The Role of Digital Supply Chain in Enhancing Industry 4.0 Capabilities that Influence for Better Strategies of Transportation Logistics:
An Applied Study on the Shipping and Transportation Services Sector in Egypt

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ABSTRACT

Purpose: This study investigates how Industry 4.0 capabilities influence transportation logistics strategy, with a focus on the mediating role played by digital supply chain efficiency, in other words, elucidating the underlying mechanisms through which Industry 4.0 capabilities shape transportation logistics strategy via digital supply chain efficiency.

Methodology: The target population consists of companies of courier services located in Egypt, like DHL, Aramex, FedEx, Bosta Sportation, and several other companies with large business volumes. Primary data was collected via questionnaires directed to employees working in supply chain departments of companies working in the shipping and transportation services.

Results: Results indicate significant associations between Industry 4.0 capabilities, Digital Supply Chain Efficiency, and Transportation Logistics Strategy. The findings are anticipated to assist companies in devising informed strategies and initiatives to leverage the full potential of Industry 4.0 in optimizing transportation logistics processes and securing sustainable competitive advantages in the digital age.

Keywords: Industry 4.0 - Transportation Logistics Strategy- Digital Supply Chain Efficiency

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The Role of Digital Supply Chain in Enhancing Industry 4.0 Capabilities that Influence for Better Strategies of Transportation Logistics:

دور سلسلة التوريد الرقمية في تعزيز قدرات الصناعة 4.0 التي تؤثر على استراتيجيات أفضل للوجستيات النقل:

دراسة تطبيقية على قطاع خدمات الشحن والنقل في مصر

الملخص

الهدف: تبحث هذه الدراسة في كيفية تأثير قدرات الصناعة 4.0 على استراتيجية لوجستيات النقل، مع التركيز على الدور الوسيط الذي تلعبه كفاءة سلسلة التوريد الرقمية، وتوضيح الآليات الأساسية التي من خلالها تشكل قدرات الصناعة 4.0 استراتيجية لوجستيات النقل عبر كفاءة سلسلة التوريد الرقمية. .

المنهجية: يتكون المجتمع المستهدف من شركات خدمات البريد السريع الموجودة في مصر، مثل DHL، وAramex، وFedEx، وBosta Sportation، والعديد من الشركات الأخرى ذات الحجم التجاري الكبير. تم جمع البيانات الأولية عبر استبيانات موجهة للموظفين العاملين في أقسام سلسلة التوريد في الشركات العاملة في خدمات الشحن والنقل.

النتائج: تشير النتائج إلى وجود ارتباطات كبيرة بين قدرات الصناعة 4.0 وكفاءة سلسلة التوريد الرقمية واستراتيجية لوجستيات النقل. ومن المتوقع أن تساعد النتائج الشركات في وضع استراتيجيات ومبادرات مستنيرة للاستفادة من الإمكانات الكاملة للصناعة 4.0 في تحسين عمليات لوجستيات النقل وتأمين مزايا تنافسية مستدامة في العصر الرقمي.

الكلمات المفتاحية: الصناعة 4.0 – استراتيجية لوجستيات النقل – كفاءة سلسلة التوريد الرقمية.

1. INTRODUCTION

The rapid advancement of digital technologies like big data, cloud computing, AI, IoT, blockchain, and 5G, along with the interconnected global economy and uncertain external factors, are significantly impacting supply chain sustainability and competitiveness. For instance, during the COVID-19 pandemic, the digital economy surged, benefiting businesses that embraced digital transformation, while others struggled to adapt. Given this influence, it's crucial for organizations to prioritize building resilient and sustainable supply chains by leveraging digital technologies to enhance competitive performance. Research and practical implementation of digital transformation in supply chains are urgently needed to achieve this goal (Ning and Yao, 2023).

The courier service industry is rapidly growing, expected to reach $658.3 billion by 2031, driven by cross-border commerce, ecommerce, and on-demand deliveries. Global parcel shipping volume is set to hit 256 billion parcels by 2027, leading to increased demands for fulfillment and delivery service (Kummern et al., 2021). This presents both opportunities and challenges, particularly in meeting the logistics needs of expanding e-commerce companies. Serving multiple companies can be lucrative but requires advanced management systems to address various challenges (Gomes et al., 2023).

Key challenges include optimizing last-mile delivery routes, integrating digital tracking systems for real-time visibility and package management, addressing infrastructure limitations and regulatory hurdles for digital technology adoption, enhancing communication channels for transparency and satisfaction, and developing strategies to mitigate external factors like traffic congestion and adverse weather. Research efforts should focus on tailored digital solutions for the courier services sector, including exploring innovative technologies like blockchain and leveraging data-driven insights for improved efficiency and customer service (Gomes et al., 2023).

The first industrial revolution achieved efficiency through the utilization of hydropower, increased adoption of steam power, and advancements in machine tools. The second industrial revolution introduced electricity and pioneered mass production through assembly lines. The third industrial revolution accelerated automation with the integration of electronics and information technology. Recently, the emergence of the fourth industrial revolution, led by Cyber-Physical Systems (CPS) technology, aims to integrate the physical world with the information era for further industrial advancement (Ning and Yao, 2023).

CPS involves engineered computing and communication systems that interface with the physical world, driving the Industrial Internet of Things and propelling industries towards a new level of growth and competitiveness, ultimately transforming economies, and opening new avenues for advancement (Munirathinam, 2020). The transportation sector can undergo transformation and enhance sustainability, safety, and efficiency by implementing Industry 4.0 technology. But sustainability's influence on Industry 4.0 and its role in promoting sustainable social, economic, and environmental growth are becoming more and more well-known (Ghobakhloo, 2020). The role of the supply chain in courier services is crucial for facilitating the seamless movement of products within the distribution network. Courier services play a fundamental role in the transportation of goods from one point to another, whether it be within internal operations or through outsourcing from vendors (Yildiz, 2014).

This research fills the gap by examining the impact of Industry 4.0 capabilities on transportation logistics strategy focusing on the intermediary function of digital supply chain efficiency. The research aims to provide valuable insights for practitioners, policymakers, and researchers by elucidating the underlying mechanisms through which Industry 4.0 capabilities influence transportation logistics strategy via digital supply chain efficiency. The findings are expected to assist companies in devising informed strategies and initiatives to maximize the potential of Industry 4.0 for optimizing transportation logistics processes and gaining sustained competitive advantage in the digital age.

Problem Statement

The problems facing the integration of digital supply chain technologies to enhance Industry 4.0 capabilities for transportation logistics include several key challenges. Firstly, there are difficulties in harmonizing data across various platforms due to compatibility issues, hindering effective data exchange and analysis. Secondly, cybersecurity threats become more pronounced as operations become more digitized, necessitating robust measures to protect sensitive information. Thirdly, limitations in infrastructure such as reliable internet connectivity pose challenges to the seamless implementation of digital technologies. Additionally, the upfront costs of technology adoption and the shortage of skilled professionals proficient in digital technologies present financial and human resource challenges. Moreover, navigating complex regulatory landscapes, achieving interoperability among stakeholders, and managing new risks associated with digitalization further complicate implementation efforts. Addressing these challenges is essential for unlocking the potential benefits of digital supply chain technologies and enhancing transportation logistics strategies within the Industry 4.0 framework.

This research is divided as follows; the first section presents the current introduction of the research. The second section provides an overview of the literature review. The third section discusses the research methodology, while the fourth section presents the results and findings of this research. The fifth section presents the research discussion, while the sixth section presents the research recommendations. The seventh section presents the research limitation and future researchers' suggestions.

2. LITERATURE REVIEW

All industries are being impacted by the rapid advancement of technology, but the supply chain may be the one most so. Businesses involved in supply chains and logistics need to keep up with significant advancements and changes. It's easy to think that digital supply chains are essential to Operations 4.0. Efficiency in digital supply chains acts as a crucial mediator in the substantial influence of Industry 4.0 capabilities on transportation logistics strategy. Enterprises can attain unparalleled levels of efficiency, adaptability, and innovation within their transportation logistics procedures by harnessing state-of-the-art technologies and optimizing supply chain operations. To thrive in the industry 4.0 era, organizations must view digital transformation not only as a necessity but also as a strategic imperative. Hence, the literature review section will delve into each study variable and elucidate the evolution of relationships stemming from exploring the influence of Industry 4.0 Capabilities on Transportation Logistics Strategy through the mediating role of Digital Supply Chain Efficiency.

Industry 4.0 Capabilities

In the world of fast technological advancement today, Industry 4.0 is a beacon of innovation and transformation. Known as the Fourth Industrial Revolution and an advancement in production and manufacturing Industry 4.0 is defined by the integration of digital technology into industrial processes. These technologies, together known as "Industry 4.0 capabilities," comprise a wide range of innovative instruments and techniques designed to transform conventional manufacturing and operational procedures. The digital, biological, and physical worlds are some of the features of modern technologies that set Industry 4.0 apart. Development goals of governments, economies, and industries are being significantly impacted by technological advancements. One of the key ideas in the growth of international industry and the global economy is Industry 4.0 (Munirathinam, 2020).

