparison matrix by considering the TFN, as illustrated in Appendix B. Appendix E includes the pairwise comparison matrix for the drivers and Appendix F for dimensions. Appendix G contains the pairwise comparison matrix used to establish the Inner Dependency Matrix. Evaluate the inner dependency matrix (Appendix H) and global weight of drivers (Appendix I) as illustrated for road freight transport. The final weight of IoT adoption drivers for freight transport is calculated by averaging the global weights assigned for rail, road, and maritime freight transport, as depicted in Fig.3.

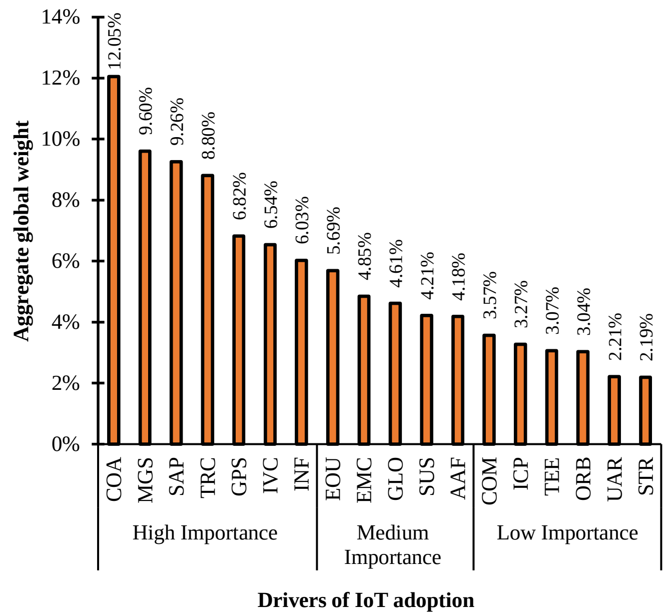

Fig. 3. FANP model for IoT adoption drivers for freight transport modes.

The highly important drivers for IoT adoption in freight transport are COA, MGS, SAP, TRC, GPS, IVC, and INF. Most of these drivers are from technology and organizational dimensions, such as three drivers from technology, three from the organization, and one from the environmental domain. On the other hand, the low important drivers are STR, UAR, ORB, TEE, ICP, and COM. Most of these drivers are from the environmental dimension, such as three drivers from the environment, two from the organization, and one from the technological domain. Thus, it can be realized that freight transport has given more priority to technology and minor importance to the organization's external environment in implementing IoT in the system.

C. Comparison of IoT adoption dimensions

The weight of IoT adoption dimensions is estimated for road, rail, and maritime freight transport separately using the FANP method. The dimension 'technology' has been kept as high priority and given almost equal weight by all modes of freight transport, as shown in Fig. 4. In contrast, organization and environment dimensions have been given medium and low weight, respectively.

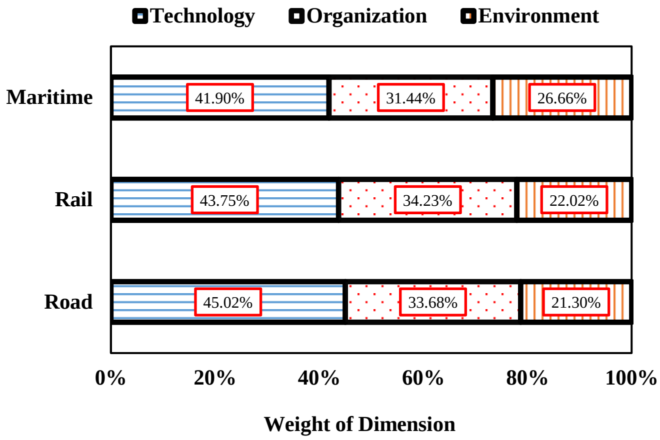

Fig. 4. Comparison of dimensions' weight for road, rail, and maritime transport.

