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Integration of Logistics 4.0 And Industry 4.0 Into Logistics Management: Challenges and Opportunities

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Abstract

The term Industry 4.0 generally refers to intelligent digitalization, the automation of products and value chain processes, and the integration of real and virtual production worlds where products, factories, people, and objects are integrated with embedded software in smart, distributed systems. The fourth industrial revolution encompasses numerous application examples in diverse fields, from healthcare to industry. However, unlike other sectors, despite the increasing strategic importance of digitalization for businesses in a changing and competitive environment, impacting established processes, business models, and industry boundaries, as well as having an ecological impact, it has been observed that logistics businesses are not sufficiently interested in this topic.The new trade strategies outlined in the United Nations' development plan focus particularly on sustainability in the industrial sector. The most effective way to keep up with the rapidly evolving technology driven by the fourth industrial revolution, and particularly to ensure sustainability in manufacturing businesses, is to integrate Logistics 4.0 into the business. Looking at today's business world, it's clear that the continuous advancement of technology has led to significant development and change in the logistics sector.In this context, the research aims to thoroughly examine the contributions of Industry 4.0 implementation to operational efficiency in the logistics sector. The theoretical part was conducted through a literature review, providing information without going into detail, while the practical part was developed through a survey and data analysis using SPSS.

Keywords: *Industry 4.0, Logistics, Operational Efficiency.*

Introduction

The concept of Industry 4.0 encompasses the development of next-generation technologies and their integration into industry segments. It is used for the intelligent analysis and production of products and processes throughout the established value chain. These goals are observed to be supported by innovative business models that create digital production, which means creating smart networks, ensuring mobility, flexibility and group work in industrial processes, and the integration of customers and suppliers (Şekkeli and Bakan, 2018).

The development of sensor technology and internet-based communication, a key achievement of Industry 4.0, have increased the diversity, volume, and speed of data provision, making it possible to maintain continuous data flow. This continuity has also changed the type of data, requiring solutions for storing large-scale images and real-time video footage. Big data and cloud computing systems have made it possible to store and analyze data from integrated digital and physical processes throughout the product lifecycle (Barreto, Amaral, Pereira, 2017).

Literature Review

The Concept of Industry 4.0

The Industry 4.0 system consists of cyber-physical systems, the Internet of Things, big data, virtual reality and simulation, 3D printers, smart factories, smart robots, and cybersecurity technologies. Cyber-Physical Systems (CPS) are defined as transformative technologies for managing systems connected to physical assets and their digital capabilities. Sensors, collection systems, and computer networks are gaining higher availability and affordability. This, in turn, is driving businesses to implement high-tech methods due to the competitive nature of the industry today (Gürel and Aşan, 2018). Ultimately, the increased use of sensors

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and network-dominated machines has resulted in the generation of high-volume and continuous data, referred to as big data. In this case, network connections provided by the Internet of Things have been further developed to manage big data and increase connectivity between machines that are smart, flexible, and adaptable to advanced technology (Lee, Bagheri, and Kao, 2014). Cyber-physical systems, utilized by existing industrial applications, have been integrated with production, logistics, and services, enabling the creation of smart factories with high economic potential. Simulation and virtual reality methods are used before the creation of smart factories to determine their suitability, and precautions can be taken against potential errors and disruptions (Çıkmak and Yazgan, 2023). Intelligent robots that can communicate with each other can manage and control the factory. However, the digitalization of entire systems can create significant cybersecurity risks, such as a complete halt in production in a factory, the potential for international wars, and the ability to control them. Therefore, companies and even countries must implement stringent cybersecurity measures (Mercimek and Geçgil, 2021).

The Logistics Sector and Industry 4.0 Applications

As Industry 4.0 technologies have entered business life, management approaches have made advanced logistics management a crucial element of today's world. Rapid changes in competitive conditions have necessitated the integration of enterprise strategies with next-generation technologies in businesses. Businesses cannot gain an advantage over their competitors independently of innovative developments involving their products, processes, or services. Logistics companies that hold market leadership in process improvement and cost efficiency aim to maintain their leadership advantage by developing optimization efforts through horizontal and vertical integration. By integrating transportation, warehousing, and inventory management with Industry 4.0 applications, logistics companies can maintain their competitive advantage in local and global markets. Meeting customer demands in the short term and with flexibility is an important goal of marketing, but the primary goal is to transform business practices. The global trade volume of the logistics sector has reached $7 trillion. In Turkey, the logistics sector accounts for 12% of GDP. The logistics sector accounts for 8-15% of the total costs of commercial activities (Cobutoğlu, 2017).

For the reasons mentioned above, achieving operational efficiency and reducing costs in the logistics sector is a crucial issue. Simultaneous monitoring of logistics activities, instantaneous measurement of performance, timely implementation of necessary interventions, and the removal of human resources from the process are cited as factors that increase speed, make processes seamless, and reduce costs (Görçün, 2016). Industry 4.0 refers to advanced digitalization in industrial factories, combining technologies provided by the internet with those used in the future in the field of "smart" objects. In this context, industrial production systems enable the control of product manufacturing processes and transform ways of doing business. Digitalization and the internet, with their high importance, explain the concept of the Internet of Things, enabling controlled data analysis by organizing data (Glas and Kleeman, 2016). Logistics 4.0, the evolving logistics processes associated with Industry 4.0, favor software-based applications over hardware-based applications. Instead of restricting devices to specific and limited areas, equipping them with new functions tailored to user needs has a positive impact on their performance and lifespan (Şekkeli and Bakan, 2018). The integration of production and logistics processes through modern technologies enables real-time data sharing among people, machines, parts, and the final product. This integration not only speeds up production line operations but also streamlines customer-supplier interactions through a more efficient flow of information. This facilitates the establishment of system-wide network standards, increased transparency in information access, minimized error rates, and agile processes. This allows businesses to adapt more quickly to changing demand conditions and develop flexible, data-driven decision-making mechanisms (Rüssman et al., 2015).

The Impact of Industry 4.0 on Logistics

The challenging conditions of international market competition and the ever-increasing needs of customers are increasing the functionality of logistics activities worldwide. It is imperative for businesses to closely monitor industrial developments to meet the uniquely complex needs of customers and to deliver products to market quickly, flexibly, and on time. Therefore, in a system where all processes are closely linked and form the value-added chain, a system that integrates logistics processes is needed to establish and manage

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a new and effective shipping system with effective control mechanisms, ensuring efficient customer relations, accessing product shipment information, tracking orders quickly and easily, and responding to problems (Ehrhardt, 2016). Logistics processes have also undergone transformation due to technological advancements, production processes, techniques used in production, and the changing approach adopted in production (Şekkeli and Bakan, 2018). The primary goal is to apply the new information and techniques introduced by Logistics 4.0, communication and scanning technologies, and the appropriate use of information provided by data acquisition and analysis, and to create implementable logistics systems. It is deemed necessary to combine the technologies applied in the sector, planning and control methods, and human-machine interaction (Frazzon, Dutra, & Vianna, 2015). In the context of production engineering, cyber-physical systems are being introduced as an integrative concept in order to improve the bidirectional information flow between systems for execution and decision-making. Developments in technology supporting physical logistics processes have led to the emergence of systems with greater information processing demands and communication capabilities (Timm & Lorig, 2015). The innovations introduced by modern systems have been applied in the logistics sector and the Logistics 4.0 system has been created. The other name for the Logistics 4.0 system, which enables simultaneous communication between machines and humans and enables the combination of smart services and products as a result of advanced internet usage, is smart logistics. The feature of smart products and services is; It has functions that enable the fulfillment of tasks performed by humans (Kılıç, 2024). Smart logistics is a logistics system that increases flexibility in businesses and can adapt to changing market and customer expectations. This system enables increased customer satisfaction, optimized production, reduced storage and production costs, and efficient warehouse and storage operations (Ak & Kağnıcıoğlu, 2021). With Logistics 4.0, a transformation has occurred from a logistics system focused on hardware to a logistics system focused on software. Within Logistics 4.0, logistics systems include autonomous subsystems in which the behaviors of individual elements are determined by other elements or subsystems within the sector. These autonomous systems constantly interact with each other to achieve their individual goals and to support the goals of relevant stakeholders. Jeschke (2016) defines smart logistics as tightly integrated and interdependent processes that emerge between independent elements through the use of large amounts of data. The structure that has the capacity to collect, organize and analyze data flows that are becoming increasingly complex today is called "big data". Big data, which refers to the accumulation and storage of very large volumes of data in real time, becomes "smart data" when processed and interpreted appropriately, thus providing strategic contributions to decision-making mechanisms. (Barreto, Amaral, Pereira, 2017). Logistics 4.0 technologies consist of intelligent systems that can make decisions autonomously, just like humans. Logistics 4.0 aims to increase the efficiency and performance of elements within the supply chain (Dussmann Group, 2016). It is stated that the system achieves its purpose through the vertical integration of elements related to the organization's hierarchical subsystems and the horizontal integration of collaboration with individuals who form the external environment (Wang et al., 2016).

Research Methodology

Scales and Data Collection Tools Used in the Research

This research presents, in an integrated manner, all scales, scale items, sources of the scales, validity and reliability information, and data collection techniques used to integrate Logistics 4.0 and Industry 4.0 applications into logistics system management.

Population and Sample

The population of the research consisted of 503 employees of logistics companies operating in the Kahramankazan District of Ankara. The sample size for this study was determined using Table 1 (Yazıcıoğlu and Erdoğan, 2004, 78).

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Table 1. Sample Sizes for α= 0.05

Population size	± 0.05 Sampling error (d)		
	p=0.5 q=0.5	p=0.8 q= 0.2	p=0.3 q=0.7
100	80	71	77
500	217	165	196
750	254	185	226
1000	278	198	244
2500	**333**	**224**	**286**
5000	357	234	303

Therefore, when Table 1 is used to determine the sample size according to the population, the sample size is 333 people with a total population size of 2300 (2500 people in the table) at a 95% confidence level. In this regard, since there may be invalid surveys among the returned surveys, the survey was distributed to 698 people online via Google forms, and since 503 surveys were returned as valid, the analysis was completed with these data.

Data Collection Tools

An online survey form was used for the data collection phase of the study. The survey consisted of four main scales: the Logistics 4.0 Awareness Scale, the Industry 4.0 Integration Level Scale, the Perceived Opportunities Scale, and the Perceived Challenges Scale.

All scales were chosen on a 5-point Likert-type scale (1=Strongly Disagree, 2=Disagree, 3=Undecided, 4=Agree, 5=Strongly Agree).

This section describes the sources from which the scales used in the study were taken, the scope and intended use of the scales, the structure of the items, and examples of validity and reliability studies in the literature. Theoretical and practical details are provided for each scale.

Scales Used in the Study

Logistics 4.0 Awareness Scale: The scale was developed to measure participants' knowledge, awareness, and technological awareness of the concept of Logistics 4.0. It is noted that the most comprehensive scale development study on this topic in Turkey was conducted by Türkay and Gündoğdu (2020). It is also worth noting that the most frequently used 8-item Logistics 4.0 Awareness scale in research was also adopted from the aforementioned study conducted in 2020.

The scale consists of 8 items. A 5-point Likert-type scale was used (1=Strongly Disagree, 2=Disagree, 3=Undecided, 4=Agree, 5=Strongly Agree). The Cronbach's alpha reliability coefficient in the study was found to be α=0.88. The items measure awareness of digitalization, sensor technologies, robotic systems, smart warehouses, and IoT applications. Industry 4.0 Integration Level Scale: This scale is used to measure the extent to which businesses have integrated Industry 4.0 technologies into their processes. The most frequently cited model in the literature is the readiness and integration indicators model developed by Sony and Naik (2019), and the 10-item Industry 4.0 Integration Scale in this study was adapted from this study.

It assesses cyber-physical systems, big data, automation level, artificial intelligence applications, and digital transformation infrastructure.

It is measured with a 5-point Likert scale. Reliability coefficients above α=0.90 have been obtained for this scale in the literature.

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Perceived Opportunities Scale: This scale measures the potential advantages that will be provided to businesses by implementing Industry 4.0 and Logistics 4.0. Cugno et al.'s (2020) meta-analysis addressing the benefits of digitalization to businesses provided the basis for the most frequently used opportunity items in the literature. The scale consists of 7 items. The items cover the following topics: cost reduction, increased efficiency, increased speed and flexibility, improved quality, and competitive advantage.

It is measured using a 5-point Likert-type scale. Reliability coefficients in the literature are found to be around α=0.85.

Perceived Challenges Scale: The purpose of this scale is to measure the obstacles businesses face in implementing Industry 4.0 technologies. A systematic review conducted by Sony and Naik (2020) categorized the most common challenges to digital transformation and formed the basis for the scales used in the literature.

The scale consists of a minimum of 6 and a maximum of 8 items. The items cover high investment costs, a lack of a skilled workforce, data security, integration difficulties, and infrastructure deficiencies. It is measured using a 5-point Likert-type scale. Reliability coefficients are generally in the range of α=0.80–0.87.

H1. As the adoption level of Industry 4.0 technologies increases, the implementation level of Logistics 4.0 increases.

H2. As the implementation level of Logistics 4.0 increases, the integration level of logistics management increases.

H3. As the integration level of logistics management increases, the perceived logistics challenges decrease.

H4. As the integration level of logistics management increases, the perceived logistics opportunities increase.

H5. Perceived challenges have a negative effect on logistics performance due to integration level (weakening moderator).

H6. Perceived opportunities have a positive effect on logistics performance due to integration level (enhancing moderator/mediator).

H7. As logistics performance increases, the company's competitive advantage increases.

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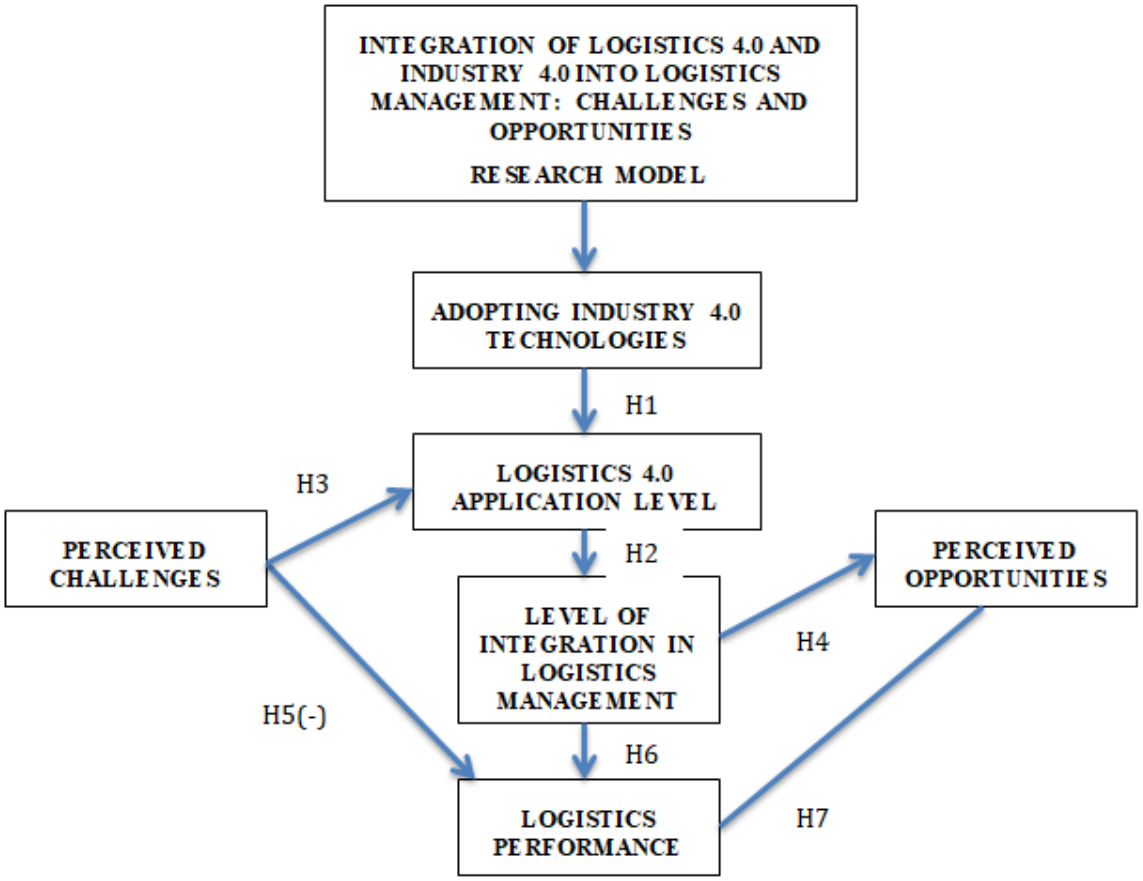

Diagram 1. Research Model

Findings

This section contains the findings of a study on the integration of Logistics 4.0 and Industry 4.0 into logistics management, analyzed using SPSS 26.0. Analyses were conducted based on data from 503 participants; demographic information was first analyzed, followed by scale reliability and descriptive statistics, and finally, correlation and regression analyses were presented in a report format.

Demographic Characteristics of Participants

A total of 503 employees of companies involved in logistics and supply chains participated in the study. Table 2 shows the frequency and percentage distributions of the demographic characteristics of the participants.

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Table 2. Demographic Characteristics of Participants

Variable	Category	f	%
Gender	Female	190	32.0
	Male	313	68.0
Age	18-25	53	10.0
	26-35	200	40.0
	36-45	100	20.0
	Above 46	150	30,0
Education	High School	81	16.0
	Associate	122	24.0
	Bachelor	220	44.0
	Graduate	80	16.0
Experience	Less than 1 year	102	20.0
	1-3 years	141	28.0
	4-6 years	120	24.0
	7 years and over	140	28.0

An examination of Table 2 reveals that 68% of the participants were male and 32% were female. More than half (60%) of the participants were between the ages of 26-35 and 36-45. An examination of participants by education level reveals that those with a bachelor's degree predominated, followed by those with an associate's degree. An examination of length of service revealed that employees with 1-3 years of experience and those with 7 or more years of experience had the same proportion. Based on this distribution, a relatively young yet experienced sample of logistics sector employees was selected.

Reliability Analysis of Scales

Table 3 shows the reliability coefficients for the Logistics 4.0 awareness, Industry 4.0 integration level, perceived opportunities, and perceived challenges scales, calculated as a result of Cronbach's alpha coefficients calculated to determine the internal consistency of the research scales.

Table 3. Cronbach's Alpha Coefficients of Scales

Scale	Number of Items	Cronbach α
Logistics 4.0 awareness	8	0.88
Industry 4.0 integration level	10	0.93
Perceived opportunities	7	0.86
Perceived challenges	7	0.84

As seen in Table 3, Cronbach's alpha coefficients for all scales ranged from 0.84 to 0.93. According to these values, the internal consistency of the scales was quite high, making their use in the study statistically appropriate ($\alpha > 0.70$).

Descriptive Statistics for Scales

Table 4 shows the arithmetic mean and standard deviation values for the main parameters used in the study. All scales were evaluated on a Likert-type scale.

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Table 4. Descriptive Statistics for Scales (n=503)

Variable	Mean	St. Dev.
Logistics 4.0 awareness	2.12	0.77
Industry 4.0 integration level	2.46	0.80
Perceived opportunities	3.85	0.68
Perceived challenges	3.58	0.72

According to Table 3, participants' perceptions of logistics 4.0 awareness levels (Mean=2.12) and Industry 4.0 integration levels (Mean=2.46) were below the midpoint of the scale. Based on this data, logistics 4.0 and Industry 4.0 applications have not yet reached the desired level of widespread adoption among the companies in the sample group. However, the values of perceived opportunities (Avg.=3.85) and perceived challenges (Avg.=3.58) were above average, revealing that employees are dominant in the idea that technology-focused transformation will bring significant opportunities but also considerable challenges.

Relationships Between Variables (Correlation Analysis)

Table 5 presents the results of the Pearson correlation analysis applied to examine the relationships between awareness of Logistics 4.0 and the perceived opportunities and challenges related to the level of Industry 4.0 integration.

Table 5. Pearson Correlation Coefficients Between Variables

Variable	Logistics 4.0 Awareness	Industry 4.0 Integration	Perceived Opportunities	Perceived Challenges
Logistics 4.0 Awareness	-	0.61	0.49	0.32
Industry 4.0 Integration	0.63	-	0.54	0.27
Perceived Opportunities	0.50	0.56	-	0.13
Perceived Challenges	0.30	0.26	0.15	-

According to Table 5, there is a positive and strong relationship between the level of Industry 4.0 integration and logistics 4.0 awareness (r=0.61). According to this result, increasing employees' awareness of logistics 4.0 concepts and technologies also increases the level of integration of Industry 4.0 applications in businesses. Additionally, the level of Industry 4.0 integration has a moderate and positive relationship with perceived opportunities (r=0.54). In this context, a higher level of integration indicates that employees perceive digitalization as providing a competitive advantage, reducing costs, and improving process efficiency more positively. Perceived challenges, on the other hand, have lower and positive relationships with other variables (r=0.13–0.30). This situation highlights the challenges of increasing technology integration by increasing complexity, investment costs, and the need for a skilled workforce.

Factors Explaining Industry 4.0 Integration (Multiple Regression Analysis)

Table 6 presents a multiple linear regression analysis to determine the impact of Logistics 4.0 awareness, perceived opportunities, and perceived challenges on the level of Industry 4.0 integration.

Table 6. Regression Model Explaining the Level of Industry 4.0 Integration

Independent Variable	B	St. Error	t	p
Constant	0.75	0.19	4.10	0.000

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Logistics 4.0 awareness	0.40	0.06	8.22	0.000
Perceived Opportunities	0.28	0.05	4.84	0.000
Perceived Challenges	0.09	0.04	2.02	0.045

As a result of the examination of the explanatory power level of the model, it is observed that the independent variables explain 51% of the total variance in the Industry 4.0 integration level (R^2=0.52; Adjusted R^2=0.51; F(3,395)=143.28; p<0.001). As seen in Table 6, