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THE DISCRETE EVENT SIMULATIONS EFFECT ON COURIER LOGISTICS DIGITIALIZATIONS AND ITS CONTRIBUTIONS TO INDUSTRY 4.0 WITHIN THE RESILIANCE ECONOMY: A QUANTITATIVE STRATEGY

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Abstract:

The swift digital transformation of courier logistics is transforming the sector, propelled by the imperatives of Industry 4.0 and the necessity for resilience in the changing global economy. This article examines the influence of Discrete Event Simulation (DES) on the digital transformation of courier logistics and its role in Industry 4.0 frameworks within the context of a resilient economy. Discrete Event Simulation (DES) functions as an effective instrument for modelling and optimising intricate logistical systems, allowing organisations to improve operational efficiency, adaptability, and sustainability. This research employs a quantitative case study methodology to analyse how DES applications tackle significant issues, including real-time decision-making, resource allocation, and supply chain disruptions. The findings highlight the crucial importance of DES in promoting digital innovation, enhancing system resilience, and facilitating the incorporation of Industry 4.0 technologies in courier logistics. This research underscores the revolutionary capacity of DES as a catalyst for attaining a robust, sustainable, and digitally optimised logistics sector.

Keywords:

Discrete Event Simulations, Courier Logistics, Digitalization, Industry 4.0, Resilience Economy, Quantitative Study.

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Introduction

The logistics business has undergone significant transformations in recent years, propelled by the emergence of digital technology and escalating expectations for a resilient economy (Zhang et al., 2024). The vulnerability of supply chains highlighted by the COVID-19 pandemic intensified the demand for resilient and adaptive systems, prompting companies to leverage advanced technologies such as discrete event simulations to improve operational efficiencies (Camur et al., 2023; Kashem et al., 2024; Dohmen et al., 2022; Schleifenheimer & Ivanov, 2024). Discrete Event Simulation (DES) is a computer-assisted modelling technique that allows organisations to replicate complex processes and enhance logistical operations in real time (Banks et al., 2020). Logistics is undergoing significant transformations due to digital technologies and the demands of the resilient economy.

The integration of digital technologies, such as DES, is poised to transform the courier logistics industry by enhancing resource allocation efficiency, decreasing delivery durations, and increasing customer satisfaction levels (Shahadat et al., 2023). Cyber-physical production systems, integrated with discrete event simulation and digital twin technologies, enabling real-time monitoring and optimisation of manufacturing processes (Monek & Fischer, 2023). Recent advancements bolster the emergence of Logistics 4.0, presenting potential for enhanced resource allocation and heightened consumer satisfaction (Albrecht et al., 2023). Furthermore, DES corresponds with the tenets of Industry 4.0, which prioritises the integration of intelligent technologies, automation, and data analytics to foster innovation and maintain competitiveness (Kagermann et al., 2020). Notwithstanding these prospective advantages, research on the precise influence of DES on the digitalisation of courier logistics and its role in Industry 4.0 within the resilience economy remains scarce.

This study seeks to address this gap by examining the role of DES in enhancing the digitalization of courier logistics and its implications for Industry 4.0. The research question guiding this study is: *How does DES contribute to the digitalization of courier logistics and its alignment with Industry 4.0 objectives within the resilience economy?*

The paper is structured as follows: Section 2 presents a review of the relevant literature, Section 3 outlines the research methodology, Section 4 discusses the findings, and Section 5 concludes with implications and future research directions.

Literature Review

The amalgamation of the Technology-Organization-Environment (TOE) framework (Tornatzky and Fleischer, 1990) and Dynamic Capabilities Theory (Teece, Pisano & Shuen, 1997) establishes a comprehensive and interdisciplinary basis for this study. It thoroughly examines the technological adoption of discrete event simulations (DES), organisational adaptability in courier logistics, environmental alignment with Industry 4.0, and overarching economic resilience, thereby facilitating a holistic comprehension of how DES-driven digitalisation revolutionises logistics operations and fosters sustainable, resilient economies.

Courier Logistics and Digitalization

Courier logistics refer to the administration of personnel and resources to transport parcels, documents, and items from one location to another in the lowest possible time (Aćimović et al., 2020; Negi, 2024; Yao et al., 2022). This sector plays a crucial role in contemporary supply chains by ensuring that items reach end customers or businesses within specified timeframes (Gala, 2023). Maghsoudi, Jafari, and Alizadeh (2020) assert that courier logistics encompasses

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parcel collection, sorting, transportation, and delivery services, all aimed at fulfilling client satisfaction (Maghsoudi, Jafari, and Alizadeh, 2020). This pertains to resource management encompassing fleet, warehouse, and staff to fulfil delivery obligations (Cheng et al., 2024; Ding et al., 2020; Jagtap et al., 2020). The delivery services of e-commerce have necessitated the optimisation of courier logistics, since the vitality of this sector is essential for maintaining the flexibility and economic stability of enterprises.

The word digitalisation denotes the application of digital techniques across various company processes to create and provide value to customers and other stakeholders (Broccardo et al., 2023; Parviainen et al., 2022). Digitalisation in logistics is defined by the implementation of enablers such as data analytics, automation, cloud computing, and artificial intelligence, as articulated by Parida, Sjödin, and Reim (2019). In courier logistics, digitalisation is evident through advanced tracking systems, optimised route determination systems, and real-time communication systems (Kalkha et al., 2023). In addition to improving operability, these solutions address challenges such as delayed delivery and resource management via data collecting and forecasting (Santhi & Muthuswamy, 2022; Ikevuje et al., 2024; Zafarzadeh et al., 2021). In this context, digital transformation plays a significant role in modernising courier logistics to meet the demands of clients and markets.

The implementation of digitalisation in courier logistics influences the efficiency, reliability, and scalability of the delivery process. Wang, Zhao, and Chen (2021) establish a direct correlation between the adoption of digital technology and the enhancement of logistics performance, demonstrating that digitalisation facilitates expedited decision-making, improved transparency, and superior customer relations. This is evidenced by market trends such as sustainability, e-commerce, sharing economies, and speed orientation, which collectively influence the efficacy of digital technology in logistics, ranging from mere avoidance to exceptional performance (Golińska-Dawson et al., 2023). Furthermore, digital transformation, coupled with appropriate smart technologies, augments relational performance within supply chain networks (Nasiri et al., 2020). In logistics companies, Dynamic System Development Method (DSDM) has been shown to positively influence the environmental, social, and economic aspects of sustainability (Saqib & Qin, 2024). For example, data acquired from IoT sensors reduces ambiguity in parcel location and enhances consumer confidence (Balfaqih et al., 2023). Similarly, it reduces human involvement in sorting and distribution centres due to expedited delivery cycles (Ferreira & Reis, 2023). The integration of digitalisation and courier logistics enhances the overall efficiency of consolidation while elevating consumer satisfaction and loyalty, as timely and accurate delivery is essential for favourable consumer experiences (Rodrigue, 2022; Vrhovac et al., 2023; Zheng et al., 2022). There for the hypothesis are:
H_1: Digitalization positively affects the Digitalization Courier Logistics.

DES and Logistics Operations

DES is a modelling methodology employed to depict the behaviour of intricate systems by simulating sequential discrete occurrences throughout time (Oliveira et al., 2022). DES entails deconstructing operations into discrete events, including package sorting, transportation, and delivery, to examine the interactions and results of diverse processes (Garn et al., 2024; Lyu et al., 2023). It may be utilised to assess scenarios, examine tactics, and forecast outcomes without interfering with actual operations (Rotunno et al., 2023; Lyu et al., 2023). DES can be combined with methodologies such as Cost-Benefit Analysis to facilitate investment decisions (Rotunno et al., 2023) and cluster analysis for the optimisation of urban freight logistics (Lyu et al., 2023). In courier logistics, DES functions as an effective instrument for scenario

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evaluation, operational strategy testing, and outcome prediction under diverse conditions without interfering with actual operations (Park et al., 2024). Its potential to mimic logistical operations renders it essential for tackling issues such as capacity planning, route optimisation, and service reliability.