Three historical industrial revolutions that preceded Industry 4.0 led to fundamental changes in the manufacturing industry: mass production on assembly lines, computer-based automation, and mechanization powered by water and steam (Demir et al., 2020).

With the invention of steam power and water in the 1780s, industry 1.0 got underway, significantly enhancing the agricultural sector, and facilitating mechanical manufacturing. The second definition of Industry 2.0 is the time frame during which mass manufacturing became the main method of production overall. Large-scale mass manufacturing was facilitated by the introduction of railroads into the industrial system through the mass manufacture of steel (Yahya and Yahya, 2018).

With the start of the Digital Revolution in the 20th century, Industry 3.0 emerged. Compared to Industry 1.0 and 2.0, this industry is more well-known because many people alive now are familiar with industries that rely on digital technologies for production. Industry 4.0 refers to a broad shift that encompasses the automation and digitization of every aspect of a company's activities, including the manufacturing process (Ing Tay et al., 2018). The following provides an explanation of the key Industry 4.0 capabilities:

Industrial Internet of Things

The concept of the Internet of Things (IoT) expands its scope across various industries with the assistance of the Industrial Internet of Things (IIoT). These industries include production, electricity, transportation, healthcare, and agriculture. IIoT is intended to maximize asset utilization, minimize downtime, and optimize productivity in industrial settings as opposed to consumer oriented IoT applications, which are primarily focused on enhancing convenience and lifestyle. According to Dorsemaine et al. (2015), the industrial internet of things is a collection of infrastructures that permit object interconnection for the purposes of management, data mining, and data access. In this meaning, items are the sensor(s) as well as actuator(s) that allow equipment to communicate with one another.

Zhou (2017) stated that the Industrial Internet of Things (IIoT), a concept that integrates control systems and sensor networks, has been used in several industries to increase productivity and safety.

Grzybowska and Hoffa-Dabrowskas (2022) noted that the term " The Industrial Internet of Things (IIoT) refers to the application of current Internet of Things (IoT) technologies to enhance productivity within industrial contexts.

The term "industrial internet of things" refers, according to Björklöf and Castro (2022), to the broad spread of networked connectivity and computing resources available to machines, instruments, and other objects that are not often thought of as computers. The data sharing, collection, and generation capabilities of these intelligent devices require little to no human participation. One common feature of all smart devices is their capacity for remote data administration, analysis, and gathering.

Big Data

It is a ground-breaking idea that has fundamentally altered how companies collect, arrange, analyze, and draw conclusions from massive volumes of structured and unstructured data. In the current digital age, where data is produced at a never-before-seen rate and volume, big data has become an indispensable tool and a driving force behind innovation in a wide range of fields and businesses. Because of its large volume, velocity, and variety, big data is therefore described by De Mauro et al. (2016) as an information asset that needs certain technology and analytical techniques to transfer it into value.

The phrase "Big Data" refers to extremely huge data sets with intricate, diverse, and complicated structures that are challenging to store, analyze, and visualize for use in subsequent procedures or outcomes (Yaseen and Obaid, 2020).

Big Data refers to datasets containing substantial amounts of information, particularly complex data, necessitating specialized processing due to its distinctiveness from other conventional datasets. Big Data has many challenges, from the point of data collection to the conclusion of the results. BD is seen in many different domains, such as science, business, government, healthcare, and transportation (Alwan and Ku-Mahamud, 2020).

Cloud Computing

A new wave of information technology called cloud computing combines distributed processing, virtualization, grid and cluster computing, and distributed computing. Cloud computing is an advanced form of computing that combines structured processing power and information data in a highly integrated manner, evolving from traditional technology (Sui and Sui, 2018).

The storage and transfer of data via a network is known as cloud computing, and it makes use of numerous key technologies for programming, data management, and storage. It mostly consists of cloud computing platform administration, distributed file systems, handling resources and timetables, virtualization technologies, and so forth (Sui and Sui, 2018).

Cloud computing is utilized in IT infrastructure to deliver services to customers online. cloud computing through a third-party supplier. It provides the final consumer with an inexpensive environment. It is a device for storing and maintaining applications and data. Any information can be obtained online, and backups can be made. The service and deployment models of cloud computing allow for low-cost service delivery to customers (Rajeswari, 2019).

Augmented Reality

A new technique called Augmented Reality (AR) involves superimposing computer visuals on the actual world. The mixing of real-world and computer-generated data is the focus of the computer science subject known as augmented reality, or AR. Computer displays that enhance a user's sensory experiences with virtual information are referred to as Augmented Reality (AR). This technique involves superimposing spatially coordinated computer-generated data over a human's field of vision to improve or enhance the visual quality of the surrounding environment (Benila et al., 2021).

With the use of augmented reality technology, it is possible to superimpose virtual visuals created by computers over the actual world. A technology known as augmented reality blends virtual and real-world imagery, allowing users to interact with it in real time and register virtual visuals with their surroundings (Muff and Fill, 2022).

System Integration

The term "system integration," also known as "integration at the system level," describes the combination of many parts, subsystems, or interactions between people to create a system that satisfies its goals (Rajabalinejad et al., 2020).

Technical organizations should aggressively invest in Augmented Reality (AR), as it is starting to be regarded to be one of the fastest-growing businesses. Because maintenance tasks take less time and have fewer chances of error, this technology can be a significant help for businesses with maintenance operations (Ing Tay et al., 2018).

Simulation

De Paula Ferreira et al. (2020) define simulation as the practice of modeling a hypothetical or actual system to analyze and study its behaviors. Simulated modeling is an essential tool for planning and exploratory model creation in order to maximize decision-making processes as well as the design and operation of complex and intelligent production systems. Businesses may find it helpful to evaluate the risks, costs, implementation difficulties, impact on operational performance, and Industry 4.0 schedule.

Additive Manufacturing

Because additive manufacturing provides on-demand manufacturing, fast prototyping, design flexibility, and sustainability advantages, it is essential for promoting creativity, productivity, and sustainability across industries. A group of technologies known as "additive manufacturing" use three-dimensional computer-aided design data to directly build physical objects. Layer by layer, Additive Manufacturing adds liquid, sheet, wire, or powdered materials to create component components that require little to no further processing (Reddy and Dufera, 2016).

Additive manufacturing, or computer-controlled 3D printing of objects, is a key component of smart manufacturing. The production of research and development (R&D) samples at industrial facilities is subject to several restrictions. When the component materials and design parameters are appropriately composed, the manufacturing process for these 3D prototypes is significantly shortened (Shadravan and Parsaei, 2023).

In additive manufacturing, materials are piled on top of one another to produce three-dimensional objects. To enable quick and on-demand production, additive manufacturing is useful. The automotive, aerospace, development, medical, and consumer products industries are among those that use additive manufacturing (Marinagi et al., 2023).

Digital Supply Chain Efficiency

Organizations looking to stay competitive and satisfy changing customer needs must prioritize supply chain operations efficiency in today's fast-paced, globally integrated business environment. The concept of "Digital Supply Chain Efficiency," a ground-breaking strategy driven by the integration of state-of-the-art digital technologies into supply chain processes, is leading the way in this attempt. The Digital Supply Chain can only be implemented successfully if the business accurately arranges to provide the crucial data in real-time across every stop in the networked system (Lee et al., 2022).

A digital supply chain is, according to Büyüközkan and Göçer (2018), an intelligent, best-fit technological system that facilitates and synchronizes interactions between organizations by raising the quality, affordability, and accessibility of services and delivering outcomes that are dependable, adaptable, and successful. Its foundation is the ability to properly interact and communicate with digital hardware, software, and networks, as well as to dispose of massive volumes of data.

A Digital Supply Chain is equipped with a special embedded system and methods that allow it to monitor and manage the inventory levels in real time, facilitate great consumer interactions with the products, provide locations and equipment, support planning, and carry out overall business operations (Lee et al., 2022).

Moreover, Grzybowska and Hoffa-Dabrowskas (2022) refereed to Digital Supply Chains, or DSCs, as cooperative digital networks created to transfer goods, services, and information via international supply chains rapidly and effectively. According to Boyson et al. (2022) a Digital Supply Chain is the pinnacle of IoT (Internet of Things) development.

Transportation Logistics Strategy

Logistics covers the entirety of information and material movements within an organization, spanning from product movement to service provision, handling incoming raw materials, production, storage of finished goods, customer delivery, and post-sales service. The logistics scope has evolved due to advancements in technology and strategic partnerships, enabling competition based on flexibility and responsiveness. The increasing significance of logistics stems from companies globalizing to access new markets, achieve greater production efficiencies, and leverage technological capabilities beyond their geographical borders. A decrease in trade barriers and the advent of advanced technologies have sparked significant interest in logistics in recent times. Presently, logistics operations encompass procurement, distribution, inventory management, packaging, manufacturing, and even customer services. In the current highly competitive landscape, numerous companies are striving to penetrate the global market and capitalize on enhanced production and sourcing efficiencies. Today's businesses rely heavily on the logistics function to maintain the smooth movement of goods, information, and materials throughout their supply chains (Gunasekaran and Ngai, 2003).

Logistics strategy is about meeting customer needs through a set of decisions across various operational areas of a company, all aimed at achieving long-term profitability. As such, it's tailored to the specific context and addresses it uniquely. A logistics strategy encompasses a strategic and competitive approach that considers various contributing factors to the company's competitive response. Numerous research efforts have been undertaken in the logistics industry to pinpoint contextual variables. It is best to think of the idea of a generic logistics strategy as a framework for standardizing decision-making across a range of logistical tasks. One or more general logistics methods should be used in combination to successfully meet the needs of the consumer logistics system. A well-executed logistics strategy enhances operational efficiency within traditional business frameworks. Customer service stands out as a primary focus area for numerous companies among the various operational aspects affected. In addition to developing theoretical viewpoints on logistics strategy, logistical managers must consider the implications of the discussed categorization of logistics strategy. It is the goal of managers to find effective ways to integrate systems and processes in order to plan and execute company logistics plans (Ochego and Wycliffe, 2020).

The consequences of logistics and transportation systems on the environment, encompassing air, water, and land resources, will become more complex as they become more integrated. Supply chain management, agile production, quick market delivery, and economic globalization are all contributing to the rise in demand for multimodal transportation infrastructure and intermodal transportation services (Rondinelli and Berry, 2000).

Order Processing

The process commences with a customer placing an order and concludes when the order is delivered and finalized. Effective order processing is crucial for upholding customer satisfaction and enhancing the overall performance of the supply chain. Efficient order processing in supply chain management necessitates seamless coordination and integration among various stakeholders, including sales teams, warehouse staff, transportation providers, and customer service representatives. Order processing management encompasses the array of activities and procedures associated with handling customer orders from their initial placement to their eventual fulfillment and delivery. It entails all the necessary steps to ensure that customer orders are received accurately, processed, tracked, and fulfilled promptly (Henry et al., 2024).

Information System

The diversity of information required at various organizational levels necessitates different information systems. With the growing dependence of managerial staff on computers and information systems for decision-making, organizations employ various systems tailored to meet managerial needs. These systems include transaction processing systems (TPS), management information systems (MIS), intelligent support systems (ISS), and office automation systems (OAS) (El-Ebiary et al., 2020).

The IS community consistently faces challenges in determining where to allocate its management, research, and educational resources. Businesses must decide how to invest limited funds, researchers must prioritize which issues to explore, academic institutions must shape educational programs, and professional societies must organize conferences to address contemporary concerns (Brancheau and Wetherbe, 1987). An information system comprises, at minimum, an individual of a particular psychological disposition encountering a problem within an organizational setting, seeking evidence to arrive at a solution. This evidence is provided through a specific mode of presentation (El-Ebiary et al., 2020).

Warehousing

Warehousing encompasses the storage of physical goods or inventory in a designated warehouse or storage facility before their sale or distribution. Warehouses are responsible for securely storing and protecting products in an organized manner, enabling straightforward tracking of item locations, arrival times, storage durations, and available quantities. Small or new businesses may begin by storing their inventory at home until space becomes limited. At that point, they might choose to rent storage space, lease a warehouse, or engage third-party logistics providers for warehousing services. In e-commerce warehousing, products are kept until an online order is placed, prompting the order to be shipped directly to the consumer from the warehouse facility. In retail stores, inventory might be temporarily housed in a warehouse before being sent to a brick-and-mortar store for shipment (Lopienski, K., 2021).

In the past, warehouse operations were limited to the distribution and storage of goods or work-in-process (WIP). But as their function has evolved, warehouses now provide manufacturing, assembly, and other value-added services. Consequently, warehouses and their operations are integral to sustainable supply chains. Despite this significance, efforts to enhance sustainability in warehousing have not garnered significant attention (Bank and Murphy, 2013).

Customer service

In manufacturing environments, customer service support relies on a database that typically contains two types of service information: (1) unstructured reports documenting machine problems and their solutions, and (2) structured data related to sales, employees, and customers for everyday management tasks (Hui and Jha, 2000).

Consumer service refers to an intangible offering provided to households rather than businesses. Delivery of such service involves various elements including service providers (e.g., company personnel), equipment such as vehicles, cash registers, and electronic devices, physical facilities like buildings, customer interactions, and individual service recipients. Examples of consumer services are prevalent in various sectors such as hospitality (hotels), personal insurance, rail travel, education, healthcare, leisure activities, catering, tourism, financial services, entertainment, and home maintenance. Consumer services differ from consumer goods, which are tangible items like shoes, laptops, and smartphones. Essentially, consumer products encompass both consumer goods and consumer services. Marketing approaches for consumer services require distinct strategies compared to those for consumer goods. Moreover, consumer service is distinct from customer service, which entails the assistance and guidance provided by a company to its product users or buyers. An example of customer service is after-sales support (Sidek et al., 2022).

Packaging

It is an essential requirement for every product, enabling storage and transportation between locations. It also serves to give the product its distinctive identity. Packaging serves as the primary initial point of interaction through which a company introduces its products to consumers. While packaging traditionally serves functions like product protection and preservation, it is increasingly recognized as an added-value process. Packaging plays a vital role in multiple sectors within the food industry and extends to areas like cosmetics, manufacturing, electronics, and more, serving essential functions. Even when products are transported in bulk, they still necessitate containers to facilitate handling, transportation, stacking, storage, and distribution (Popa and Belc, 2007).

In recent decades, packaging materials, their designs, and attributes have undergone significant advancements and notable innovations. The advancement can mainly be credited to the adoption of advanced technologies in producing novel materials with unique properties, diverse packaging shapes and sizes, and the integration of scavengers into the polymer structure or packaging itself.

These scavengers function as absorbers or releasers of substances, facilitating the monitoring of the product's surrounding environment within the package. Additionally, they provide consumers with insights into any changes or contamination in storage conditions (Ait-Oubahou et al., 2019).

Inventory Planning

Inventory stands as the most significant asset for numerous organizations, often representing up to half of the company's expenditures or even half of the total capital investment. Inventory management, a crucial aspect of manufacturing and supply chain operations, involves overseeing stocks of goods. In the manufacturing process, raw materials and work-in-progress items are utilized to produce finished products, which are then either stored as inventory or sold. Additionally, some finished products may also be utilized in subsequent operations. Inventory management is a pivotal aspect of organizational management, serving as a cornerstone of supply chain management and logistics within material management systems. Depending on the organization's goals, warehouses may need inventories to meet customer or humanitarian needs. Effective control of inventory is essential for achieving operational success and enhancing organizational performance (Munyaka and Yadavalli, 2022).

Inventory planning involves predicting and determining the optimal quantity of a product to order to effectively meet future sales demands. While seemingly straightforward, inventory planning is critical for preventing sales and fulfillment issues and maintaining high levels of customer satisfaction. Over the past five decades, forecasting and planning for inventory management have garnered significant focus from the Operational Research (OR) community due to its profound impact on decision-making, spanning from the strategic to the operational levels within organizations (Syntetos et al., 2009).

Hypotheses Development

Rahman et al. (2022) Explored the impact of the Internet of Things, big data, smart factories, cyber-physical systems, and Industry 4.0 on the performance of the freight logistics industry in Canada and Bangladesh, both of which are service-oriented nations. The research employed a cross-sectional quantitative methodology to identify distinctions among subgroups within the samples from both nations. Through selective sampling, networking, and relationship-building efforts, 210 survey questionnaires were obtained from employees working in logistics companies. Examination of the data utilizing smart partial least squares-structural equation modeling (PLS-SEM) revealed that Industry 4.0 significantly enhanced and progressed the efficiency of the services sector in both economies.

Through a systematic review of 115 publications published between 2012 and 2020, Sun et al. (2022) offered an elucidation of the impact of Industry 4.0 technologies on sustainable logistics. Its goal was to provide quantitative insights and comprehensive summaries of current and potential research areas in sustainable logistics within the Industry 4.0 era. The findings indicate that Industry 4.0 technologies have the potential to enhance the social impact, environmental sustainability, and economic efficiency of logistics organizations.

Chhabra and Kr Singh (2022) identified sixteen barriers to the adoption of green logistics in the Indian manufacturing sector, placing them within the framework of Industry 4.0 and the circular economy. Expert information was obtained through a questionnaire. The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method was utilized to evaluate the extent of influence and interconnections among barriers, enabling the classification of barriers into categories based on their causes and consequences. Furthermore, a sensitivity analysis was performed to confirm the results. These results are expected to assist industrial firms in devising strategies for integrating green logistics, thereby aiding them in achieving long-term sustainability goals.

Mnyakin (2023) Performed an extensive review of literature concerning the utilization of cloud computing, Internet of Things (IoT), and artificial intelligence (AI) in smart transportation systems. The investigation uncovered diverse AI applications such as demand prediction, traffic control, proactive maintenance, driver support, and autonomous vehicles. Similarly, IoT enables real-time fleet management, smart parking, traffic monitoring, networked vehicles, and remote diagnostics. Cloud computing facilitates predictive maintenance, mobility-as-a-service, data analytics, scalable infrastructure, and vehicle-to-cloud connectivity, streamlining these processes, by combining these technologies, a comprehensive smart transportation system may be created, increasing the general effectiveness of transportation networks.

Khan et al. (2024) examined how Industry 4.0 technologies were being implemented in the transportation sector and how this was improving sustainability. To determine how Industry 4.0 was being applied and what its effects were in the transportation sector in relation to sustainability, a thorough assessment of the literature was carried out. The outcomes demonstrated how Industry 4.0 technology had greatly aided transportation sector sustainability. Blockchain innovation, The World Wide Web (WWW). The most common technologies employed in the transportation sector include robotics and sensors, big data analytics (BDA), RFID, GPS, and radio frequency identification (RFID). Also, the utilization of Industry 4.0 technology held significant promise in mitigating transportation and logistics interruptions and enhancing sustainable performance.

After discussing what previous studies have covered, the researcher can develop the first hypothesis, as follows:

H1: There is a significant relationship between Industry 4.0 Capabilities and Transportation Logistics Strategy

Through the efficiency of the digital supply chain, the integration of Industry 4.0 capabilities into the transportation logistics strategy provided a potent synergy that significantly boosted operational performance, cost-effectiveness, and customer happiness. Organizations could achieve a competitive advantage in the dynamic and quickly changing business climate of today by optimizing transportation logistics operations, improving visibility and transparency, and utilizing sophisticated technology and data-driven approaches. When digital supply chain efficiency was paired with Industry 4.0 capabilities, it became a strategic enabler for businesses looking to prosper in the digital era.

Dalenogare et al. (2018) explored the potential impacts of Industry 4.0 technologies on industrial performance by conducting regression analysis. This analysis investigated the relationship between the expected benefits of different Industry 4.0 technologies in terms of operations, side effects, and products using secondary data obtained from a comprehensive study encompassing 27 industries, which comprised 2225 Brazilian enterprises. The results indicated a positive association between certain technologies and industrial performance, although the anticipated benefits of other technologies were not yet evident, likely due to their early adoption stages.

By dividing Industry 4.0 technologies into front-end and base categories, Frank et al. (2019) sought to assess how the adoption patterns of these technologies impacted manufacturing entities. A survey was conducted across 92 industries to investigate the incorporation of these technologies. Data collected underwent analysis through cluster analysis and independence tests. The results suggested that the efficiency of organizational operations was significantly influenced by the adoption of smart manufacturing practices.

Joshi and Sharma (2022) Utilizing survey data comprising 202 valid responses, the study investigated the relationship between Industry 4.0 technologies (I4TEs) and digital supply chains (DSCs). Confirmatory factor analysis (CFA) and partial least squares structural equation modeling (PLS-SEM) were employed to validate the constructs and examine the mediating role of digital supply chains. The findings revealed a positive impact of Industry 4.0 technologies on long-term enterprise performance, with digital supply chains fully mediating the relationship between Industry 4.0 technologies and sustainable performance.

In their analysis of the COVID-19 pandemic, Tortorella et al. (2023) focused on the utilization of Industry 4.0 technologies and the intermediary function of resilience capacities within healthcare supply chains in Brazil and India. It involved 179 practitioners from various stages of the healthcare supply chain. Multivariate data techniques were employed to analyze the collected data. The results indicate that resilience capacities have mitigated the influence of Industry 4.0 technologies on the efficiency of healthcare supply chains, particularly since the onset of the COVID-19 pandemic.

After discussing what previous studies have covered, the researcher can develop the second hypothesis, as follows:

H2: There is a significant relationship between Industry 4.0 Capabilities and Digital Supply Chain Efficiency

The objective of Khan et al. (2023) was to investigate the research explored how supply chain traceability (SCT) and digital platforms could improve comprehensive data and streamline inventory management (EIM). Partial least squares structural equation modeling (PLS-SEM) techniques and SmartPLS3 software were employed for analysis. Data from Pakistani supply chain (SC) experts were gathered through the snowball sampling technique facilitated by software. The study's findings regarding the impact of supply chain traceability (SCT) on comprehensive information and efficient inventory management (EIM) indicated that successful management of information and inventory through digital platforms and supply chain traceability relied significantly on transparency.

To achieve higher overall supply chain flexibility, Gupta et al. (2019) used Organization Information Processing Theory (OIPT) to clarify the relationship between smart supply chains and information system flexibility. It broadened the application of OIPT theory and provided managers with useful advice in an effort to improve flexibility in dynamic environments. The research empirically assessed the theoretical framework using Structural Equation Modeling and the Partial Least Square Method. It found a significant correlation between information system agility and intelligent supply chain components, based on a study involving 150 participants. Moreover, the study illustrated a positive association between the flexibility components of information systems and the attributes of smart supply chain management, resulting in enhanced supply chain flexibility.

García-Arca and Carlos (2008) aimed to investigate current packaging methodologies from a supply chain viewpoint and propose sustainable packaging alternatives to mitigate the environmental footprint of supply chain activities at Midas Safety. The approach involved conducting interviews with a glove manufacturing and exporting firm. Qualitative research techniques such as semi-structured open-ended interviews and observations were employed to grasp Midas Safety's present procedures in packaging and supply chain management, as well as their strategies for integrating sustainability. The findings highlighted the significance of both internal elements, such as the adoption of alternative packaging materials, and external factors, such as the accessibility of local suppliers, in fostering the effective implementation of sustainable packaging strategies.

After discussing what previous studies have covered, the researcher can develop the third hypothesis, as follows:

H3: There is a significant relationship between Digital Supply Chain Efficiency and Transportation Logistics Strategy

The hypotheses developed should be tested by collecting data and analyzing it using suitable statistical techniques. The following section discusses how data was collected as well as the target population of respondents' and how they had been reached to get their responses.

3. Research Methodology

The study utilizes an illustrative descriptive design to depict the relationship among research variables. The target population consists of companies of courier services located in Egypt, like DHL, Aramex, FedEx, Bosta Sportation, and several other companies with large business volumes. Primary data collection was collected via questionnaires directed to employees working in the supply chain department of such companies. Sample is collected with convenience non-random sampling frame since there is no sampling frame for employees working in companies of the shipping and transportation sector.

Primary data were collected through a questionnaire, with participants asked to rate their agreement with statements on a Likert scale ranging from 1 to 5. Due to the absence of a specific sampling frame and the large number of companies in Egypt, the sample size was determined using the 95% confidence level formula outlined by Saunder and Townsend (2016). This calculation determined a minimum of 385 respondents required for an infinite population. Despite distributing 700 surveys, a response rate of 65.86% was achieved, resulting in 461 responses collected. Among these, 412 responses were considered valid with no missing information.

The research variables are presented as: **Independent Variable** is Industry 4.0 Capabilities (Industrial Internet of Things, Big Data, Cloud Computing, Augmented Reality, System Integration, Simulation, and Additive Manufacturing). **Dependent Variable** is Transportation Logistics Strategy (Order Processing, Information System, Warehousing, Customer Service, Packaging, and Inventory Planning). **Mediator** is Digital Supply Chain Efficiency. The conceptual framework model was developed as illustrated in Figure 1.

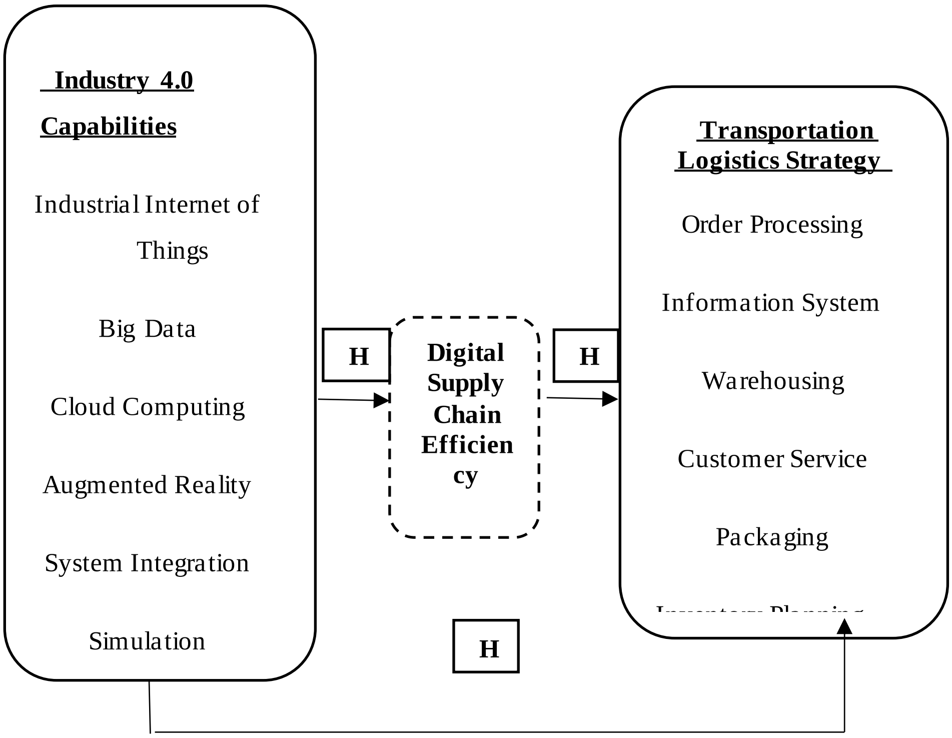

Figure 1: Research Framework
Source: Designed by the Researcher

The questionnaire was used to measure the relationship between Industry 4.0, which is measured by 7 dimensions (Industrial Internet of Things, Big Data, Cloud Computing, Augmented Reality, System Integration, Simulation, and Additive Manufacturing), and Transportation Logistics Strategy, which is measured by 6 dimensions (Order Processing, Information System, Warehousing, Customer Service, Packaging, and Inventory Planning) through the mediation role of digital supply chain efficiency.

The measurements statements of Industrial Internet of Things, Big Data, Cloud Computing, Augmented Reality, and Additive Manufacturing was adopted from the study of Marinagi et al. (2023), System Integration was measured by 2 statements adopted from Geleilate et al. (2021) and Simulation was measured by 3 statements adopted from Efthymiou and Ponis (2021), Order Processing was measured by 3 statements adopted from Amaresan (2021), Information System was measured by 4 statements from the study of Carreón et al. (2015), Warehousing was measured by 3 statements adopted from Alsqour and Owoc (2015), Customer Service was measured by 3 statements from the study of Phau and Ferguson (2013), Packaging was measured by 4 statements adopted from Williams et al. (2012), and Inventory Planning was measured by 3 statements adopted from Muhande and Iravo (2017).

Table 1 shows the descriptive analysis for the respondent profiles. 53.7% of the entire sample, or the bulk of responders, are between the ages of 18 and less than 25. As 70.6% of the entire sample, respondents overwhelmingly identify as men. Graduates make up the majority of respondents (54.1%). The remaining 26.2% of the sample is made up of students.

Table 1: Descriptive Analysis for Respondents Profile

Item	Category	Frequency N=412	Percent %
Gender	Male	291	70.6
	Female	121	29.3
Income Level	Less than 5000	100	24.3
	5000- less than 10000	265	64.3
	10000- less than 15000	38	9.2
	15000 or above	19	4.6
Bachelor's Degree	Students	108	26.2
	Graduated	223	54.1
	Master's Degree	51	12.4
	Doctorate Degree	30	7.3
Age	18 -25	221	53.67
	26-40	124	30.09
	41- 60	34	8.25
	60+	33	8.00

Source: Statistical Package for Social Sciences (SPSS)

4. FINDING AND RESULTS

Descriptive Analysis for Research Variables

Table 2 presents a range of statistical measures including the lowest and highest values, as well as averages and standard deviations for various variables. Industrial Internet exhibited a mean of 3.25 with a standard deviation of 1.194, while Big Data showed a mean of 3.24 and a standard deviation of 1.175. Cloud Computing displayed a mean of 3.23 and a standard deviation of 1.175, whereas Augmented Reality presented a mean of 3.22 with a slightly higher standard deviation of 1.382. System Integration showcased a mean of 2.88 and a standard deviation of 1.192, while Simulation demonstrated a mean of

2.84 with a standard deviation of 1.146. Additive Manufacturing revealed a mean of 3.07 and a standard deviation of 1.206, and Digital Supply Chain Efficiency displayed a mean of 3.42 with a standard deviation of 1.201. Order Processing exhibited a mean of 3.45 and a standard deviation of 1.214, while Information System showed a mean of 3.66 with a standard deviation of 1.190. Warehousing presented a mean of 3.62 and a standard deviation of 1.175, while Customer Service showcased a mean of 3.66 with a slightly higher standard deviation of 1.233. Packaging exhibited a mean of 3.73 and a lower standard deviation of 1.123, and finally, Inventory Planning displayed a mean of 3.70 with a standard deviation of 1.188. These statistical measures offer valuable insights into the central tendencies and variability of the variables within the dataset.

Table 2: Descriptive Analysis for the Research Variables

	N	Minimum	Maximum	Mean	Std. Deviation
Industrial Internet	412	1	5	3.25	1.194
Big Data	412	1	5	3.24	1.175
Cloud Computing	412	1	5	3.23	1.175
Augmented Reality	412	1	5	3.22	1.382
System Integration	412	1	5	2.88	1.192
Simulation	412	1	5	2.84	1.146
Additive Manufacturing	412	1	5	3.07	1.206
Digital Supply Chain Efficiency	412	1	5	3.42	1.201
Order Processing	412	1	5	3.45	1.214
Information System	412	1	5	3.66	1.190
Warehousing	412	1	5	3.62	1.175
Customer Service	412	1	5	3.66	1.233
Packaging	412	1	5	3.73	1.123
Inventory Planning	412	1	5	3.70	1.188

Source: Statistical Package for Social Sciences (SPSS)

The Measurement Model

The results of the Confirmatory Factor Analysis (CFA) indicate a robust model fit based on several fit indices. The Chi-square/df ratio, at 0.000, falls well below the excellent threshold of 2, suggesting an excellent fit. Additionally, the p-value of 0.915 exceeds the 0.05 threshold, indicating a non-significant difference between the observed and expected covariance matrices. The Goodness-of-Fit Index (GFI) of 0.899 and Adjusted Goodness-of-Fit Index (AGFI) of 0.963 both surpass the recommended threshold of 0.90, affirming a good model fit. Furthermore, the Normed Fit Index (NFI), Tucker-Lewis Index (TLI), and Comparative Fit Index (CFI) all exhibit values exceeding 0.90, with NFI and TLI reaching 0.999 and CFI slightly below 0.021.

These values indicate a high level of model fit, with TLI meeting the recommended threshold of 0.95. The Root Mean Square Residual (RMR) of 0.001 is below the acceptable threshold of 0.08, suggesting a satisfactory fit. Additionally, the Root Mean Square Error of Approximation (RMSEA) of 0.972 is well below the desired threshold of 0.05, further supporting the adequacy of the model fit. Overall, the CFA results indicate a strong fit between the proposed model and the observed data, providing confidence in the validity of the structural model. For a comprehensive presentation of these indicators derived from the CFA, alongside a comparative analysis against recommended thresholds, Table 4 in this study provides detailed insights.

Figure 2 illustrates the execution of confirmatory factor analysis, portraying factor loadings through prominent arrows. The arrows signify strong factor loadings, with values exceeding the 0.4 threshold. To delve into the specific numerical values of these factor loadings, readers are directed to Table 3 for a detailed examination.

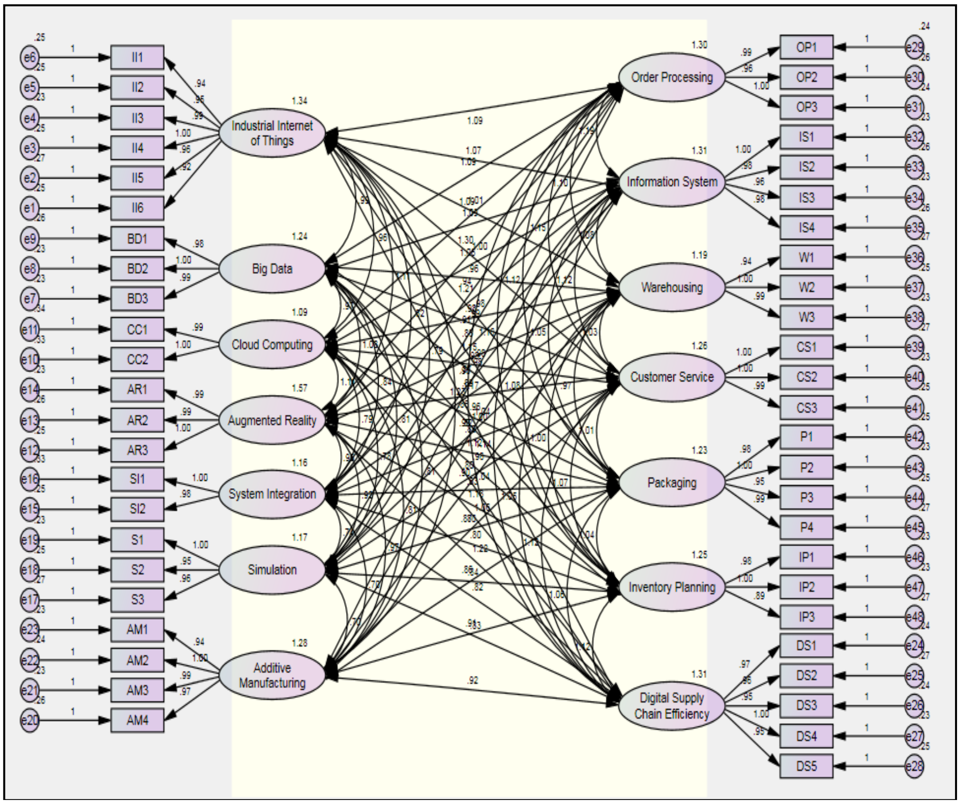

Figure 2: CFA for the Measurement Model

Source: AMOS

Table 3 offers a thorough display of the factor loadings (FL), indicating the strength of item loadings onto their corresponding variables. Notably, all factor loadings consistently exceed or equal the crucial threshold of 0.40, affirming the robust validity of the examined constructs. Additionally, it is crucial to underscore that the associated p-values uniformly dip below the pre-established threshold of 0.05, underscoring the substantive significance of the statements concerning their connection to the respective constructs.

