Journal of Korea Trade Vol. 27, No. 5, October 2023, 63-90
https://doi.org/10.35611/jkt.2023.27.5.63
ISSN 1229-828X

Impact of Logistics 4.0 Technology Adoption on Logistics Performance: The Mediating Effect of Logistics Innovation Capability and the Mediated Moderation Effect of Firm Size*

JKT 27(5)
Received 8 May 2023
Revised 15 September 2023
Accepted 13 October 2023

Young-Min Kim†
Department of Global Trade and Logistics, Seoul Cyber University, South Korea

Abstract

Purpose – This study aims to identify the relationship between logistics companies' Logistics 4.0 technology adoption with logistics innovation capability and logistics performance, and analyze the mediating effect of logistics innovation capability and the mediated moderation effect of firm size through logistics innovation capability.

Design/methodology – Research models and hypotheses were established based on prior research related to Industry 4.0, Logistics 4.0, logistics technology, logistics performance, and firm size. The survey was conducted on the employees of logistics companies, and exploratory factor analysis, reliability analysis, confirmatory factor analysis, discriminant validity analysis, structural equation model analysis, mediation effect, moderation effect, and the mediated moderation effect analysis were performed.

Findings – The adoption of Logistics 4.0 technology was found to significantly affect logistics innovation capability and logistics performance. Logistics innovation capability was found to significantly affect logistics performance. Moreover, logistics innovation capability was found to have a significant mediation effect on the relationship between Logistics 4.0 technology adoption and logistics performance. The moderation effect based on firm size was found to have a partial effect on logistics innovation capability and logistics performance, but the mediated moderation effect was not significant.

Originality/value – This study is meaningful in that it empirically analyzed the relationship of Logistics 4.0 technology adoption with logistics innovation capability and logistics performance, the mediating effect of logistics innovation capability, the moderation effect of firm size, and the mediated moderation effect of firm size, which were not addressed in previous studies.

Keywords: Adoption of Logistics Technology, Logistics 4.0, Logistics Performance, Logistics Technology
JEL Classifications: L25, L87, L91, M15

1. Introduction

Technologies related to the fourth industrial revolution, such as artificial intelligence (AI), blockchain, autonomous vehicles, unmanned robots, big data, and the Internet of Things (IoT), are rapidly spreading. In particular, the COVID-19 pandemic has accelerated the digital transformation, and the logistics sector is no exception. The Republic of Korea has established a digital-oriented Korean version of the New Deal to promote and spread digital innovation and dynamism throughout the economy. The Ministry of Land, Infrastructure,

* This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF- 2021S1A5A2A01065278).
† **First and Corresponding author:** young688@iscu.ac.kr
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and Transport presents the Logistics 4.0 policy with keywords such as smart logistics, cooperative autonomous driving, drones, and digital twins. As such, Logistics 4.0 is a crucial national policy and the core direction of the logistics industry.

The Korea SCM & Logistics Festival suggested the trends in the introduction and utilization of Logistics 4.0 technology by logistics companies, and leading logistics firms are introducing new logistics technologies through digital transformation. There will undoubtedly be many changes to increase logistics efficiency and productivity using Logistics 4.0 technology in the logistics field. Nevertheless, large logistics firms and small and medium-sized logistics firms significantly differ in the adoption of Logistics 4.0 technology. As larger leading logistics firms can invest in Logistics 4.0 technologies and secure related experts, the introduction and utilization of Logistics 4.0 technology is not problematic for them. However, small and medium-sized logistics firms are not fully aware of the need for Logistics 4.0 technology, and they face practical problems such as investment costs and securing human resources, thus hindering their adoption of new logistics technologies. Kim Young-Min (2020) pointed out that there was a difference between the two types of firms: regarding employees and sales volume, large logistics companies fully recognized the need for Logistics 4.0 technology, but small and medium-sized logistics companies had a relatively low awareness of this need. Small and medium-sized logistics firms are passive in the adoption of Logistics 4.0 technology, resulting in lower logistics efficiency. It is necessary to fully recognize these problems in advance and prepare alternatives to enable large and small and medium-sized logistics companies to actively adopt Logistics 4.0 technology to improve their logistics performance.

The efficiency of Industry 4.0 technology is also confirmed in trade. Lee Byung-Moon, Jeong Hee-Jin, and Park Kwang-So (2017) analyzed the impact of the fourth industrial revolution on trade and export promotion strategy. Jung Jong-Hee and Kim Seong-Ho (2022) presented the results indicating that innovation orientation had a positive effect on SCM 4.0 and operational performance for export SMEs. In addition, Lee Chang-Sook and Woo Kwang-Myung (2022) emphasized the need for blockchain technology for seamless electronic trade. Other research includes a comparative analysis of clothing consumption patterns in Korea and China by applying an AI-based decision tree model (Choi Chang-Hwan, Nguyen, and Wang, 2023), the use intention of IoT-based smart home system (Shen, Chen, Jiang, and Ji, 2022), the introduction of blockchain technology to improve operational efficiency (Wu and Jin, 2022), digital transformation strategies of multinational companies (Lee Jong-Hak, Kim Young-Woo, and Kang Ji-Sang, 2023), and humanity management for the coexistence of human-machine-environment (Lee Wang-Hyung, 2022).

The research on Logistics 4.0 can be said to be in its infancy. Most studies focus on introducing Logistics 4.0 and adoptable technologies, or on exploring how to use them, while empirical research remains scarce on higher logistics performance. It is necessary to conduct empirical studies on the effects of Logistics 4.0 technology on logistics performance to theoretically contribute to the adoption of related technologies by logistics companies.

And while research in the engineering for the development of Logistics 4.0 technology has progressed considerably, research has not been actively conducted in the business field. In other words, as logistics firms aspire to strengthen their logistics innovation capability and improve their logistics performance through Logistics 4.0 technology, it is necessary to empirically verify the causal relationships and suggest practical implications for the adoption of Logistics 4.0 technology to improve their performance. Additionally, to improve logistics performance by adopting Logistics 4.0 technology for both large and small and medium

logistic firms, it is necessary to verify how the outcome of Logistics 4.0 technology adoption differs depending on logistics firm size, and formulate adoption strategies suitable for both large and small and medium-sized logistics firms that face difficulties in adopting the technology.

Therefore, this study aims to identify the relationship between logistics companies' Logistics 4.0 technology adoption with logistics innovation capability and logistics performance, and empirically analyze the mediating effect of logistics innovation capability and the mediated moderation effect of firm size through logistics innovation capability. Based on the results of an empirical analysis, this study presents strategic implications for logistics firms to improve their logistics performance through the adoption and utilization of Logistics 4.0 technology, that is, the logistics technologies related to the fourth industrial revolution.

2. Literature Review

2.1. Industry 4.0 and Performance

Chauhan, Singh, and Luthra (2021) analyzed the relationship between internal and external barriers for the introduction of Industry 4.0, and the relationship between the introduction and performance of Industry 4.0 (operational performance and supply chain (SC) capability). The results showed that external and internal barriers had a negative effect on the introduction of Industry 4.0, and that the introduction of Industry 4.0 had a significantly positive effect on operational performance and SC capability. The moderation effect of external and internal barriers on the relationship between the introduction and performance of Industry 4.0 was confirmed to be partially significant.

Li, Dai, and Cui (2020) analyzed the relationship between Industry 4.0-related digital technology and economic and environmental performances, the mediating effect of the digital SC platform, and the mediated moderation effect of environmental dynamism. The results showed that the digital SC platform had a significant mediating effect on the relationship between the digital technology of Industry 4.0 and economic and environmental performances, and the performance was improved when there was a high level of environmental dynamism, confirming that the mediated moderation effect was also significant.