The notion of resilient courier logistics operations pertains to the ability of logistics functions to recover and maintain the continuity of logistics activities in the face of disruptions or challenges (Aron & Sgarbossa, 2023). Al-Qasimi et al. (2024) define logistics resilience as the capacity of systems to adapt and perform successfully despite adverse situations, hence preventing operational disruptions. In courier logistics, resilience denotes the capacity to manage demand fluctuations, respond to contingencies, and overcome challenges such as future disasters, epidemics, or any disruptions within the supply chain (Aloui et al., 2021; Umar & Wilson, 2023). In this instance, resilience strategies often encompass resource diversification, risk management initiatives, and the use of advanced technologies for prompt visibility and assessment (Kumar, 2024). Resilient logistics networks are essential in a volatile environment to consistently provide and uphold customer satisfaction.

The integration of DES enhances operational flexibility in courier logistics by facilitating forecasting and scenario testing (Lyu et al., 2023; Lyu et al., 2021). Vázquez-Serrano et al. (2021) emphasise that tools such as DES improve system robustness by identifying vulnerabilities and optimising operations. DES provides simulations of logistics and its operations, as well as analyses of potential disruptions, for the development of mitigation plans and resource allocation (Monek & Fischer, 2023). For example, when integrated with value stream mapping, DES can reduce warehouse supply chain lead times and improve decision-making in pharmaceutical logistics (Abideen & Mohamad, 2020). DES has demonstrated its ability to capture operational specifics in road construction and convert material logistics plans into cost efficiencies (Alvanchi et al., 2021). The amalgamation of DES and resilience ensures that courier logistics can adapt dynamically while maintaining operational efficiency and prioritising client happiness (Umar & Wilson, 2023). There for the hypothesis are:
H_2: DES positively affects the Digitalization Courier Logistics.

Digitalized and Industry 4.0

Digitalisation in courier logistics entails the implementation of modern technology to enhance, optimise, and automate delivery and courier operations (Albrecht et al. 2023). The emergence of technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), blockchain, and big data analytics is key to this change (Firouzi et al., 2023). Digitisation enables real-time visibility, automated routing, and predictive analytics, enhancing efficiency, reducing costs, and improving customer happiness (Tadimarri et al., 2024). Courier firms that utilise digital solutions can improve the efficiency and timeliness of deliveries while ensuring transparency in the supply chain, hence enhancing the whole delivery experience for clients and stakeholders (Rahamneh et al., 2023). Digital technologies generally offer substantial benefits to logistics and supply chain management, including enhanced operational efficiency, transparency, and competitiveness.

Industry 4.0 emphasises the establishment of intelligent links and networks to facilitate the integration of digital technologies across many sectors, hence fostering the decentralisation of concepts and the execution of enhancements (Ghobakhloo et al., 2021). It aims for automation, real-time data dissemination, predictive decision-making, and enhanced operational adaptability (Ahmadvand et al., 2022). In logistics, these objectives are achieved through the

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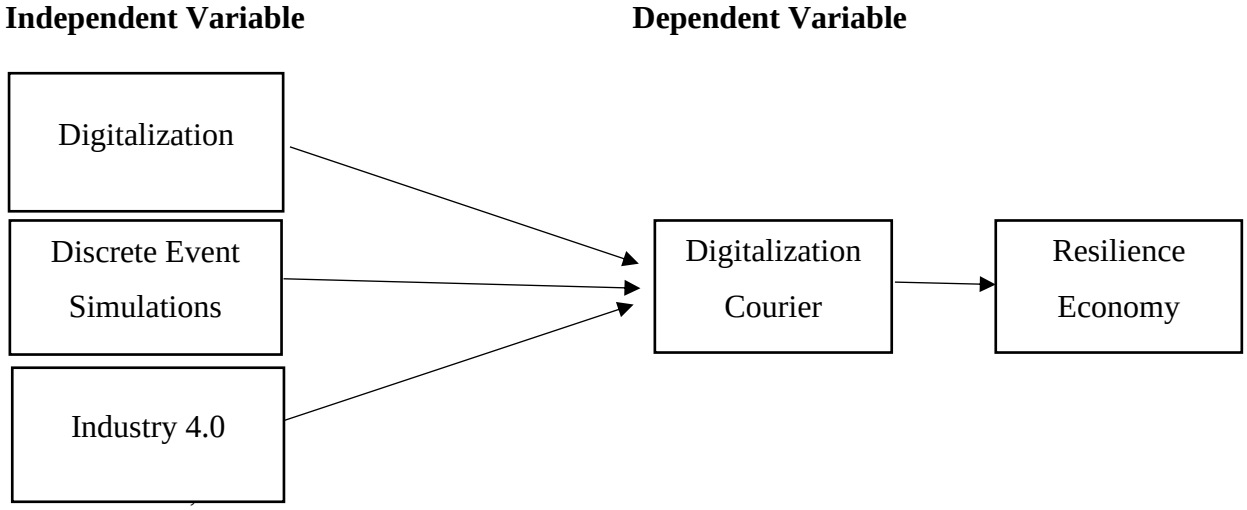
integration of technologies focused on dynamic resource management, autonomous processes, and adaptable supply chains (Cano et al., 2021). Industry 4.0 seeks to establish ecosystems that integrate digital and physical surroundings to respond swiftly to market demands and disruptions.

The transition to digitalisation in courier logistics is crucial for achieving Industry 4.0 objectives, as it provides critical tools for optimising corporate processes and ensuring successful integration. Real-time tracking and data exchange enhance dynamism and integration, which have been the primary focus of Industry 4.0 (Ivanov et al., 2020). A poll of 230 individuals indicated that digital logistics and blockchain technology can enhance the management of Global Supply Chain Management (GSCM), yielding competitive advantages and customer benefits (Ilii Method, 2024). A recent study involving 300 supply chain managers concluded that the extent of digital supply chain digitalisation and the utilisation of digital tools positively impact supply chain resilience, asserting that further digitalisation is crucial to address new uncertainties in the modern business environment (Dorsaf Zouari et al., 2020). Moreover, Wong et al. (2020) discovered that supply chain resilience yields benefits. Huang et al. (2023) demonstrate that Industry 4.0 technology and IT enhancements augment overall supply chain resilience via collaboration and real-time visibility. Xu et al. (2024) demonstrate that digital transformation improves organisations' supply chain risk management during disruptions by utilising sourcing and geographic diversification, yielding beneficial results. These advancements are closely associated with the operational flexibility and sustainability characteristic of Industry 4.0. There for the hypothesis are:
H_3: Industry 4.0 positively affects the Digitalization Courier Logistics.

Research Methodology

The study employed a deductive quantitative design. These designs involve studying quantities and relationships between factors and are suitable for documenting prevalence or testing hypotheses (Heddle, 2002). In the deductive section, data was collected from the literature and surveys administered to the relevant respondents (Schutt, 2007). The study identified the key variable essential for the successful implementation of the study. Based on this information, an a priori conceptual framework (Figure 1) and the hypotheses were developed and utilised as inputs for the subsequent preparation and administration of a survey (Banks, 2007).

Figure 1: Conceptual Framework Study



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A quantitative study utilised (Malhotra, 1991; Malhotra and Grover, 1998). A structured questionnaire to gather data from 200 logistics professionals employed in courier companies. The questionnaire was designed based on existing literature and included items related to DES, digitalization, Industry 4.0, and resilience. The five-point Likert scale measured the constructs (Sullivan & Artino, 2013) with 1 representing "Strongly Disagree" and 5 representing "Strongly Agree."

Data analysis was performed via SPSS. SPSS provides researchers with tools for various statistical procedures, including descriptive statistics, bivariate correlations, regression analyses, ANOVA, and multivariate techniques (L. Meyers et al., 2013). The initial phase entailed (Vyas & Kumaranayake, 2006) assessing the reliability and validity of the measuring scales by principal component analysis (PCA). The subsequent phase entailed the examination of the study hypotheses by multiple linear regression analysis. Multiple linear regression (MLR) analysis is a versatile statistical technique for examining research hypotheses across various fields. It can be used to test for evaluate hypotheses in hypnosis research (Stare, 1971) and provide more accurate probability values than chi-square tests (McNeil, 1974). MLR allows researchers to compare squared multiple correlation coefficients of unrestricted and restricted predictive equations to test hypotheses (Stare, 1971).

Data Analysis

Descriptive Statistics

The descriptive statistics collected information from 200 logistics professionals working in courier companies. (Table 1)

Table 1: Descriptive Statistics

Descriptive	Frequency	%
Gender		
Male	120	60%
Female	80	40%
Age		
20–29 years	30	15%
30–50 years	140	70%
Above 50 years	30	15%
Work Experience in Logistics Sector		
Less than 2 years	10	5%
2–5 years	30	15%
More than 5 years	30	80%

Among the respondents, 60% were male while 40% were female. In terms of age distribution, 70% of the respondents fell within the 30–50 years age group, an indication of a relatively experienced labour force within the industry. Additionally, 80% of the sample possessed more than five years of working experience in the logistics industry, showing the sample's experience in courier logistics and digitalization. Such demographics indicate that the respondents are endowed with the requisite industry knowledge to present credible information on the study variables.

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Reliability and Validity

The convergent validity checking process is done by looking for the loading factor of each indicator. A factor value of 0.5 or higher is considered sufficiently large to justify the use of latent buildings (Chin, 1998; Ghozali, 2014; Hair et al., 2010). The minimum limit for the agreed load factor in this study is: 0.5, given that each structure has an AVE value of 0.5 (Ghozali, 2014). The PCA findings demonstrated that all constructs exhibited adequate reliability, with Cronbach's alpha values exceeding 0.70. The convergent validity of the constructs was also confirmed, with factor loadings exceeding 0.50.The table 2 and table 3 below is a summary of the results.

Table 2 Reliability Analysis

Construct	Cronbach's Alpha (α)	Reliability Level
Discrete Event Simulations (DES)	0.82	High Reliability
Digitalization of Courier Logistics	0.85	High Reliability
Industry 4.0 Contributions	0.83	High Reliability
Resilience Economy	0.81	High Reliability

Table 3 Convergent Validity Analysis

Construct	Lowest Factor Loading	Higher Factor Loading
Discrete Event Simulations (DES)	0.61	0.81
Digitalization of Courier Logistics	0.65	0.85
Industry 4.0 Contributions	0.62	0.80
Resilience Economy	0.60	0.80

The analysis of validity and reliability indicates that the measurement scales employed in this study are both theoretically and statistically robust. The survey items demonstrated strong internal consistency, as indicated by Cronbach's Alpha values exceeding 0.70, thereby confirming the reliability of the construct. Factor loadings exceeding 0.50 confirmed convergent validity, indicating that each item accurately represented its respective concept. The assessment of discriminant validity indicated that the average variance extracted (AVE) surpassed the squared correlations of the constructs. This suggests that each idea is distinct and aligns with the study's framework. The results affirm the validity and reliability of the measurement model and the hypothesis testing data.

Hypothesis Testing

The hypotheses were evaluated by multiple linear regression analysis utilising SPSS in the study. The table 4 below is a summary of the results:

Table 4 Hypothesis Testing

Hypothesis	Relationship	Standardized β	p-value	Result
H_1	Digitalization positively affects the Digitalization Courier Logistics	0.45	$p < 0.05$	Supported
H_2	DES positively affects the Digitalization Courier Logistics	0.52	$p < 0.05$	Supported
H_3	Industry 4.0 positively affects the Digitalization Courier Logistics.	0.38	$p < 0.05$	Supported

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- **H_1**: Digitalization positively affects the Digitalization Courier Logistics **($\beta = 0.45$, $p < 0.05$)**. The findings show that digitalisation has a major positive effect on the performance of courier logistics, therefore demonstrating that the incorporation of digital technology increases efficiency, lowers delays, and raises general service quality.
- **H_2**: DES positively affects the Digitalization Courier Logistics **($\beta = 0.52$, $p < 0.05$)**. The results reveal that by allowing real-time decision-making, routing optimisation, and disturbance of logistical operations reduction, DES is absolutely important in increasing resilience.
- **H_3:** Industry 4.0 positively affects the Digitalization Courier Logistics **($\beta = 0.38$, $p < 0.05$)** The findings demonstrate that digitalisation in courier logistics is a main enabler of Industry 4.0 objectives, including automation, real-time tracking, and data-driven decision-making, therefore producing more creative and effective logistics systems.