Table 3: Item Loading after Confirmatory Factor Analysis

			Estimate	S.E.	C.R.	P
II6	<---	Industrial Internet of Things	.917	.030	30.867	***
II5	<---	Industrial Internet of Things	.956	.031	30.966	***
II4	<---	Industrial Internet of Things	1.000			
II3	<---	Industrial Internet of Things	.993	.030	32.766	***
II2	<---	Industrial Internet of Things	.955	.030	31.520	***
II1	<---	Industrial Internet of Things	.940	.030	31.257	***
BD3	<---	Big Data	.986	.032	31.081	***
BD2	<---	Big Data	1.000			
BD1	<---	Big Data	.984	.033	30.268	***
CC2	<---	Cloud Computing	1.000			
CC1	<---	Cloud Computing	.990	.041	23.892	***
AR3	<---	Augmented Reality	1.000			
AR2	<---	Augmented Reality	.986	.029	33.797	***
AR1	<---	Augmented Reality	.990	.029	34.647	***
SI2	<---	System Integration	.982	.044	22.435	***
SI1	<---	System Integration	1.000			
S3	<---	Simulation	.961	.034	27.892	***
S2	<---	Simulation	.945	.033	28.271	***
S1	<---	Simulation	1.000			
AM4	<---	Additive Manufacturing	.967	.032	30.597	***
AM3	<---	Additive Manufacturing	.987	.031	31.575	***
AM2	<---	Additive Manufacturing	1.000			
AM1	<---	Additive Manufacturing	.942	.031	30.890	***
DS1	<---	Digital Supply Chain	.973	.030	32.590	***

			Estimate	S.E.	C.R.	P
		Efficiency				
DS2	<---	Digital Supply Chain Efficiency	.958	.031	31.360	***
DS3	<---	Digital Supply Chain Efficiency	.949	.029	32.225	***
DS4	<---	Digital Supply Chain Efficiency	1.000			
DS5	<---	Digital Supply Chain Efficiency	.948	.030	31.711	***
OP1	<---	Order Processing	.993	.031	32.352	***
OP2	<---	Order Processing	.962	.031	31.416	***
OP3	<---	Order Processing	1.000			
IS1	<---	Information System	1.000			
IS2	<---	Information System	.976	.031	31.864	***
IS3	<---	Information System	.964	.030	32.493	***
IS4	<---	Information System	.979	.031	31.684	***
W1	<---	Warehousing	.942	.033	28.571	***
W2	<---	Warehousing	1.000			
W3	<---	Warehousing	.986	.033	30.189	***
CS1	<---	Customer Service	1.000			
CS2	<---	Customer Service	.997	.032	30.774	***
CS3	<---	Customer Service	.992	.033	30.079	***
P1	<---	Packaging	.978	.032	30.896	***
P2	<---	Packaging	1.000			
P3	<---	Packaging	.952	.031	30.258	***
P4	<---	Packaging	.992	.032	30.529	***
IP1	<---	Inventory Planning	.984	.031	31.487	***
IP2	<---	Inventory Planning	1.000			
IP3	<---	Inventory Planning	.886	.031	28.507	***

Source: AMOS Output

Verification of Assumptions

The Kolmogorov-Smirnov test, commonly employed to evaluate normality, was utilized to assess the distribution of data in Table 4. It was observed that for each variable, the calculated P-values were less than 0.05, indicating departure from normality. Consequently, an informal assessment was conducted to evaluate approximate normality, the outcomes of which are summarized in Table 4.

Table 4: Normality Testing for Research Variables

Research Variables	Kolmogorov-Smirnov[a]			Skewness		Kurtosis	
	Statistic	df	Sig	Statistic	Std. Error	Statistic	Std. Error
Industrial Internet	.224	412	.000	-.382	.120	-.772	.240
Big Data	.207	412	.000	-.259	.120	-.836	.240
Cloud Computing	.231	412	.000	-.416	.120	-.722	.240
Augmented Reality	.242	412	.000	-.389	.120	-1.142	.240
System Integration	.223	412	.000	-.007	.120	-.648	.240
Simulation	.250	412	.000	-.053	.120	-.507	.240
Additive Manufacturing	.190	412	.000	-.006	.120	-.760	.240
Digital Supply Chain Efficiency	.211	412	.000	-.152	.120	-1.252	.240
Order Processing	.207	412	.000	-.167	.120	-1.274	.240
Information System	.217	412	.000	-.223	.120	-1.415	.240
Warehousing	.191	412	.000	-.329	.120	-.927	.240
Customer Service	.224	41	.000	-.306	.12	-	.24

Research Variables	**Kolmogorov-Smirnov[a]**			**Skewness**		**Kurtosis**	
	Statistic	df	Sig	Statistic	Std. Error	Statistic	Std. Error
		2			0	1.285	0
Packaging	.225	412	.000	-.226	.120	-1.322	.240
Inventory Planning	.222	412	.000	-.359	.120	-1.093	.240

Source: Statistical Package for Social Sciences (SPSS)

By examining the Variance Inflation Factor (VIF) values presented in the table, it is evident that they are all below 5 for the variables. This suggests that there is no issue of Multicollinearity in our multiple linear regression model, as all VIF values are within an acceptable range.

Table 5: VIF Values for Research Variables

Research variables	**VIF**
Industrial Internet	3.508
Big Data	3.468
Cloud Computing	3.803
Augmented Reality	4.178
System Integration	2.132
Simulation	2.133
Additive Manufacturing	2.289

Source: Statistical Package for Social Sciences (SPSS)

Testing the Research Hypotheses

Structural Equation Modeling (SEM) analysis was utilized to evaluate the influence of the research variables, chosen for its impartiality and independence from data normality distribution, as evidenced in Table 6 the SEM results, delineated below, provide valuable insights into the relationships between the variables:

Hypothesis 1 delves into the association between Industry 4.0 Capabilities and Transportation Logistics Strategy. Within this hypothesis, six sub-hypotheses scrutinize distinct facets of this relationship. Firstly, concerning the significant relationship between Industry 4.0 Capabilities and Order Processing, Cloud Computing, Augmented Reality, System Integration, and Simulation demonstrate a significant positive effect on Order Processing, with p-values below 0.05 and corresponding estimates of 0.255, 0.194, 0.097, and 0.057, respectively. Conversely, Industrial Internet of Things, Big Data, and Additive Manufacturing show insignificant effects on Order Processing, as their p-values exceed 0.05. Secondly, investigating the link between Industry 4.0 Capabilities and Information System, Big Data and Cloud Computing exhibit significant positive effects on Information System, with p-values below 0.05 and corresponding estimates of 0.179 and 0.526, respectively. Conversely, other factors including Industrial Internet of Things, Augmented Reality, System Integration, Simulation, and Additive Manufacturing show insignificant effects on Information System, as their p-values exceed 0.05.

Moving on to the third sub-hypothesis, examining the relationship between Industry 4.0 Capabilities and Warehousing, Industrial Internet of Things, Cloud Computing, Augmented Reality, System Integration, and Additive Manufacturing display significant positive effects on Warehousing, with p-values below 0.05 and corresponding estimates of 0.108, 0.363, 0.136, 0.182, and 0.119, respectively. Conversely, Big Data and Simulation show insignificant effects on Warehousing, as their p-values exceed 0.05. In the fourth sub-hypothesis, focusing on the association between Industry 4.0 Capabilities and Customer Service, Cloud Computing, Augmented Reality, and System Integration exhibit significant positive effects on Customer Service, with p-values below 0.05 and corresponding estimates of 0.311, 0.127, and 0.102, respectively. However, Industrial Internet of Things, Big Data, Simulation, and Additive Manufacturing show insignificant effects on Customer Service, as their p-values exceed 0.05.

In the fifth sub-hypothesis, exploring the connection between Industry 4.0 Capabilities and Packaging, Cloud Computing and Additive Manufacturing manifest significant positive effects on Packaging, with p-values below 0.05 and corresponding estimates of 0.323 and 0.085, respectively. Conversely, Industrial Internet of Things, Big Data, Augmented Reality, System Integration, and Simulation show insignificant effects on Packaging, as their p-values exceed 0.05. Lastly, investigating the significant relationship between Industry 4.0 Capabilities and Inventory Planning in the sixth sub-hypothesis, Cloud Computing, Augmented Reality, and Additive Manufacturing demonstrate significant positive effects on Inventory Planning, with p-values below 0.05 and corresponding estimates of 0.248, 0.171, and 0.112, respectively. In contrast, Industrial Internet of Things, Big Data, System Integration, and Simulation show insignificant effects on Inventory Planning, as their p-values exceed 0.05.

Hypothesis 2 investigates the relationship between Industry 4.0 Capabilities and Digital Supply Chain Efficiency. Notably, the analysis reveals significant positive effects of Big Data, Cloud Computing, Augmented Reality, and Additive Manufacturing on Digital Supply Chain Efficiency, as indicated by p-values below 0.05 and corresponding estimates of 0.130, 0.547, 0.213, and 0.094, respectively. Conversely, Industrial

Internet of Things, System Integration, and Simulation demonstrate insignificant effects on Digital Supply Chain Efficiency, with p-values exceeding 0.05. These findings underscore the significant impact of specific Industry 4.0 Capabilities on enhancing Digital Supply Chain Efficiency, while highlighting the varying degrees of influence across different technological domains.

Hypothesis 3 explores the relationship between Digital Supply Chain Efficiency and Transportation Logistics Strategy. Analysis reveals a significant positive effect of Digital Supply Chain Efficiency on several components of Transportation Logistics Strategy. Notably, Digital Supply Chain Efficiency significantly influences Order Processing, Customer Service, Packaging, and Inventory Planning, as indicated by p-values below 0.05 and corresponding estimates of 0.354, 0.344, 0.182, and 0.314, respectively. However, there is an insignificant effect of Digital Supply Chain Efficiency on Information System and Warehousing, with p-values exceeding 0.05. These findings underscore the significant role of Digital Supply Chain Efficiency in enhancing specific aspects of Transportation Logistics Strategy, while highlighting variations in its impact across different components.

For Hypothesis 6, which posits that Digital Supply Chain Efficiency acts as a mediator between Industry 4.0 Capabilities and Transportation Logistics Strategy, the previous findings reveal significant effects of Big Data, Cloud Computing, Augmented Reality, and Additive Manufacturing on Digital Supply Chain Efficiency. Moreover, Digital Supply Chain Efficiency demonstrates significant effects on Order Processing, Customer Service, Packaging, and Inventory Planning. Thus, Digital Supply Chain Efficiency potentially mediates the relationship between these Industry 4.0 Capabilities and various components of Transportation Logistics Strategy.

Notably, Digital Supply Chain Efficiency partially mediates the relationship between Cloud Computing, Augmented Reality, and Order Processing, as these effects remain significant in the presence of Digital Supply Chain Efficiency. Conversely, it fully mediates the relationship between Big Data, Additive Manufacturing, and Order Processing, as these effects become insignificant in the presence of Digital Supply Chain Efficiency. Similarly, Digital Supply Chain Efficiency partially mediates the relationship between Cloud Computing, Augmented Reality, and Customer Service, while fully mediating the relationship between Big Data, Additive Manufacturing, and Customer Service.

Additionally, it partially mediates the relationship between Cloud Computing, Additive Manufacturing, and Packaging, while fully mediating the relationship between Big Data, Augmented Reality, and Packaging. Finally, Digital Supply Chain Efficiency partially mediates the relationship between Cloud Computing, Augmented Reality, Additive Manufacturing, and Inventory Planning, while fully mediating the relationship between Big Data and Inventory Planning. These observations underscore the complex interplay between Industry 4.0 Capabilities, Digital Supply Chain Efficiency, and various aspects of Transportation Logistics Strategy, highlighting both partial and full mediation effects in different scenarios.

Table 6: SEM Analysis for the Research Variables

			Estimate	P	
Digital Supply Chain Efficiency	<---	Industrial Internet of Things	.076	.119	.850
Digital Supply	<---	Big Data	.130	.042	

			Estimate	P	
Chain Efficiency					
Digital Supply Chain Efficiency	<---	Cloud Computing	.547	***	
Digital Supply Chain Efficiency	<---	Augmented Reality	.213	***	
Digital Supply Chain Efficiency	<---	System Integration	-.043	.342	
Digital Supply Chain Efficiency	<---	Simulation	.011	.799	
Digital Supply Chain Efficiency	<---	Additive Manufacturing	.094	.015	
Order Processing	<---	Industrial Internet of Things	.034	.299	
Order Processing	<---	Big Data	.057	.176	
Order Processing	<---	Cloud Computing	.255	.002	
Order Processing	<---	Augmented Reality	.194	***	
Order Processing	<---	System Integration	.097	.003	.968
Order Processing	<---	Simulation	.057	.049	
Order Processing	<---	Additive Manufacturing	.045	.094	
Order Processing	<---	Digital Supply Chain Efficiency	.354	***	
Information System	<---	Industrial Internet of Things	.078	.082	
Information System	<---	Big Data	.179	.002	
Information System	<---	Cloud Computing	.526	***	
Information System	<---	Augmented Reality	.095	.080	.879
Information System	<---	System Integration	.050	.246	
Information System	<---	Simulation	.033	.398	
Information System	<---	Additive Manufacturing	.023	.532	
Information System	<---	Digital Supply Chain	.085	.259	

			Estimate	P	
		Efficiency			
Warehousing	<---	Industrial Internet of Things	.108	.020	
Warehousing	<---	Big Data	.001	.984	
Warehousing	<---	Cloud Computing	.363	.002	
Warehousing	<---	Augmented Reality	.136	.015	
Warehousing	<---	System Integration	.182	***	.846
Warehousing	<---	Simulation	.045	.275	
Warehousing	<---	Additive Manufacturing	.119	.002	
Warehousing	<---	Digital Supply Chain Efficiency	.071	.355	
Customer Service	<---	Industrial Internet of Things	.033	.504	
Customer Service	<---	Big Data	.046	.462	
Customer Service	<---	Cloud Computing	.311	.011	
Customer Service	<---	Augmented Reality	.127	.031	
Customer Service	<---	System Integration	.102	.031	.827
Customer Service	<---	Simulation	-.002	.963	
Customer Service	<---	Additive Manufacturing	.035	.377	
Customer Service	<---	Digital Supply Chain Efficiency	.344	***	
Packaging	<---	Industrial Internet of Things	.059	.242	
Packaging	<---	Big Data	.110	.087	
Packaging	<---	Cloud Computing	.323	.010	
Packaging	<---	Augmented Reality	.107	.076	
Packaging	<---	System Integration	.084	.084	.789
Packaging	<---	Simulation	.038	.385	
Packaging	<---	Additive Manufacturing	.085	.038	
Packaging	<---	Digital Supply Chain Efficiency	.182	.026	

			Estimate	P	
Inventory Planning	<---	Industrial Internet of Things	-.006	.892	
Inventory Planning	<---	Big Data	.097	.108	
Inventory Planning	<---	Cloud Computing	.248	.034	
Inventory Planning	<---	Augmented Reality	.171	.003	
Inventory Planning	<---	System Integration	-.020	.669	.837
Inventory Planning	<---	Simulation	.076	.069	
Inventory Planning	<---	Additive Manufacturing	.112	.004	
Inventory Planning	<---	Digital Supply Chain Efficiency	.314	***	

Source: AMOS Output

The model fit indices, including CMIN/DF (1.007), GFI (0.910), CFI (0.999), AGFI (0.895), and RMSEA (0.004), all fall within acceptable ranges. Figure 3 visually represents the SEM model that was employed to analyze the impact of the research model.

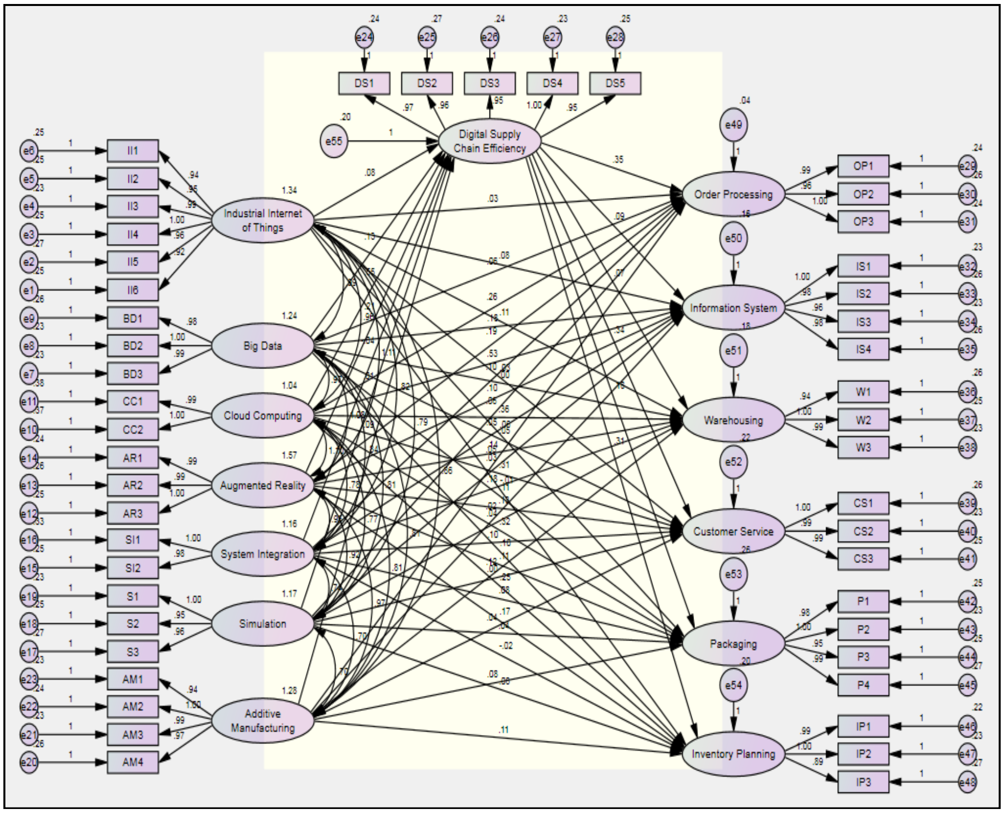

Figure 3: SEM for the Research Variables

Source: AMOS

5. Research Discussion and Conclusion

The current study investigates how Industry 4.0 Capabilities (Industrial Internet of Things, Big Data, Cloud Computing, Augmented Reality, System Integration, Simulation, and Additive Manufacturing) relate to Transportation Logistics Strategy components such as (Order Processing, Information Systems, Warehousing, Customer Service, Packaging, and Inventory Planning), with a focus on the mediating role of digital supply chain efficiency.

Most studied Industry 4.0 Capabilities including (Big Data, Cloud Computing, Augmented Reality, and Additive

Manufacturing) were found to have positive significant effects on digital supply chain efficiency. Accordingly, the adopted result is consistent with the investigation of previous studies (Tortorella et al., 2023, Joshi and Sharma, 2022, Dalenogare et al., 2018, and Frank et al., 2019). But studied Industry 4.0 Capabilities (Industrial Internet of Things, Simulation, System Integration) were found to have insignificant effects on digital supply chain efficiency. So, there is a significant influence of Industry 4.0 Capabilities, and Digital Supply Chain Efficiency is partially supported. This means that policymakers should invest in digital infrastructure, regulatory frameworks, and skills development to integrate Industry 4.0 capabilities into supply chain operations, promoting innovation and inclusivity.

Based on the previous results, most studied Industry 4.0 Capabilities including (cloud computing, augmented reality, system integration and simulation) were found to have positive significant effects on order Processing, but (industrial internet of things, big data and additive manufacturing) were found to have insignificant effects on order Processing and there is a significant influence between Industry 4.0 Capabilities (big data and cloud computing) on information system. but (industrial internet of things, additive manufacturing, augmented reality, system integration and simulation) were found to have insignificant effects on information system. Industry 4.0 Capabilities including (cloud computing, Augmented Reality, system Integration and simulation) were found to have positive significant effects on Warehousing, but (Industrial Internet of Things, Augmented Reality, Additive Manufacturing, Augmented Reality, System Integration and Simulation) were found to have insignificant effects on Warehousing. there is a significant influence between Industry 4.0 Capabilities (System

Integration, Augmented Reality and Cloud Computing) on Customer Service.

Industrial internet of things, additive manufacturing, augmented reality, system integration and Simulation were found to have insignificant effects on customer service. there is a significant influence between Industry 4.0 Capabilities (additive manufacturing and cloud computing) on Packaging, but (industrial internet of things, big data, augmented reality, simulation and system integration) were found to have insignificant effects on Packaging. there is a significant influence between Industry 4.0 Capabilities (augmented reality, additive manufacturing and cloud computing) on inventory planning, but (industrial internet of things, additive manufacturing, system integration, simulation and big data) were found to have insignificant effects on Inventory Planning.

There are some studies, which are considered consistent with these results (Mnyakin 2023, Khan et al. 2024, Rahman et al. 2022, and Sun et al. 2022). So, there is a significant influence of Industry 4.0 Capabilities and transportation logistics strategy " is partially supported, according to previous results. Policymakers should integrate Industry 4.0 capabilities into digital supply chain operations, enhancing efficiency in order processing, information systems, warehousing, customer service, packaging, and inventory planning, thereby driving competitiveness and improving digital supply chain efficiency.

Most studied Digital Supply Chain Efficiency were found to have positive significant effects on Inventory Planning, Packaging, Customer Service and Order Processing and were found to have insignificant effects on Warehousing. Based on the previous results, there is a significant relationship between Digital Supply Chain Efficiency and Transportation Logistics Strategy" is fully supported, according to previous results, there are some studies, which consistent with these results (García-

Arca and Carlos, 2008, Khan et al., 2023, Gupta et al., 2019). Policymakers should prioritize digital supply chain efficiency improvements in inventory planning, packaging, customer service, and order processing, while addressing inefficiencies in warehousing through automation and robotics strategies.

6. Research Recommendation

Certainly, here are some suggestions to improve the correlation between Industry 4.0 Capabilities (comprising Industrial Internet of Things, Big Data, Cloud Computing, Augmented Reality, System Integration, Simulation, and Additive Manufacturing) and Transportation Logistics Strategy (covering Order Processing, Information System, Warehousing, Customer Service, Packaging, and Inventory Planning) by leveraging the mediating role of digital supply chain efficiency.

To optimize its transportation logistics strategy, a shipping company should conduct thorough cost-benefit analyses to prioritize investments in Industry 4.0 capabilities such as Industrial Internet of Things, Big Data, Cloud Computing, Augmented Reality, System Integration, Simulation, and Additive Manufacturing, while considering scalability and long-term sustainability. Investing in robust integration platforms to facilitate seamless data flow, adopting advanced simulation tools for scenario planning, and exploring additive manufacturing for decentralized production can unlock efficiency, agility, and competitiveness. Prioritizing scalable information systems leveraging Big Data analytics and Cloud Computing can enhance real-time visibility and decision-making, while investments in reliable tracking systems, effective communication channels, and streamlined customer service operations can improve customer satisfaction.

Continuous improvement through feedback mechanisms and a commitment to addressing customer needs ensures ongoing enhancement of service quality and operational efficiency

In conclusion, it underscores the significance of enhancing digital supply chain efficiency through the utilization of advanced analytics, IoT sensors, and blockchain technology. This enhancement will result in improved visibility, traceability, and responsiveness, empowering businesses to attain agility and competitiveness in transportation logistics. The incorporation of Industry 4.0 capabilities, encompassing Industrial Internet of Things, Big Data, Cloud Computing, Augmented Reality, System Integration, Simulation, and Additive Manufacturing, will be seamlessly integrated into diverse logistics operations.

7. LIMITATION AND FUTURE RESEARCHERS SUGGESTION

Although this study provides significant insights into the interaction among Industry 4.0 capabilities, digital supply chain efficiency, and transportation logistics strategy, it's important to recognize specific constraints and suggest directions for future investigation.

Sample Size and Scope: The study's limitations could stem from the size and scope of the sample utilized. Subsequent research endeavors might consider enlarging the sample size or incorporating data from a wider array of industries to improve the applicability of the results.

Data Collection Methods: The reliance on specific data collection methods, such as surveys or case studies, may have introduced bias or limitations in capturing the full complexity of Industry 4.0 adoption in transportation logistics. Future studies could employ mixed-method approaches or utilize alternative data sources for a more comprehensive understanding.

Temporal Factors: The study may not fully capture the dynamic nature of Industry 4.0 technologies and their impact on transportation logistics strategy over time. Future research could incorporate longitudinal studies to track changes and trends in real-time, providing a more nuanced understanding of the evolving landscape.

Mediating Variables: While this study focused on the mediating role of digital supply chain efficiency, there may be other mediating variables that influence the relationship between Industry 4.0 capabilities and transportation logistics strategy. Exploring additional mediating factors could provide a more holistic understanding of the mechanisms at play.

Future research should consider exploring the enduring impacts of Industry 4.0 adoption on transportation logistics strategy, encompassing its influence on performance, competitiveness, and sustainability. Moreover, delving into the role of emerging technologies like artificial intelligence and blockchain in shaping the trajectory of transportation logistics could yield significant insights for both practitioners and policymakers. By attending to these areas of inquiry, researchers can push the boundaries of our comprehension regarding the intricate interplay between Industry 4.0 capabilities and transportation logistics strategy, thereby fostering the evolution of more efficient and sustainable logistical frameworks in the digital age.

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