Ślusarczyk, Tvaronaviciene, Haque, and Olah (2020) analyzed the impact of Industry 4.0 technology on the performance of logistics companies in Hungary, Canada, and Poland. The results showed that although antecedent factors such as Industry 4.0 technology-related knowledge limitation, implementation barriers, potential awareness, preparation for change, and technology had different influences in each country, they all had significant impacts on the performance of logistics firms.

Chetthamrongchai and Jermsittiparsert (2020) targeted pharmaceutical firms and analyzed the relationship between perceptions of robots and AI, technological knowledge, Industry 4.0 implementation, and environmental performance. The results confirmed that the awareness of robots and AI and technological knowledge had significant effects on the implementation of Industry 4.0 and environmental performance. Furthermore, the mediating effect on the implementation of Industry 4.0 was also found to be significant in the relationship between the awareness of robots and AI, technological knowledge, and environmental performance.

Kamble, Gunasekaran, Ghadge, and Raut (2020) targeted small and medium-sized automobile parts manufacturing companies and developed a performance measurement system

that can evaluate investment in smart production systems by applying automation, data exchange, CPS, IoT, and AI technologies, reflecting Industry 4.0. Performance was evaluated using measurement indicators such as cost, quality, flexibility, time, integration, optimized productivity, and the potential for socially and ecologically sustainable development. Compared to the traditional production method, the production system with the Industry 4.0 technology was confirmed to provide a competitive advantage.

Stentoft, Jensen, Philipsen, and Haug (2019) analyzed the relationship between the motivation, barriers, preparedness, and implementation related to Industry 4.0 for small and medium-sized manufacturing enterprises. The results showed that motivation for digital technology had a significantly positive effect on digital technology preparedness, barriers had a negative effect, and preparedness for Industry 4.0 significantly affected its implementation.

Tang and Veelenturf (2019) emphasized that the applications of Industry 4.0 technologies (e.g., robots, AI, autonomous vehicles, blockchain, drones, and IoT) to the logistics and transportation fields can create economic, environmental, and social values. Along with such economic value (i.e., quick delivery via drones or robots, the reliability of storage using robots, the reduction of operation costs through inventory monitoring and restocking via smart sensors, and higher efficiency through blockchain-based transportation), there could be higher competitiveness in the social and environmental dimensions.

Park Chan-Kwon and Kim Chae-Bogk (2019) studied technology application priorities and weights for responding to the fourth industrial revolution and emphasized the importance of big data in digital-based technologies, mobile communication (mobile) in hyper-connected technology, robots in convergence technology, and smart manufacturing and logistics in smart industrial technology. In logistics technology, big data, AI, robots, mobile communication, and unmanned transportation (autonomous driving) had high priority, and blockchain, 3D printing, and drones were ranked relatively low.

Summarizing the aforementioned previous studies, the introduction, motives, and readiness for Industry 4.0 technology contribute not only to operational, economic, and environmental performance of businesses but also to enhancing supply chain capabilities and competitiveness. Therefore, it can be inferred that the introduction and utilization of logistics 4.0 technology similarly have an impact on logistics innovation capability and logistics performance.

2.2. Logistics 4.0 and Performance

Kim Young-Min (2022) analyzed the effect of the acceptance of fourth industrial revolution logistics technology on logistics safety performance. It was found that the ease, sociality, and sense of efficacy of accepting Logistics 4.0 technology significantly affected logistics safety performance. It was necessary to actively utilize new logistics technologies (e.g., intelligent logistics robots, autonomous driving technology, IoT, and AI) for the improvement of logistics safety behavior and safety performance. It was also emphasized that such utilization enabled the reduction of accidents in the logistics process and improved logistics performance.

Kim Young-Min (2021) conducted a study on the intention of logistics firms to use logistics robots by applying the integrated technology acceptance model. The findings revealed that performance expectations, social influence, and innovation in the use of logistics robots all had a significant impact on the intention to use, and the intention to use had a significant impact on logistics performance.

Kim Young-Min and Lee Won-Dong (2021) analyzed the relationships between the necessity of Logistics 4.0 technology, job satisfaction, and logistics management performance. The necessity of Logistics 4.0 technology was found to significantly affect job satisfaction and logistics management performance, and job satisfaction had a significant mediating effect on the relationship between the necessity for Logistics 4.0 technology and logistics management performance.

Bag, Gupta, and Luo (2020) targeted manufacturers of automobile parts and automobiles, and analyzed the effect of technological, organizational, and environmental competencies on Logistics 4.0 competency, and the correlation between Logistics 4.0 competency and corporate performance. A significant effect was found on Logistics 4.0 competency in the order of technological, environmental, and organizational competency. Moreover, Logistics 4.0 competency also significantly affected corporate performance.

Facchini, Oleskow-Szlapka, Ranieri, and Urbinati (2020) developed and presented a maturity model of Logistics 4.0 focusing on the application of Industry 4.0. A corporate propensity for Industry 4.0 and Logistics 4.0, the current technology used in the logistics process, and the level of investment in Industry 4.0 for the transition toward Logistics 4.0 were analyzed.

Osmolski and Kolinski (2020) attempted to analyze the differentiation of Logistics 4.0 in recent solutions for logistics processes. They emphasized the necessity to introduce a logistics process to which intelligent CPS, IoT, and automation technologies were applied. To this end, automation, intelligence, an unmanned flow of products, materials, and information were important in the logistics ecosystem.

Cichosz, Wallenburg, and Knemeyer (2020) presented barriers, success factors, and leading introductions for the digital transformation of logistics companies. The major obstacles were the complexity of the logistics network and process, lack of resources, and resistance to change; the key success factors were the leaders who had a vision for digital transformation and wanted to introduce it, active support at the organizational culture level, and active participation of employees and partners.

Winkelhaus and Grosse (2020) developed a comprehensive framework for Logistics 4.0 by applying the concept of Industry 4.0 to logistics. As solutions that support Logistics 4.0, IoT, cyber-physical systems, big data, cloud computing, and mobile-based systems were presented; they can be developed as future strategies and technologies in logistics business, and utilized for developing new technological solutions for the present and future.

Kim Young-Min (2020), targeting logistics firms, analyzed the differences in the perception of the necessity of Logistics 4.0 technology. The differences, depending on the number of employees of logistic firms, were found to be significant in AI, IoT, self-driving trucks, ships with autonomous navigation systems, and logistics robots. The differences based on sales volumes were found to be significant in blockchain, IoT, self-driving trucks, ships with autonomous navigation systems, big data, and logistics robots. Furthermore, small and medium-sized logistics firms did not fully recognize the need for new logistics technologies compared to large enterprises.

Radivojević and Milosavljević (2019) inferred the concept of Logistics 4.0 out of Industry 4.0 and emphasized that it included automatic identification, automatic data collection, integration, and data processing and analysis. They suggested, as representative Logistics 4.0 technologies, IoT, wireless sensors, cloud computing, blockchain, big data, robotics, automation, augmented reality, drones, and 3D printing.

Son Jeong-Soo (2019) analyzed the development process of the logistics platform and its

effects on corporate competitiveness, focusing on the case of Samsung SDS, regarding the logistics innovation technology followed by the fourth industrial revolution. It was identified that corporate competitiveness could be enhanced by securing the convenience and reliability of logistics solutions.

Lee Choong-Bae, Noh Jin-Ho and Kim Jeong-Hwan (2017) investigated the awareness of shippers and logistics companies of how the fourth industrial revolution-related technologies affected the efficiency and effectiveness of logistics management. They identified that AI could be applied efficiently in transportation and unloading, IoT and big data in transportation and storage, cloud in SCM and storage, robots in unloading and storage, 3D printing in transportation and inventory management, and drones in transportation.

Summarizing the relevant previous studies on logistics 4.0 and performance, it is indicated that the introduction, adoption, and acceptance of logistics 4.0 technology have an impact on logistics safety performance, logistics performance, job satisfaction, logistics capabilities, logistics competitiveness, and the efficiency and effectiveness of logistics management. Therefore, in this study, it can be inferred that the introduction of logistics 4.0 technology has a significant influence on both logistics innovation capability and logistics performance.

2.3. Logistics Innovation Capability

Wang, Asian, Wood, and Wang (2020) analyzed the effect of logistics innovation capability on SC risk in the era of Industry 4.0 by targeting the Australian transportation industry. The results confirmed that logistics innovation capability had a negative relationship with risks in terms of companies, customers, and the environment. Ultimately, it was emphasized that logistics firms were able to strengthen their logistics innovation capability to reduce the risk of SC.

Son Yong-Jung (2020) evaluated the priority of logistics policy for logistics innovation and fostering the smart logistics industry. As for logistics innovation plans, he noted that it was necessary to develop and disseminate smart logistics technologies, emphasizing, in detail, the necessity of developing advanced smart logistics technologies and a logistics center using drones and robots, as well as establishing a mid-to-long-term roadmap for smart logistics.

Lyu, Chen, and Huo (2019) identified the relationship between logistics resources, capabilities, and operational performance, and revealed that logistics resources affected integrated capabilities and operational performance.

Soh Seung-Bum and Park Jeong-Soo (2019) analyzed the relationship between logistics capability and corporate performance, as well as the moderation effect of information technology human resource management and information technology system management. The results showed that logistics capability significantly affected corporate performance, and information technology human resource management had a significant moderating effect on the relationship between logistics capability and corporate performance, whereas information technology system management had a partially significant moderating effect.

Cho Yong-Hyun (2018) analyzed the relationship between the innovation activities, innovation performance, service quality, and management performance of logistics firms. As a result, the innovation activities of logistics firms significantly affected innovation performance and service quality; and innovation performance and service quality significantly affected financial performance.

Na Jung-Ho and Kwon Seung-Ha (2018) targeted logistics firms and analyzed the relationship between logistics cooperation, supply chain capability, and logistics performance. As

a result, it was found that logistics cooperation and supply chain capability significantly affected the improvement of logistics performance, and supply chain capability also directly affected logistics performance.

Chung Young-Hoon and Park Min-Young (2015) compared the perceptions of the importance of logistics capabilities between shipper companies and logistics companies. It was found that shipper companies emphasized logistics capabilities such as logistics services, information systems, corporate competency, partnership relationships, and corporate image. Further, Korean third-party logistics service providers valued logistics capabilities, in the order of logistics services, information systems, partnership relationships, corporate competency, and corporate image.

Ho and Chang (2015) analyzed the effect of innovation and service capability on corporate performance for logistics services, and found that innovation and service capability significantly affected corporate performance. Furthermore, service capability could be strengthened through innovation capability.

Ralston, Grawe, and Daugherty (2013) analyzed the effect of logistics excellence on logistics competency and performance, and revealed that logistics innovation and differentiated logistics services significantly affected logistics performance.

Huang and Huang (2013) presented a logistic capability measurement index, emphasizing that the logistics capability of logistics firms had an important influence on corporate performance. They noted that logistics capability could be measured as service, innovation, and flexibility capabilities, and it was necessary to identify the relationship between resources, competency, competitive advantage, and corporate performance.

Liu and Luo (2012) analyzed the effect of logistics capability on performance, confirming that flexibility capability and information integration capability significantly affected competitive advantage, and process capability significantly affected corporate performance.

Zhao, Dröge, and Stank (2011) analyzed the effect of logistics capabilities such as customer concentration and information concentration capability on corporate performance. As a result, it was found that customer concentration capability directly affected corporate performance, but information concentration capability had no significant effect.

Sandberg and Abrahamsson (2011) analyzed the effect of logistics capability on sustainable competitive advantage. The results confirmed that operational and dynamic competencies significantly affected competitive advantage. They emphasized that managerial knowledge, cross-functional teamwork, control, and learning were necessary for operational competence.

Chung Lak-Chae (2008) analyzed the effect of the logistics capabilities and partnerships of innovative small and medium-sized enterprises on logistics performance. It was found that both logistics network capabilities and logistics information technology capabilities significantly affected logistics performance, and partnerships significantly affected logistics performance.

Lee Choong-Bae and Yang Jae-Hoon (2007) analyzed the causal relationship between electronic logistics capabilities and the logistics performance of companies, and revealed that information technology and network competency significantly affected both strategic and operational performances.

Summarizing the relevant previous studies on logistics innovation capability, it is evident that logistics innovation capability influences risk reduction in supply chains, firm performance, innovation performance, financial performance, and logistics performance. Therefore, in this study, it can be inferred that the logistics innovation capability resulting

from the adoption of logistics 4.0 technology has a direct and indirect impact on logistics performance.

2.4. Firm Size and Performance

Lee Da-Young, Park Yu-An, and Cho Keun-Tae (2021) identified the relationship between external cooperation partner types and innovation performance in the open innovation activities of companies, universities, and public research institutes, and confirmed the moderation effect of firm sizes, such as large and small and medium-sized companies based on the number of employees. Regarding cooperation and innovation activities with public research institutes, firm size was found to have a significant moderation effect, but companies and universities were found to have no significant effect.

Chung Heun-Bae and Lee Hyun-Woo (2020), targeting start-up companies, investigated the effect of quality management system process execution on differentiated competitive advantage and business performance, and the moderation effect of firm size. Firm size was found to have a partial moderation effect on differentiated competitive advantage.

Kim Kyung-Ho and Chung Jin-Hwa (2018) confirmed the productivity effect of the external R&D investment of companies and the moderation effect of firm size. It was found that corporate investment in R&D significantly affected corporate productivity improvement, but the moderation effect of firm size was found to be insignificant.

Fang Guang-Zhu, Park Ki-Kyoung, and Park Jong-Chul (2017) investigated the moderation effect of firm size regarding the effect of crisis types and response strategies on consumers' attitudes toward companies. Firm size was found to have a significant moderation effect.

Lee Chang-Soo (2016) analyzed the effect of environmental uncertainty and the appropriateness of the logistics information system on logistics performance, and the moderation effect of firm size. As a result, it was revealed that the larger the firm size, the more efficient the logistics performance, indicating that the moderation effect of firm size was significant.

Park Chul-Soon (2012) confirmed the moderation effect of firm size in the relationship between integrated supply chain and corporate performance. The firm sizes, based on their size, were divided into large and small firms, and the relationship between internal integration, supplier integration, customer integration, and corporate performance was examined. As a result, firm size was found to have a significant moderation effect on the relationship between supplier integration, customer integration, and performance based on firm size.

Zhang Guo-Wei and Lee Sang-Man (2012) identified the relationship between corporate ethics and competitive advantage, and the moderation effect of firm size in Chinese companies. They categorized firms into large companies and SMEs based on the number of employees, and they were found to have a complete moderation effect for the differentiation advantage and a partial moderation effect for the cost advantage.

Yeo Eun-Ah, Park Kwang-Hee, and Kim Moon-Young (2008) analyzed the relationship between organizational culture, innovation capability, and commercial performance, and the moderation effect of firm size. Firm size based on the number of employees was found to have a significant moderation effect.

Summarizing the relevant previous studies on firm size, it is evident that firm size has a moderating effect on productivity improvement, innovation performances, firm performances, and managerial performances. Therefore, it can be inferred that firm size may have

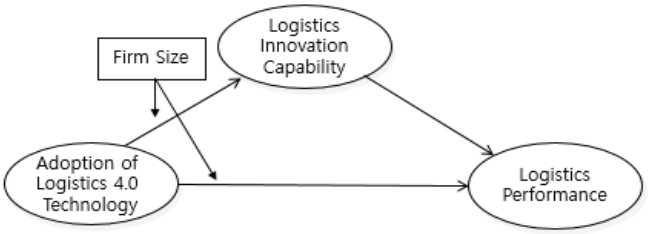
a significant moderating effect in the relationship between the adoption of logistics 4.0 technology, logistics innovation capability, logistics performance, and firm size.