The technological drivers are crucial for IoT adoption in freight transport. Transporters should be given more importance in achieving a competitive advantage in the market by mitigating visibility, agility, and sustainability in the transport system. Technological drivers also helped improve the safety and security of freight transport through tracking and tracing the vehicles. The IoT-enabled devices also enhanced customer involvement and experience through real-time and accurate information.

The organizational drivers assist the management in accomplishing the objectives by building necessary resources and providing capable employees through various training and standard operating manuals. The low important dimension for IoT adoption is the environment, which includes policy and guidelines, sustainability, and globalization. Even then, maritime freight transport has given comparatively more importance to the environmental dimension as maritime transport needs government support to develop infrastructure such as port development, modernization, and connectivity. It is also necessary to maintain strong policies and guidelines for domestic and international as it includes cross-border transport.

D. Comparison of IoT adoption drivers

The weight of IoT adoption drivers is determined separately for road, rail, and maritime freight transport with the help of the FANP method. Fig. 5 compares the weights of IoT adoption drivers among road, rail, and maritime freight transport. It is observed that all freight transport modes have some common priority. Based on the priority of IoT adoption decisions by all three modes, the drivers are categorized into High, Medium, and Low. Of 18 drivers, five are of high priority, eight are of medium priority, and five are of the low priority.

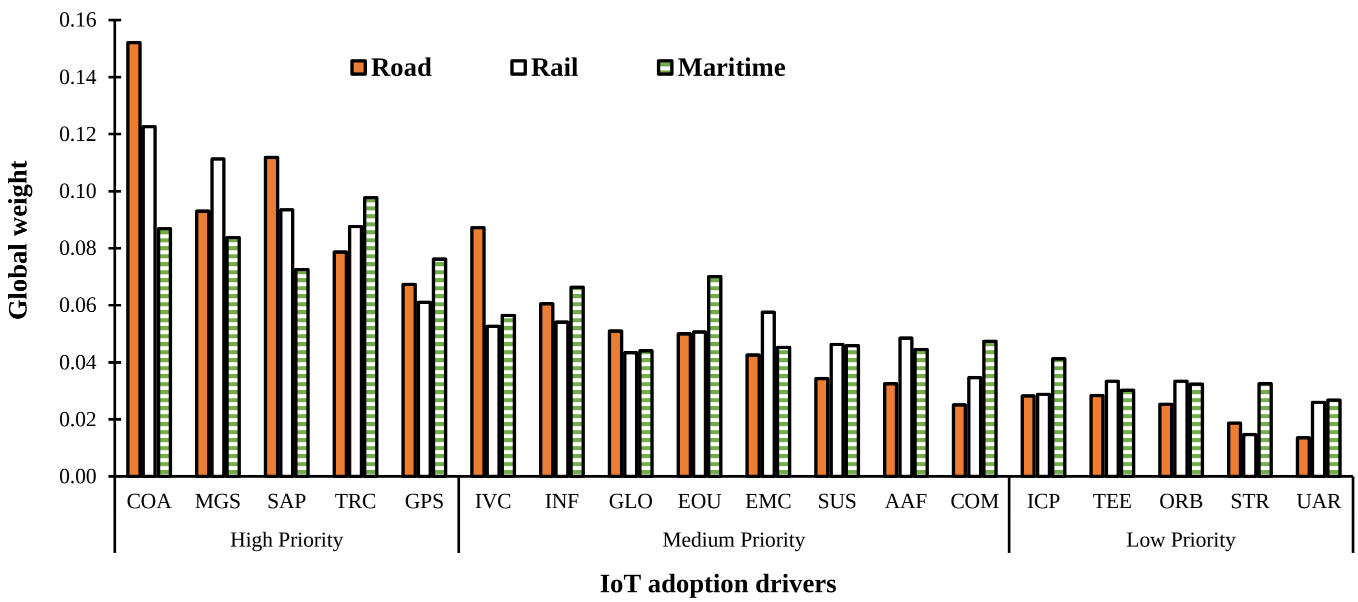

Fig. 5. Comparison of drivers' weight for the data from road, rail, and maritime transport concerning common priority.

The five high-priority drivers are COA, MGS, SAP, TRC, AND GPS, as shown in Fig. 5. The high-priority drivers are primarily from the technology dimension, such as three drivers from technology, each from the organization and environmental dimensions. On the other hand, the low weighted drivers are UAR, STR, ORB, TEE, and ICP. The low weighted drivers are from the organizational and environmental dimensions, such as three drivers from the organization and two from the environmental dimensions. This section explains the probable reasons and necessities: why are transport managers prioritizing the above five drivers?

Competitive advantage specifies the characteristics or capabilities of freight transport, which help the customers select a particular transport company over others, such as less transit time, real-time updates, easy pickup and drop, last-mile delivery, brand, and reputation. The transport managers trying to achieve competitive advantage by providing value to the customers in the specified operating conditions through the best utilization of resources. This competitive advantage of the transport company is becoming sustainable through generic strategies developed by Porter, such as differentiation, cost leadership, and focus advantage. The transport company should

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achieve a sustainable competitive advantage by creating a VIRO (Value, Imitability, Rarity, and Organization) framework that categorizes the internal resources through valuable, inimitable, rear, and organized freight transport, which helps to identify the competitive resources. Therefore, the transport company needs to determine the competitive resources to become a sustainable transporter in a global market.

The competitive advantage in freight transport is accomplished by providing additional value in the transport service with many strategies and effective methods through innovative technology, and IoT is one of them. The transporters must be ready to fulfill the requirements of implementing IoT according to its capabilities. The freight transporters need to understand the benefits of technological readiness before adopting IoT in freight transport [54]. It requires systematic planning to restructure the existing infrastructures step by step per the requirements of IoT adoption in a particular transport company. This prior readiness helps the transporters achieve smooth IoT integration and steadily monitor the uses and benefits of IoT adoption [55]. Many researchers have also shown a positive relationship between technological readiness and technology implementation [56], [57].

With increasing technological involvement in freight transport, security and privacy becomes highly challenging as four groups of devices are interconnected in IoT networks, such as software, hardware, components, and people, and inevitably encounter security, privacy, and trust issues. The security issues in IoT networks are authentication, availability, confidentiality, and data integrity, and privacy issues are profiling, identification, inventory attack, localization and tracking, and secure data transmission [58], [59]. These issues are the key reasons for demotivating technology adoption in many areas, but IoT, along with some intelligent computational techniques, such as Fuzzy system, Neural network, and Blockchain, reduces these security issues and develop a sustainable framework to embrace I4.0 [58]. Due to this, transporters and IoT adopters from any industry have prioritized security and privacy the most.

Besides the three drivers, the transporters expect support from internal management and government through policies. Most of the infrastructure used for freight transport is shared infrastructure facilitated or leased by the government. For example, railway tracks, roads, and sea routes are shared infrastructure facilitated by the government, and some railway terminals and berths of the port are the infrastructure leased through some schemes. To benefit from this infrastructure, the government has assisted some groups according to the county's availability and requirements and external driving drivers like globalization and sustainability. The internal management of transport companies needs to embrace their visions while considering government policies.

Apart from the five high-priority drivers for IoT adoption in freight transport, the eight medium-priority drivers are Ease of Use, Accuracy and flexibility, Compatibility, Investment Cost, Infrastructure, Employee capability, Globalization, and Sustainability, as shown in Fig. 5. Some drivers are external driving drivers such as sustainability and globalization, which are unavoidable and extremely important for the growth of freight transport along with the social, economic, and environmental balance for current and future development. Some drivers like infrastructure, investment cost, and employee capability are the essential components of freight transport that reflect the pattern of development and growth of the transporter. These drivers link driving and dependence to adopt IoT and positively influence logistics performance and international trade [60]. Compatibility is essential to smoothly integrating the new IoT system and the existing infrastructure. Accuracy, flexibility, and Ease of use are necessary benefits for IoT adoption in freight transport.

Apart from the common priority among the drivers for road, rail, and maritime freight transport shown in Fig. 5, the freight modes also have some individual preferences. Fig. 6 compares the individual preferences of road, rail, and maritime freight transport based on the relative weight of IoT adoption drivers. For example, IVC, COA, SAP, and GLO are the preferable drivers for road freight transport compared to rail and maritime, as shown in Fig. 6. Similarly, MGS, EMC, AAF, TEE, ORB, and SUS are the preferred drivers for rail freight transport, and EOU, TRC, GPS, COM, ICP, STR, INF, and UAR are the preferred drivers for maritime freight transport. The drivers 'Investment Cost (IVC), Management Support (MGS), and Ease of Use (EOU)' have been given comparatively higher priority for road, rail, and maritime freight transport, respectively.

For road freight transporters, investment costs are relatively higher prioritizing drivers than other modes. Generally, road freight transport is the best for short distances and door-to-door delivery. Road transporters must be flexible to manage the required performance more effectively than others. IoT and newly innovated technology help road transporters maintain this flexibility optimally through continuous investment in the system.

The rail freight transporters have given comparatively higher priority to 'management support' as rail transport has a massive infrastructure and is monitored by the management (government) overall. Though some schemes promote the decentralization of rail transport and its infrastructure, the ultimate control is in the hands of the government. The government provides internal and external support for rail transport through policies according to the nation's requirements. For example, the transportation charge of empty and flat rakes for liquid medical oxygen was free during COVID-19 in India.

Among all IoT adoption drivers, maritime freight transporters have emphasized 'Ease of use', as sea transport mainly focuses on bulk cargo and higher volumes of goods. I4.0 technologies and IoT-enabled devices help smooth and safely handle the goods and manage the operations of large vessels efficiently, such as mooring systems for ships, automated material handling systems, and regular checks for operation, inspection, and maintenance of the vessel before departure. It also improves some intangible processes, such as excise documentation, shipping finance, marine insurance, booking, and tracking of cargo [61].

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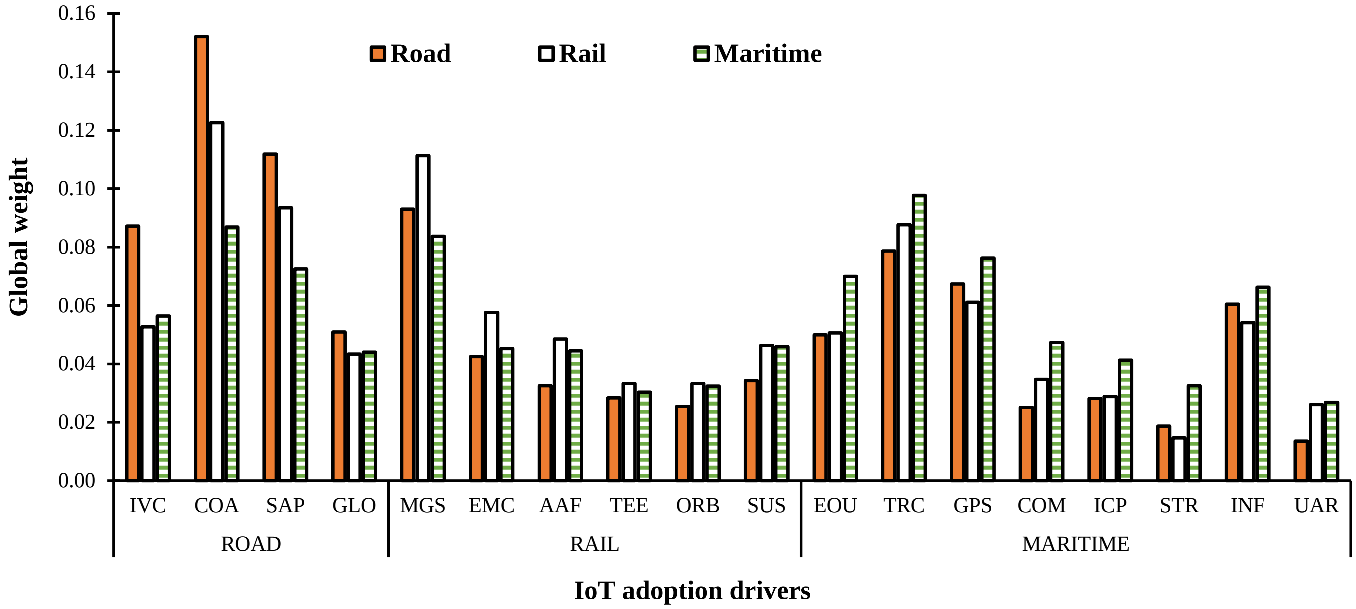

Fig. 6. Comparison of drivers' weight for road, rail, and maritime transport concerning mode priority.

E. Ranking of freight modes for IoT Adoption

After estimating the weight of IoT adoption drivers, we have scrutinized the suitability of IoT adoption of different freight modes through the MCDM ranking method. The MULTIMOORA method is used to rank road, rail, and maritime freight transport and compared this ranking with some other groups of MCDM method such as TOPSIS, VIKOR, WASPAS, and PROMETHEE II to ensure the validity and reliability of the results. The steps of the MULTIMOORA method are discussed in Appendix C. The initial decision matrix has been developed with the help of an expert opinion. The weight of drivers is the aggregate weight calculated using the FANP method. The initial decision matrix is normalized to make each driver comparable.

The initial ranking of freight modes is obtained using a normalized score and aggregated weight of drivers. The initial ranking in the MULTIMOORA method has been done for the ratio system, the reference system, and the full multiplication form, as shown in Table II. According to the ration system and full multiplication form, maritime freight transport is the most suitable mode, followed by road and rail. However, according to the reference system, road freight transport is the most suitable mode, followed by maritime and rail. The MULTIMOORA method's final ranking is based on dominance theory, as shown in Table II. The most suitable mode for IoT adoption in freight transport is maritime transport, followed by road and rail.

TABLE II
INITIAL AND FINAL RANKING OF FREIGHT MODES FOR IOT ADOPTION

Freight modes	Initial ranking			Final ranking
	Ratio system	Reference point	Full multiplication form	
Road	2	1	2	2
Rail	3	3	3	3
Maritime	1	2	1	1

The robustness of the ranking result is verified by comparing the MULTIMOORA result with other well-known MCDM ranking methods such as TOPSIS, VIKOR, WASPAS, and PROMETHEE II. These methods have belonged to various MCDM categories, such as TOPSIS and VIKOR, the distance-based or reference level method; WASPAS, the value measurement or utility-based method; and PROMETHEE II, the outranking method. The MULTIMOORA method combines value measurement (ratio system and full multiplication form) and distance-based method (reference system). Fig. 7 shows the comparative ranking of road, rail, and maritime freight transport for IoT adoption. It was clear from Fig. 7 that the ranking result of the MULTIMOORA method is robust, as all methods except VIKOR have the same ranking preference.