Discussion

The study's results provide substantial empirical support for the theory that digitalisation significantly enhances courier logistics performance. This aligns with other research highlighting the transformative impact of smart technologies, data analytics, and automation on optimising logistics operations (Wamba et al., 2020). Digitalisation facilitates real-time tracking, predictive analytics, and process automation, thereby enhancing service delivery through increased efficiency, reduced operational costs, and decreased complexity. The positive correlation between digitalisation and logistics performance suggests that courier companies investing in advanced digital technologies, such as cloud-based logistics platforms and IoT-enabled tracking systems, are more likely to achieve superior operational outcomes. Despite these advantages, companies may encounter challenges such as cybersecurity issues, the need for workforce digital upskilling, and integration complexities; thus, strategic planning and investment in digital infrastructure are increasingly critical.

The research confirms that enhancing logistics resilience primarily relies on Discrete Event Simulation (DES). This finding aligns with contemporary research highlighting the application of simulation-based models in risk management, process optimisation, and decision-making within dynamic logistics contexts (Tako & Robinson, 2019). DES assists companies in developing robust mitigation strategies to counteract supply chain disruptions, evaluating various logistical scenarios, and predicting traffic congestion. Resilience is critical in courier logistics due to the sector's susceptibility to delivery delays, fluctuating demand, and external shocks such as geopolitical events or pandemics. The significance of DES as a strategic tool in contemporary logistics management is highlighted by its ability to simulate risks and provide real-time adjustments. Future research may explore the interaction between DES and emerging technologies such as blockchain-based logistics monitoring and artificial intelligence-driven predictive analytics to enhance resilience.

The research highlights that digitalisation significantly influences the adoption of Industry 4.0, thereby reinforcing the argument that digital transformation serves as a catalyst for logistical innovation and competitive advantage (Xu et al., 2021). Industry 4.0 technologies, including cyber-physical systems, big data analytics, robots, and smart sensors, depend fundamentally on digitalisation for optimal integration and functionality. The findings indicate that organisations adopting digital transformation are better positioned to leverage Industry 4.0 advancements, thereby enhancing customer-centric solutions, efficiency, sustainability, and overall effectiveness. Significant concerns remain that necessitate further investigation,

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including high implementation costs, interoperability issues, and regulatory challenges. Future research should evaluate the impact of long-term digitalisation on environmental sustainability in logistics, particularly concerning green supply chain practices and the reduction of carbon footprints.

This study provides a thorough analysis of the interactions among digitalisation, DES, industry 4.0, and logistics resilience; however, several avenues for future research are still available. A longitudinal study may be conducted to assess the temporal changes in digital transformation trends and their ongoing impact on logistics performance. Secondly, a deeper understanding of the contextual elements influencing the adoption of digitalisation and resilience is necessary through comparative research across various sectors and geographical regions. Third, examining the integration of DES models with blockchain, artificial intelligence, and machine learning may offer a comprehensive solution to enhance logistical resilience. Future studies must consider human factors, particularly the impact of digitalisation on job roles, worker competencies, and resistance to technological change in logistics operations. Addressing these gaps will enhance the subject's advancement and provide legislators and logistics professionals with practical information.

Conclusion

The study's results align with previous research, demonstrating the significant role of DES and digitalisation in enhancing courier logistics resilience and facilitating Industry 4.0 advancement. The findings suggest that to enhance performance and adaptability in a dynamic supply chain environment, logistics firms should invest in digital infrastructure, simulation technologies, and automation tools.

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