3. Research Model and Hypothesis

3.1. Research Model

The adoption of Industry 4.0 technology, digital technology, and Logistics 4.0 technology has been found to positively affect SC capabilities and performance such as corporate, operational, environmental, and logistics performance (Chauhan et al., 2021; Kim Young-Min, 2021; Kim Young-Min and Lee Won-Dong, 2021; Li et al., 2020; Bag et al., 2020; Wang et al., 2019). Moreover, logistics innovation capability reduces the risk of SC and ultimately improves logistics performance (Wang et al., 2019), and logistics capability or logistics innovation capability directly affects logistics performance or corporate performance (Lyu et al., 2019; Soh Seung-Bum and Park Jeong-Soo, 2019; Cho Yong-Hyun, 2018, Na Jung-Ho and Kwon Seung-Ha, 2018). Few studies have identified the relationship between the size of a logistics company and its logistics performance. Some studies have analyzed the moderation effect of firm size on performance in manufacturing companies, and most studies indicated a significant moderation effect (Chung Heon-Bae and Lee Hyun-Woo, 2020; Kim Kyung-Ho and Chung Jin-Hwa, 2018; Fang et al., 2017). Based on previous research, the following research model is proposed for analyzing the relationship between Logistics 4.0 technology adoption, logistics innovation capability, and logistics performance, the mediating effect of logistics innovation capability, and the moderation effect as well as the mediated moderation effect of firm size.

Fig. 1. Research Model



3.2. Research Hypothesis

If Logistics 4.0 technologies such as AI, big data, IoT, and intelligent logistics robots are introduced and used in logistics, both logistics innovation capability and logistics performance can be improved. Furthermore, while Logistics 4.0 technology has a direct impact on logistics performance, it also has an indirect impact on logistics performance through logistics innovation capability (Chauhan et al., 2021; Kim Young-Min, 2021; Kim Young-Min and Lee Won-Dong, 2021; Li et al., 2020; Bag et al., 2020; Wang et al., 2019; Lyu et al., 2019; Soh Seung-Bom and Park Jeong-Soo, 2019; Cho Yong-Hyun, 2018, Na Jung-Ho and Kwon Seong-Ha,

2018). Based on previous studies in which firm size was found to have different moderation effects on corporate performance (Chung Heon-Bae and Lee Hyun-Woo, 2020; Kim Kyung-Ho and Chung Jin-Hwa, 2018; Fang et al., 2017), it can be inferred that the size of logistics companies can play a moderation role in the relationship between Logistics 4.0 technology adoption and logistics innovation capability and logistics performance. Accordingly, the following research hypotheses were suggested:

H1. The adoption of Logistics 4.0 technology by logistics companies has a positive effect on logistics innovation capability.
H2. The logistics innovation capability of logistics firms has a positive effect on logistics performance.
H3. The adoption of Logistics 4.0 technology by logistics companies has a positive effect on logistics performance.
H4. Logistics innovation capability has a positive mediating effect on the relationship between logistics firms' adoption of Logistics 4.0 technology and logistics performance.
H5. Firm size has a positive moderation effect on the relationship between logistics companies' adoption of Logistics 4.0 technology and logistics innovation capability.
H6. Firm size has a positive moderation effect on the relationship between logistics firms' adoption of Logistics 4.0 technology and logistics performance.
H7. In the relationship between logistics firms' adoption of Logistics 4.0 technology and logistics performance, firm size has a mediated moderation effect through logistics innovation capability.

3.3. Composition of the Questionnaire

The adoption of Logistics 4.0 technology refers to the degree to which Logistics 4.0 technologies (e.g., AI, big data, and intelligent logistics robots) are introduced and used for work. It was measured using eight questions such as improved competitiveness by utilizing Logistics 4.0 technologies. Logistics innovation capability indicates the level of innovative improvements in logistics capability through the adoption and utilization of Logistics 4.0 technologies. It was measured using seven questions such as the improved visibility and transparency of logistics activities by utilizing Logistics 4.0 technologies. Logistics performance refers to the degree of improving the performance of logistics companies by adopting Logistics 4.0 technologies. It was measured using four questions such as the increased satisfaction with logistics services due to the application of Logistics 4.0 technologies.

The questionnaire was surveyed on a five-point Likert scale, with 1 being "no impact at all", 3 being "moderate", and 5 being "high impact," implying that higher scores indicated higher impacts.

3.4. Research and Analysis Method

A survey was conducted to confirm the relationship between Logistics 4.0 technology adoption, the logistics innovation capability, and logistics performance of logistics companies. The survey was conducted on employees of logistics company from March 29 to April 26, 2022. A total of 457 questionnaires were collected, and 449 of them were used for the final analysis, excluding eight copies with insufficient responses. The questionnaires were sent and collected by email.

Table 1. Composition of the Questionnaire

Variables	Measurement items	Related studies
Adoption of Logistics 4.0 Technology	ALT1. Competitiveness can be improved using Logistics 4.0 technology. ALT2. New logistics strategies can be established using Logistics 4.0 technology. ALT3. Difficulties in logistics activities can be overcome using Logistics 4.0 technology. ALT4. Rational logistics-related decision making is possible using Logistics 4.0 technology. ALT5. New logistics services can be provided using Logistics 4.0 technology. ALT6. Effective processing of logistics tasks is possible using Logistics 4.0 technology. ALT7. Logistics 4.0 technology is generally useful in logistics. ALT8. The adoption and utilization of Logistics 4.0 technology are required.	Chauhan et al. (2021) Sari and Santoso (2020) Naglic et al. (2020) Li et al. (2020) Stentoftet al. (2019) Hassan et al. (2017)
Logistics Innovation Capability	LIC1. The adoption and utilization of Logistics 4.0 technology improve the visibility and transparency of logistics activities. LIC2. The agility, flexibility, and responsiveness of logistics activities are improved by adopting and using Logistics 4.0 technology. LIC3. The adequacy of supply and delivery time is ensured with the adoption and utilization of Logistics 4.0 technology. LIC4. The adoption and utilization of Logistics 4.0 technology enables preemptive analysis and the improvement of logistics activities. LIC5. The reliability and quality of logistics services are improved with the adoption and use of Logistics 4.0 technology. LIC6. Efficient logistics activities are possible due to the adoption and utilization of Logistics 4.0 technology. LIC7. The adequate control of logistics costs is possible with the adoption and use of Logistics 4.0 technology.	Bag et al. (2020) Wang et al. (2020) Lim Seung-Min and Song Gwang-Seok (2019) Hwang Seok-Jun et al. (2012) Lee Jae-Yul and Shin Han-Won (2009)
Logistics Performance	LP1. Satisfaction with logistics services increases with the adoption and utilization of Logistics 4.0 technology. LP2. The adoption and utilization of Logistics 4.0 technology enable higher competitiveness of logistics services. LP3. Logistics operating profit increases due to the adoption and use of Logistics 4.0 technology. LP4. The logistics market expands with the adoption and use of Logistics 4.0 technology.	Kim Young-Min (2022) Kim Young-Min (2021) Nantee and Sureeyatanapas (2021) Bag et al. (2020)

A frequency analysis was performed to identify the general statistics of the research targets, and Cronbach's alpha coefficient, which indicates internal consistency, was measured to identify the reliability of each research concept. Additionally, an exploratory factor analysis was performed to determine the factor structure of the measurement items. These analyses were conducted using the SPSS 26.0 statistical program. Thereafter, the validity of the measurement items was verified through confirmatory factor analysis, and the causal hypothesis was verified through structural equation model analysis. To this end, Amos 26.0 statistics package was used. The analysis of the mediation effect, moderation effect, and mediated moderation effect was performed using the SPSS 26.0 statistical program and SPSS Process Macro (Hayes, 2013/2018).

4. Results of Empirical Analysis

4.1. Demographic Characteristics

The characteristics of this study sample are shown in Table 2. First, regarding the gender of the respondents, among the 449 valid samples, there were 267 males (59.5%) and 182 females (40.5%). Regarding age, 234 respondents (52.1%) were aged 31~40 years, 107 (23.8%) aged 41~50 years, and 91 (20.3%) aged 30 years or less. Regarding job position, there were 164 (36.5%) assistant manager, 112 (24.9%) manager, and 85 (18.9%) junior staff. Regarding the number of employees, 214 respondents (47.6%) belonged to a firm with 1,001 employees or more, 149 (33.2%) to a company with 300 employees or less, and 86 (19.2%) to a firm with 301~1000 employees. Regarding sales, 159 respondents (35.3%) worked for a company with sales of KRW one trillion or more, 75 (16.7%) for a company with sales of KRW 100 billion~less than 500 billion, and 65 (14.5%) for the firm with sales of KRW 500 billion~1 trillion. The work experience of the respondents was as follows: 163 respondents (36.3%) had 6~10 years of work experience, 127 (28.3%) had 11 years of work experience or more, and 81 (18.0%) with 1~3 years of work experience.

Table 2. Demographics Characteristics of Respondents

		Frequency	Rate(%)			Frequency	Rate(%)
Gender	Men	267	59.5	Sales	Less than 10 Billion	47	10.5
	Women	182	40.5	(KRW)	10~less than 50 Billion	60	13.4
Age	30 and younger	91	20.3		50~less than 100 Billion	43	9.6
	31~40 years	234	52.1		100~less than 500 Billion	75	16.7
	41~50 years	107	23.8		500~less than 1 trillion	65	14.5
	51 and older	17	3.8		1 trillion or more	159	35.3
Job	Junior staff	85	18.9	Career	1~3 years	81	18.0
Position	Assistant manager	164	36.5		4~5 years	78	17.4
	Manager	112	24.9		6~10 years	163	36.3
	Department head	75	16.7		11 years or more	127	28.3
	Executives	13	2.9				
Number of	300 or less	149	33.2				
Employees	301~1,000	86	19.2				
	1,001 or More	214	47.6		Total	449	100.0

4.2. Results of Reliability Analysis

An exploratory factor analysis was performed to identify the theoretical structure of the variables adopted in this study. In other words, through exploratory factor analysis, the factors regarding Logistics 4.0 technology adoption, logistics innovation capability, and logistics performance were distinguished from each other; furthermore, whether the measurement items had convergent validity was investigated. Principal component analysis was used as the factor extraction method, and varimax rotation, a simple method that enables a clearer analysis between the factors, was used as the rotation method.

The factor analysis revealed that KMO (Kaiser-Meyer Olkin) = .839, indicating that the selection of variables for factor analysis was appropriate; Bartlett's χ^2= 2006.447 ($p< .001$), indicating that the null hypothesis—the population correlation matrix is the unit matrix—was rejected. In this process, two variables that hindered the validity of factor analysis were found and then removed (LIC7, LP1). Three factors—Logistics 4.0 technology adoption, logistics innovation capability, and logistics performance—were extracted and the eigenvalues were 4.790, 1.660, and 1.540, respectively. All of the factors had factor loadings greater than 0.5. The study then attempted to verify the validity of the measurement model using confirmatory factor analysis based on the measurement variables to be input into the empirical model.

Table 3. Results of Exploratory Factor Analysis

Construct	Items	VARIMAX-Rotated Loadings		
		Adoption of Logistics 4.0 Technology	**Logistics Innovation Capability**	**Logistics Performance**
Adoption of Logistics 4.0 Technology	ALT7	**.703**	.241	.126
	ALT3	**.690**	.088	.027
	ALT6	**.670**	.075	.188
	ALT1	**.660**	.127	.077
	ALT8	**.649**	.128	.192
	ALT5	**.643**	.179	.057
	ALT4	**.626**	.107	.053
	ALT2	**.593**	.214	.030
Logistics Innovation Capability	LIC2	.122	**.686**	.007
	LIC6	.079	**.638**	.127
	LIC5	.154	**.623**	.137
	LIC4	.141	**.608**	.118
	LIC3	.136	**.606**	.061
	LIC1	.184	**.527**	.060
Logistics Performance	LP3	.096	.114	**.850**
	LP2	.082	.087	**.828**
	LP4	.207	.077	**.560**
Eigenvalue		4.790	1.660	1.540
Variance		28.179	9.766	9.057
Accumulated Variance		28.179	37.944	47.001

4.3. Results of Confirmatory Factor Analysis

A reliability analysis was performed to evaluate the internal consistency of the variables before the confirmatory factor analysis. The value of the Cronbach's alpha exceeded 0.7 in each research unit (.700~.830), and the reliability of the research scale was confirmed. The initial confirmatory factor analysis of the measurement model revealed the following model fit: χ^2=314.345 (p=.000), df=116, GFI= .922, AGFI= .897, CFI= .896, and RMSEA= .620. As the model fit was deemed somewhat lower than the recommended standard value, the model was revised in consideration of the correction index and remarkably low level of factor loading. LP.4 was also deleted in this process.

Then, the final confirmatory factor analysis indicated the following model fit: χ^2= 241.595 (p=.000), df=110, GFI= .930, AGFI= .904, CFI= .908, TLI= .889, and RMSEA= .063. As the χ^2 index was insignificant, it cannot be said that the real and theoretical models were completely consistent, but the χ^2 index was greatly influenced by the complexity of the model or the number of samples. Therefore, it is necessary to supplement this with other fitness indices that can complement the sensitivity of the χ^2 index. As other fitness indices including RMSEA, which can most representatively estimate the confidence interval, were at particularly good levels, the fit of this research model was evaluated as good (Brown, 2006; Byrne, 2016).

In general, the fact that the fit index of the confirmatory factor analysis is good itself can be a premise for recognizing the reliability or validity. As the fit of the confirmatory factor analysis model was recognized, the convergent validity of the measurement items was verified. Regarding the method, based on the suggestion of Hair et al. (2006), this study focused on whether the factor loading was statistically significant, whether the minimum standard was 0.5, and whether the ideal standard was at least 0.7. It also examined whether the C.R. value was at least 0.7, and the AVE value was at least 0.5.

Table 4. Results of Confirmatory Factor Analysis

Construct	Items	Standardized Loading	t-value	Cronbach's Alpha	C.R	AVE
Adoption of Logistics 4.0 Technology	ALT1	.600***	-	.830	.917	.582
	ALT2	.534***	9.274			
	ALT3	.583***	9.925			
	ALT4	.537***	9.311			
	ALT5	.595***	10.076			
	ALT6	.659***	10.850			
	ALT7	.745***	11.759			
	ALT8	.661***	10.872			
Logistics Innovation Capability	LIC2	.510***	-	.700	.820	.477
	LIC3	.524***	7.166			
	LIC4	.553***	7.378			
	LIC5	.560***	7.419			
	LIC6	.526***	7.179			
Logistics Performance	LP2	.747***	-	.757	.830	.710
	LP3	.816***	6.072			

Note: *** $p < .001$

The confirmatory factor analysis indicated that the factor loadings of the measurement items were all statistically significant, and the loadings of 0.5 or higher were confirmed. Hence, convergent validity was established in the research unit. Furthermore, as for C.R and AVE values, which were examined as a supplementary analysis, the C.R value greatly exceeded the standard value of 0.7, and most of the AVE values also exceeded the standard value of 0.5. However, in the case of logistics innovation capability, although the AVE value did not reach the standard value of 0.5, it was close (AVE= .477). The factor loadings were significant and the C.R value was high, indicating that there was no problem with validity. It was explained that even though AVE did not meet the criteria, if important goodness-of-fit such as RMSEA were met, validity would be sufficiently acknowledged (Byrne, 2016; Joo Hye-Young and You Byoung-Boo, 2021). Therefore, after examining the convergent validity, the discriminant validity was determined

Although discriminant validity is tested from various viewpoints, this study adopted the method of Fornell and Lacker (1981) ($\sqrt{AVE} > \phi$), which is evaluated as the strictest method. Here, it was examined whether the square root of the average variance extraction value was greater than the value of the correlation coefficient, by calculating the correlation coefficient between each construct and the square root of each average variance extraction value. As shown in the correlation matrix in Table 5, in the case of Logistics 4.0 technology adoption, logistics innovation capability and logistics performance, which were used for the causal analysis. In this study, all correlation coefficients appeared significantly positive, confirming that the direction of the correlation coefficient was consistent with the direction in the hypothesis.

More specifically, the adoption of Logistics 4.0 technology and logistics innovation capability was found to have a correlation of .421. Here, ($\sqrt{AVE}$) of the Logistics 4.0 technology adoption was .763, and ($\sqrt{AVE}$) of logistics innovation capability was .691, indicating that the values exceeded the correlation value of both concepts (.421) ($\sqrt{AVE} > \phi$). As a result of examining the discriminant validity of all research concepts in this manner, it was found that the discriminant validity of this research concepts was strictly established.

Furthermore, the correlation between each variable was between .216 and .421, much lower than 0.8, at which multicollinearity should be considered, showing an overall stable value (Kline, 2005). Therefore, it was judged that the possibility of multicollinearity between the independent variables in this study was not high.

Table 5. Results of Discriminant Validity Analysis

Constructs	Mean	S.D.	1	2	3	4	5
Firm Size_dummy 1	.192	.393	-				
Firm Size_dummy 2	.477	.500	-.464**	-			
Adoption of Logistics 4.0 Technology	4.128	.448	-.061	-.001	.763		
Logistics Innovation Capability	4.265	.434	-.044	-.055	.421**	.691	
Logistics Performance	3.737	.718	.009	-.082	.255	.216**	843

Note: 1. The values in diagonal line represents the square root values of average variance extracted (AVE) for each construct.
2. ** $p < .01$.

4.4. Verification of Research Hypothesis

4.4.1. Path analysis

Before testing the research hypothesis, the fit of the path analysis model was examined. As a result, the fit of this structural equation model was as follows: χ^2=241.595 (p= .000), df=87, GFI= .930, AGFI= .904, CFI= .908, RMSEA= .068. This path analysis model was found to be acceptable at a particularly good level, except for the χ^2 value.

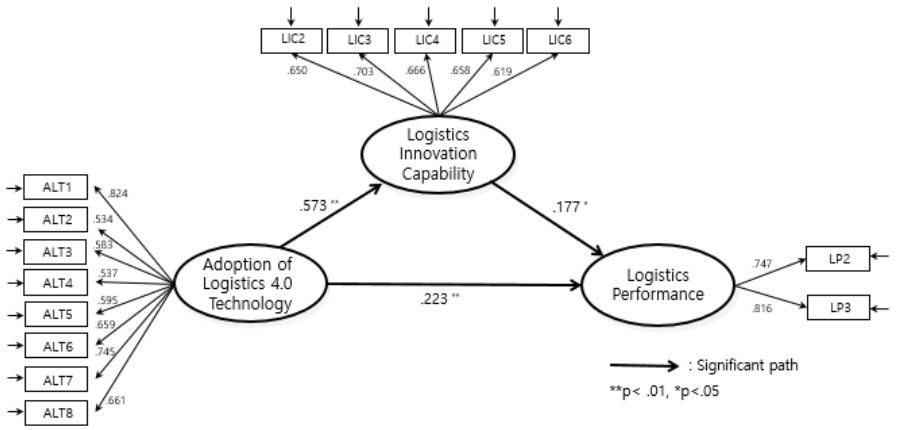
Table 6. Goodness-of- fit of Path Analysis

	GFI	AGFI	CFI	RMSEA
Criteria	≧.90	≧.90	≧.90	<.080
Results	.930	.904	.908	.068

Hypothesis 1 assumed a positive causal relationship of the Logistics 4.0 technology adoption with logistics innovation capability. As a result, Logistics 4.0 technology adoption was found to have a positive effect on logistics innovation capability (standardized β= .573, t-value=6.631, p< .01). Therefore, hypothesis 1 was supported. These results explain that logistics innovation capability is positively improved by introducing and utilizing Logistics 4.0 technology in logistics companies. Ultimately, logistics companies need to improve their logistics innovation capability by actively introducing and utilizing Logistics 4.0 technology suitable for the characteristics of the logistics process. This study's results are consistent with the outcome of Chanhan et al. (2021), in which the adoption and implementation of Industry 4.0 significantly affected supply chain capability. Hypothesis 2 aimed to confirm whether logistics innovation capability positively affects logistics performance. The results showed that logistics innovation capability had a positive effect on logistics performance (standardized β = .177, t-value=1.985, p< .05). Thus, hypothesis 2 was supported. In other words, an increase in logistics innovation capability within logistics companies leads to a positive impact on logistics performance. Therefore, to improve the performance ultimately pursued by a logistics company, it is necessary to actively introduce Logistics 4.0 technology for efficient logistics. The results of this study are consistent with the outcomes of the following studies: the relationship between Logistics 4.0 capability and corporate performance (Bag et al., 2020), the relationship between logistics innovation capability and SC risks (Wang et al., 2019), and logistics capability and corporate performance (Soh Seung-Bum and Park Jeoung-Soo, 2019). Hypothesis 3 was established to confirm whether the introduction of Logistics 4.0 technology directly affects logistics performance. As a result, the adoption of Logistics 4.0 technology was shown to have a positive effect on logistics performance (standardized β = .233, t-value= 2.689, p< .01), and accordingly, hypothesis 3 was supported. Due to the requirement of initial investment when logistics companies adopt Logistics 4.0 technologies, there is a tendency to perceive that the technologies cannot contribute to reduce logistics costs in the short term. However, as the utilization of digital logistics technologies directly affects the improvement of logistics performance, such as lowering logistics costs in the long term, it is necessary to actively adopt and utilize Logistics 4.0 technologies suitable for the characteristics of the logistics business. The following studies showed that Logistics 4.0 or Industry 4.0 technologies significantly affected corporate performance: the relationship between Industry 4.0 tech-

nology adoption and operational performance (Chauhan et al., 2021), the relationship between digital technology, and economic and environmental performance (Li et al., 2020), the relationship between Industry 4.0 technology and the performance of logistics companies (ŚLUSARCZYK et al., 2020), and the relationship between Industry 4.0 implementation and export performance (Naglic et al., 2020). Moreover, the results of this study are consistent with the outcomes of those studies. Therefore, the adoption and utilization of Logistics 4.0 technology not only lead to an increase in logistics innovation capability but also directly enhance logistics performance.

Fig. 2. Results of Path Analysis



4.4.2. Mediating effect analysis

This study aimed to verify whether the adoption of Logistics 4.0 technology positively affected logistics innovation capability, and whether there was a positive (+) mediation effect of increasing logistics performance through logistics innovation capability. Traditionally, the method of Baron and Kenny (1986) and the Sobel Test are widely used to verify the mediation effects. Bootstrapping results, which are attracting more attention because sophisticated mediation effects can be suggested, were presented with these methods, which have been used widely and traditionally.

In Table 7, it can be confirmed that a, b, c, and c′ are significant, but the influence of c′ decreased compared to c. Therefore, from the perspective of Baron and Kenny (1986), it can be assumed that a partial mediation effect occurred. However, as the significance of the size (ab) of the mediating effect was unclear, the Sobel test was performed to confirm the statistical significance of ab. As a result, the mediating effect was found to be significant at a significance level of one percent.

Additionally, as the Sobel Test's assumption that ab should be normally distributed is largely unrealistic (Preacher and Hayes, 2004), the significance of the size of the mediating effect was further verified using the bootstrapping method. To verify the mediating effect of logistics innovation capability between Logistics 4.0 technology adoption and logistics performance, Hayes (2018)'s Process macro-Model 4 was applied, 5,000 bootstrap samples were

designated, and the confidence interval was set to 95% for analysis. As a result, the mediating effect was found to be in the range of .0227~.1576, and there was no "0" between the lower limit (LLCI) and upper limit (ULCI) of the section, indicating that the mediating effect was significant. In other words, it was confirmed that the logistics innovation capability plays a mediating role between Logistics 4.0 technology adoption and logistics performance. Therefore, Hypothesis 4, which assumed the positive mediation effect of logistics innovation capability, was supported. Although research aiming to identify the mediating effect of logistics innovation capability in the relationship between Logistics 4.0 technology adoption and logistics performance has not been conducted, it was possible to confirm the indirect effect of logistics innovation capability through this study. Even though there are many negative perceptions about the performance of Logistics 4.0 technology adoption, it is necessary to recognize that Logistics 4.0 technology directly affects the improvement of logistics innovation capability, thereby positively affecting the improvement of logistics performance.

Table 7. Results of Mediation Effect Analysis

Causal relationship	β	S.E	t	p	Sobel's test
ALT → LP (*c*)	.255	.073	5.569	<.001	2.535 (p<.01)
ALT → LIC (*a*)	.421	.042	9.815	<.001	2.535 (p<.01)
LIC → LP (*b*)	.132	.083	2.632	<.010	2.535 (p<.01)
ALT → LIC → LP (*c´*)	.199	.080	3.976	<.001	2.535 (p<.01)

4.4.3. Moderation effect analysis

The moderation effect of firm size was analyzed in the path in which the adoption of Logistics 4.0 technology affected logistics innovation capability, and the moderation effect was analyzed through hierarchical regression analysis. The firm size was categorized into three groups: less than 300 employees, 301~1,000 employees, and more than 1,001 employees. Since firm size is a nominal scale, it cannot be directly utilized in regression analysis that requires continuous variables. Therefore, it was treated as a dummy variable for analysis. In this analysis, a distinction was made based on the criterion of less than 300 employees. In comparison, firms with 301 to 1,000 employees were reclassified as Size_dummy1, and those with more than 1,001 employees were reclassified as Size_dummy2. The results are presented in Table 8. It was confirmed that the adoption of Logistics 4.0 technology, which was input at the first stage, had a significantly positive (+) effect on logistics innovation capability at a significance level of 1%. In the second step, a dummy variable of firm size was input, but it did not have a significant effect on logistics innovation capability in firms with 301~1,000 employees and with more than 1,001 employees. However, in the final third stage, the effects of Logistics 4.0 technology adoption and the interaction term with more than 1,001 employees on logistics innovation capability were found to be significant at a significance level of 5%. In other words, as for the Interaction term 2 (a*c), the firm size was analyzed to have a moderation effect in the path in which the Logistics 4.0 technology adoption affected logistics innovation capability. As the interaction term had a positive (+) effect, it was

analyzed that a firm size with more than 1,001 employees had a greater influence on logistics innovation capability due to Logistics 4.0 technology adoption, compared to a firm size with less than 300 employees. Hypothesis 5 was partially supported because the influence of Logistics 4.0 technology adoption on logistics innovation capability was partially significant depending on firm size.

Table 8. Results of Moderated Regression Analysis (Dependent Variable: Logistics Innovation Capability)

Step	Variables	Standardization β			R^2	Δ R^2	Δ F
		Step 1	Step 2	Step 3			
Step 1	ALT (*a*)	.406***	.402***	.268***	.165	.165	88.780***
Step 2	Size_dummy 1 (*b*)		-.045	-.047	.170	.005	30.610***
	Size_dummy 2 (*c*)		-.082	-.087			
Step 3	Interaction Term 1 (*a***b*)			.080	.179	.009	19.430***
	Interaction Term 2 (*a***c*)			.143**			

Note. *** p< .01, ** p< .05

To identify whether the effect of Logistics 4.0 technology adoption on logistics performance varies was based on firm size, a moderation effect analysis was conducted. The results are presented in Table 9. The adoption of Logistics 4.0 technology, which was input at the first stage, had a significantly positive (+) effect on logistics performance. Next, a dummy variable of firm size was input at the second stage. Size_dummy 1 refers to firm size with 301~1,000 employees and Size_dummy 2 refers to firm size with more than 1,001 employees. In the second stage, Size_dummy 1 was insignificant but Size_dummy 2 was significant at a significance level of 10%. However, the logistics performance slightly decreased at the firm size with more than 1,001 employees, compared to the size with less than 300 employees. In the final third stage, it was found that Logistics 4.0 technology adoption and the interaction term of the firm size with 301~1,000 employees significantly affected logistics performance. In other words, the Interaction term 1 (a*b) was weak but significant at the 10% significance level (p= .057), indicating a partial moderation effect in the path in which the Logistics 4.0 technology adoption affected logistics performance. Furthermore, as the interaction term had a negative effect, a firm size with 301~1,000 employees was found to have a lower impact on logistics performance regarding Logistics 4.0 technology adoption, compared to a firm size with fewer than 300 employees. Hypothesis 6 was partially supported because the effect of the Logistics 4.0 technology adoption on logistics performance was partially significant according to firm size.

As a result, Hypotheses 5 and 6, which assumed that firm size has a positive moderation effect on the relationships between logistics firms' adoption of Logistics 4.0 technology, logistics innovation capability, and logistics performance, were partially supported. Several studies argue that firm size has a significant moderation effect on corporate performance (Chung Heon-Bae and Lee Hyun-Woo, 2020; Fang et al., 2017; Lee Chang-Soo, 2016; Park Chul-Soon, 2012), although some studies reported contradictory results (Kim Kyung-Ho and

Chung Jin-Hwa, 2018). For firms with a large size, it is easier to secure investment and professionals for adopting Logistics 4.0 technologies, whereas small and medium-sized logistics firms can be expected to face difficulties. However, both small and medium-sized as well as large logistics firms need to improve their logistics performances through the active adoption of Logistics 4.0 technology. Especially in small and medium-sized logistics companies, there is a tendency to rely on manpower for logistics operations rather than adopting logistics 4.0 technology. It's important to recognize that this can have a negative impact on logistics innovation capabilities and performance. Small and medium-sized logistics companies also need to invest actively in the adoption of logistics 4.0 technology. Additionally, large logistics companies should actively support the introduction and utilization of logistics 4.0 technology through collaboration with small and medium-sized logistics companies.

Table 9. Results of Moderated Regression Analysis (Dependent Variable: Logistics Performance)

Step	Variables	Standardization β			R^2	ΔR^2	ΔF
		Step 1	Step 2	Step 3			
Step 1	ALT (*a*)	.255***	.253***	.326***	.065	.065	31.342***
Step 2	Size_dummy 1 (*b*)		-.017	-.024	.007	.007	11.676**
	Size_dummy 2 (*c*)		-.093*	-.089*			
Step 3	Interaction Term 1 (*a***b*)			-.106*	.080	.008	7.772***
	Interaction Term 2 (*a***c*)			-.044			

Note. *** $p < .01$, ** $p < .05$, * $p < 1.0$

This study generated graphs (see Fig. 3) to more intuitively understand the moderation effect of firm size on the relationships between logistics firms' adoption of Logistics 4.0 technology, logistics innovation capability, and logistics performance.

Fig. 3. Interaction Effects of Logistics 4.0 Technology Adoption and Firm Size

4.4.4. Mediated moderation effect analysis

Statistical estimation using logistics innovation capability and logistics performance as dependent variables was found necessary to analyze the mediated moderation effect.

Furthermore, as the firm size was divided into Dummy 1 and Dummy 2 in this study, the analysis of the mediated moderation effect was also performed by dividing the control variables into the cases of Dummy=1 and Dummy=2. First, in the case of a firm with 301~1,000 employees (Dummy=1), the logistics innovation capability (Mi) was found to significantly increase due to Logistics 4.0 technology adoption (X). Firm size (W) did not have a moderation effect, and the interaction term (X*W) with the Logistics 4.0 technology adoption was also found to be insignificant at a significance level of 5%. Conversely, logistics performance significantly increased due to the introduction of Logistics 4.0 technology, and firm size (W) was found to be significant at a significance level of 5%. However, the interaction term (X*W) was significant at a significance level of 10%. Logistics innovation capability (Mi) significantly affected logistics performance (Y) at a significance level of 1%. As the size of the mediated moderation effect, $a_3 b$, was .062 and due to the presence of "0" in the 95% bootstrap confidence interval (LLCI~ULCI), it was assumed that there was no mediated moderation effect in this model.

Table 10. Results of the Mediated Moderation Effects (Dummy=1)

Antecedent	Consequent									
	Logistics Innovation Capability (Mi)					Logistics Performance (Y)				
		Coeff	S.E	*t*	*p*		Coeff	S.E	*t*	*p*
ALT (X)	a_1	.397	.045	8.697	<.001	c'_1	.381	.086	4.441	<.001
Size (W)	a_2	-.326	.470	-.699	>.05	c'_2	1.646	.822	2.002	<.05
X * W	a_3	.075	.115	.659	>.05	c'_3	-.3911	.200	-1.953	<.10
LIC (M_i)		-	-	-	-	b	.224	.083	2.709	<.01
Constant	i_M	2.638	.189	13.937	<.001	i_Y	1.197	.396	3.023	<.01
Observation		449					449			
R^2		.178					.087			
F statistic		F= 32.213, p< .001					F= 10.676, p< .001			
Test of mediated moderation effect ($a_3 b$)					Boot SE		Boot LLCI		Boot ULCI	
.062					.029		-.034		.083	

Note. Dummy=1 means a firm with a size (W) of 300~1,000 employees.

In the case of firms with more than 1,001 employees (Dummy=2), logistics innovation capability (Mi) significantly increased due to the adoption of Logistics 4.0 technology (X). However, firm size (W) did not have a moderation effect and the interaction term (X*W) with the Logistics 4.0 technology adoption was found to be insignificant at the significance level of 5%. Furthermore, logistics performance significantly increased due to the adoption of Logistics 4.0 technology, whereas firm size (W) and the interaction term (X*W) were insignificant at the significance level of 5%. However, logistics innovation capability (Mi) significantly affected logistics performance(Y) at a significance level of 5%. As the size of the mediated moderation effect, $a_3 b$, was .017 and due to the presence of "0" in the 95% bootstrap confidence interval (LLCI–ULCI), it was assumed that there was no mediated moderation effect in this model.

Therefore, Hypothesis 7, in which firm size, have the mediated moderation effect in relationship with Logistics 4.0 and logistics performance, was believed to have a mediated moderation effect on logistics performance, was not supported.

Table 11. Results of the Mediated Moderation Effects (Dummy=2)

Antecedent		Consequent							
		Logistics Innovation Capability (Mi)					Logistics Performance (Y)		
		Coeff	S.E	*t*	*p*		Coeff	S.E	*t*	*p*
ALT (X)	a_1	.367	.060	6.168	<.001	c'_1	.316	.109	2.907	<.01
Size (W)	a_2	-.373	.345	-.694	>.05	c'_2	-1.61	.606	-.266	>.05
X * W	a_3	.079	.083	.950	>.05	c'_3	-.013	.146	-.266	>.05
LIC (M_i)		-	-	-	-	b	.221	.083	2.524	<.05
Constant	i_M	2.771	.247	11.207	<.001	i_Y	1.590	.491	3.238	<.01
Observation		449					449			
R^2		.182					.085			
F statistic		F= 32.980, p< .001					F= 10.290, p< .001			
Test of mediated moderation effect (a_3b)					Boot SE		Boot LLCI		Boot ULCI	
.017					.020		-.0221		.060	

N**ote**. Dummy=2 means a firm with a size (W) of more than 1,001 employees.

5. Conclusion

New logistics technologies have emerged in tandem with the spread of the fourth industrial revolution. Logistics firms have pursued efficient logistics by adopting Industry 4.0-related technologies, that is, Logistics 4.0 technologies. However, as related studies are insufficient, it is necessary to clearly analyze the relationship between the adoption of Logistics 4.0 technology and performance. Therefore, this study attempted to identify the relationship between the adoption of Logistics 4.0 technologies, logistics innovation capability, and logistics performance of logistics companies. It attempted to empirically analyze the mediating effect of logistics innovation capability and the mediated moderation effect of firm size via logistics innovation capability.

Based on previous studies related to Industry 4.0 and Logistics 4.0, this study established research models and hypotheses, and surveyed logistics companies. As a result, the adoption of Logistics 4.0 technology was found to significantly affect logistics innovation capability and logistics performance. And Logistics innovation capability was found to significantly affect logistics performance. Moreover, logistics innovation capability was found to have a significant mediation effect on the relationship between the adoption Logistics 4.0 technology and logistics performance. The moderation effect based on firm size was found to have a partial effect on logistics innovation capability and logistics performance, but the mediated moderation effect was not significant.

Based on the empirical analysis results, the following are the implications. First, logistics firms need to improve their logistics innovation capability and logistics performance through

the adoption of Logistics 4.0 technology. Given that related technologies have been rapidly developed due to the spread of the fourth industrial revolution, and such technological innovation positively affects corporate performance, it is necessary for logistics companies to have a higher level of logistics innovation capability to improve their logistics performance. This is possible through the active adoption and utilization of Logistics 4.0 technology.

Second, with the adoption of Logistics 4.0 technology, logistics innovation capability plays an important role in improving logistics performance. In other words, logistics firms can build a high level of logistics innovation capability by adopting Logistics 4.0 technologies and applying them to the logistics business, ultimately affecting logistics performance positively. However, in logistics firms, it is perceived that the adoption of Logistics 4.0 technology requires additional costs, resulting in a negative impact on logistics performance. However, while the adoption will incur additional costs in the short term, it is necessary to actively adopt Logistics 4.0 technologies because in the long term, logistics performance will eventually improve while costs will be reduced.

Third, in the relationship between Logistics 4.0 technology adoption and logistics innovation capability and logistics performance, the effects differ depending on firm size. Thus, it is necessary to apply the Logistics 4.0 technology adoption strategy differently based on the characteristics of the logistics companies. Regarding the improvement of logistics performance, logistics companies with a relatively small number of employees were found to achieve a higher logistics performance by introducing Logistics 4.0 technologies, compared to large companies. In other words, it was confirmed that the effect of adopting Logistics 4.0 technologies was greater for small logistics companies than for large ones. Thus, small firms should invest in the Logistics 4.0 technology adoption more actively. However, as for logistics innovation capability, a higher effect was found in a relatively large logistics companies than in a small logistics companies. This is because large logistics companies with a great amount of internal and external resources as well as advanced basic capabilities can easily convert Logistics 4.0 technologies into logistics innovation capability.

Fourth, as the interaction effect of Logistics 4.0 technology adoption and firm size on logistics performance via logistics innovation capability was found to be insignificant, it is necessary to directly maximize the impact on logistics capability and logistics performance through the adoption of Logistics 4.0 technology.

This study is meaningful in that it empirically analyzed the relationship of Logistics 4.0 technology adoption with logistics innovation capability and logistics performance, the mediating effect of logistics innovation capability, the moderation effect of firm size, and the mediated moderation effect of firm size, which were not addressed in previous studies. However, regarding Logistics 4.0 technology, there may be different adoption intentions and varying investment willingness based on the size of the logistics companies. However, this study could not present clear results about these aspects. And the study has a limitation that within the 449 samples, the same logistics companies have been included. It is necessary for future studies to carry out empirical research to derive strategies for adopting Logistics 4.0 technologies based on the size of logistics companies.

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