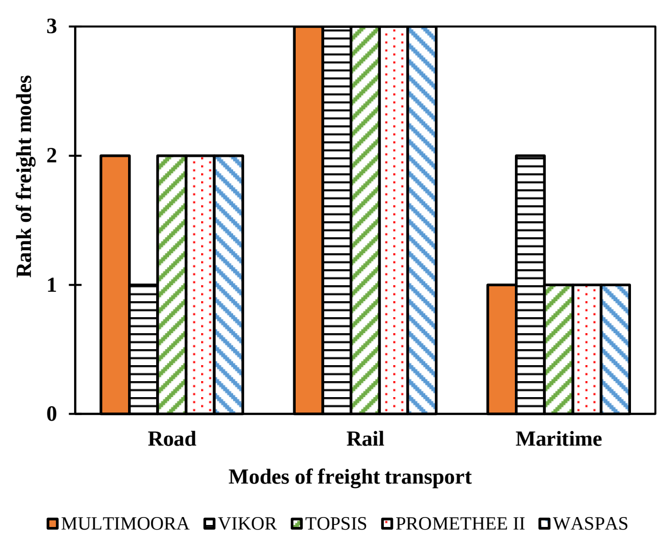

Fig. 7. Comparative ranking of MCDM methods for the adoption of IoT in road, rail, and maritime freight transport.

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Maritime transport is the most suitable mode to implement IoT because of its complex systems of operating conditions and interconnected partners. Implementing IoT improves the efficiency and effectiveness of the operations of the maritime supply chain and cooperation among supply chain partners. IoT and some I4.0 technologies help the transport system to smoothly integrate supply chain partners, such as shipping lines, port terminals, freight forwarders, and land-based logistics systems. Policymakers and international institutions should encourage the maritime supply chain to operate with interoperability in international trade and shipping with international standards [62]. One example of an international standard is using containers in freight transport.

Apart from this, freight transport has a diverse form of critical activity in many operational areas that can improve through IoT integration, such as cargo tracking and monitoring, document management and reporting, online booking platform, shipping finance, marine insurance, trade analysis, route planning, voyage safety, energy efficiency, emission control, fleet management, port operation, and port infrastructure system [61]. IoT technologies establish a real-time link between the ocean and the coastline, and operators can make more informed and effective decisions that enrich the operations performance [63]. IoT in maritime transport improved many operational activities, such as automatic mooring systems which adjust the vessel at the right height before and after the arrival for loading and unloading, standard check for operation, inspection, and maintenance of the vessel, real-time tracking of route, vessel, and cargo, and continuous information about environmental and weather condition. It can also be employed for remote steering and remote pilotage.

Besides this, IoT is a cost-reducing driver through reducing technical downtime, operation costs, scheduling automatic maintenance, and reducing response time. It also optimizes the vessel performance through real-time data analysis of fuel and engine, which reduces emission and save money over time. So, IoT-enabled maritime transport improves remote connectivity, vessel performance, and effective decision-making, reducing fuel consumption, emissions, and costs.

IoT and other technologies associated with I4.0 assist in optimizing the present system, generating new business prospects, and improving the maritime supply chain and international trade. At the same time, IoT adoption involves some risks to security and privacy. Policymakers and government entities should provide some relaxation to motivate and restrictions to avoid monopoly in the supply chain and ensure the maritime stakeholders that IoT and I4.0 help accomplish Sustainable Development Goals [62].

V. Implications

There is a paucity of freight transport studies concerning the adoption of the Internet of Things. This study substantially contributes to the IoT literature and explores the practical use of results corresponding to transporters, developers, and policymakers.

A. Theoretical Implications

The present study recognizes the important IoT adoption drivers for freight transport and classifies them into technology, organization, and environment contexts. The study estimates the relative weight of the drivers and distinguishes the most and least significant drivers for freight transport. The most significant drivers for freight transport come under the technological context, as these drivers are the most fundamental for IoT adoption. However, transport managers rarely comprehend or trust such innovative technology. In contrast, the least significant drivers come under the external environmental context as most of these drivers do not contribute directly to the revenue of the transport company, and that is why the policymakers enforced the transporters to maintain a particular standard, such as pollution (sustainability) and safety. This classification of drivers is a unique contribution to the literature on IoT in freight transport.

This study also provides a comparative analysis of IoT adoption drivers under road, rail, and maritime freight transport. These three modes differ substantially due to their infrastructure requirement, travel time, load carrying capacity, environmental consequence, and risks. Road transport is preferred for small quantities for short haul and last-mile deliveries, while rail transport is safer and more efficient for bulk transport, and maritime transport is suitable for large volumes and most efficient mode of freight transport for long haul. Usually, maritime transport is used for international transportation, while road and rail are used for domestic and last-mile transportation.

The comparative analysis compares the weight of dimensions and drivers among road, rail, and maritime transports. The findings highlight the most and least prioritized drivers and dimensions for each mode of freight transport, which provides a critical understanding to the transporters about IoT adoption. These findings provide distinct directions to each mode of transporters for IoT adoption in terms of prioritization of dimensions and drivers. These insights of the study are novel and unique in the literature on the freight transport domain. Further, the study scrutinizes the suitability for IoT adoption among road, rail, and maritime freight transports. The finding shows maritime transport as the best mode to implement IoT. This finding is also a unique contribution to the literature, especially in freight transport.

B. Managerial Implications

The current study also contributes to the real-life managerial implications for road, rail, and maritime transporters. In the era of I4.0, a centralized transportation system is necessary to achieve the fastest, safest, most affordable, and most sustainable modes of freight transport. The implementation of IoT in the transport system and the requirement of the industrial revolution can help to develop a centralized system with effective monitoring of real-time visibility. One of the findings of the study inference that each mode of freight transport has a unique direction of achieving the competitive advantage through management support and intervention of government policies by making the transport sector capable of upgrading innovations through the seamless integration of IoT devices in freight transport. The finding also infers that the freight transport industry should improve the security and privacy of data with optimal investment in technological infrastructure and updated training programs for the employees to make the entire system convenient to work with.

This study's three most impactable stakeholders are transport management, IoT developers, and policymakers. This study can serve as a reference document for policymakers and government to comprehend the influence of IoT adoption on different freight transport modes. The policymakers can use the findings to develop the policy to adapt IoT in road, rail, and maritime freight transport to satisfy the current competitive market requirement and make it a sustainable transport system for the prospects. This policy helps to estimate the appropriate modal share of freight transport for a country to satisfy future demand and reduce greenhouse gas emissions. As in India's case, the government plans to increase the modal share of rail freight transport under land transport to enable reliable service to accomplish the environmentally friendly and sustainable mass transport system.

The transport management of road, rail, and maritime transport are the ultimate decision-makers for implementing IoT in freight transport. The transport management develops the strategy aligned with the supply chain partners on the updated guidelines and policy of innovative technology development and implementation to achieve the lowest possible logistics cost. Along with an overall direction of freight transport to accomplish the competitive advantage, each freight mode has distinct capabilities and features intended to implement IoT. Road transport focuses more on investment costs rather than risks. In contrast, rail transport emphasizes management support, and maritime transport believes more in the ease of using the technology in the ports.

The developers are one of the crucial stakeholders for technology development and application research, as the quality of the device and competition among developers are vital drivers for transport management. Findings recognized that maritime transport is the most suitable mode of freight transport for adopting IoT. This implies that IoT developers should concentrate more on maritime transport. Developers should also focus on other findings related to maritime transport, such as the global weight, to understand and implicate the necessity of prioritizing the drivers. The developers should also try to identify why the land mode of freight transport is leisure to implement IoT in the existing transport system.

VI. Conclusions

This is a comparative study of drivers influencing IoT adoption in different modes of freight transport. It compares road, rail, and maritime transport suitability for IoT adoption using an integrated TOE-FANP-MULTIMOORA method. The study identified 18 drivers, classified them using the TOE framework, and determined the weight for each dimension and drivers. The findings suggest that transporters should pay close attention to the technological dimension and the five most significant drivers supporting IoT adoption in freight transport: Competitive Advantage, Management Support, Security and Privacy, Technology Readiness and Capabilities, and Government Policy and Support. The findings also suggest some critical drivers that need great attention for each mode of freight transport, like Investment Cost for Road transport, Management Support for Rail transport, and Ease of use for Maritime transport.

Further, the study identifies maritime transport as the most suitable mode of freight transport to adopt IoT, considering multiple criteria from the perspectives of technology, organization, and environment. The study's findings also provide general guidelines to modify policy and modal share considering globalization and sustainability for government and policymaking agencies and directions to get prospective customers for IoT developers.

The present research study can be extended further in many directions. The number of experts in the study is adequate to satisfy the requirements of the methodologies. However, increasing the number of experts in each mode of freight transport would provide a better representativeness of the whole freight transport industry and more exhaustive results. With increasing number of experts, this research can be further extended by developing a hierarchical framework and cause-effect relationship among identified drivers for road, rail, and maritime freight transport. Apart from the number of experts, information regarding the affiliation of the company is also not provided to ensure the confidentiality of the experts. The future study can also perform an empirical impact analysis to scrutinize IoT adoption's impact on freight transport performance using statistical analysis. A comparative study can be performed between developed and developing countries to understand variations in IoT adoption in freight transport concerning relative weight, hierarchical framework, and cause-and-effect relationships among the drivers. Refer to Upadhyay [64] for further research scopes.

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Binay Kumar Rajak received B. Tech. degree in Production Engineering from the Birsa Institute of Technology Sindri, Dhanbad, India, in 2010 and M. Tech. degree in Industrial Engineering from the Indian Institute of Technology (IIT) Delhi, India, in 2013. He is currently working towards the Ph.D. degree in Production and Operation Management with the IIT Kharagpur, India.

He has teaching experience of about five years in Mechanical and Automobile Engineering. He has author a research paper in IEEE Transactions on Engineering Management and International Journal of Logistics Economics and Globalisation. His research interest includes IoT, Blockchain, Industry 4.0, Port Logistics, and Supply Chain & Logistics Management.

Swagato Chatterjee received B. Tech. degree in Civil Engineering from the IIT Kharagpur, India, and FPM (Ph.D.) degree in marketing from the Indian Institute of Management, Bangalore, India. He is currently a Senior Lecturer, Digital Marketing and Analytics at Queen Mary University of London. He has authored or coauthored several papers in repute journals, including European Journal of Marketing, Decision Support Systems, Tourism Management, International Journal of Hospitality Management, Journal of Service Theory and Practice, Journal of Business Research, IEEE Transactions of Engineering Management, etc. His research interests include Relationship marketing, User Generated Content, and Text Mining.

Amit Upadhyay received M. Tech. in Industrial Engineering and Ph.D. in Operation Research from IIT Delhi in 2008 and 2016, respectively.

He is currently an Assistant Professor in the Department of Management Studies, IIT Roorkee, working in the areas operations management and business analytics. Besides teaching at IIT Kharagpur and IIM Calcutta, he has worked with companies like Indian Oil, Container Corporation, P&G, and GatewayRail for consultancy and training programs. He has authored several papers in reputed journals, including INFORMS Journal on Applied Analytics, International Journal of Production Research, Transportation Research Part E.

Dr. Upadhyay is a recipient of the Outstanding Innovation in Service Systems Engineering Award from IISE & Penn State University, USA, 2021

M. Vimala Rani received Ph.D. degree in Operations Management from the Indian Institute of Science (IISc), Bangalore, India.

She is currently an Assistant Professor in operations at Vinod Gupta School of Management, Indian Institute of Technology Kharagpur, West Bengal, India since 2019. She has worked as Research Associate for one year at the Department of Management Studies, IISc, Bangalore. She has also worked as an Assistant Professor at Amrita School of Business, Bangalore, India. Her research interest is developing mathematical and heuristic algorithms for problems related to Industrial Engineering and Management problems. She has authored several papers in reputed journals, including International Journal of Production Research, Journal of Information and Optimization Sciences, Opsearch. One of her research articles received a Highly Commended Paper award by Emerald, and another article received the Best Research Paper award.

Dr. Vimala has received a gold medal and the Best Ph.D. thesis award from the council of Indian Institute of Science (IISc), Bangalore, India.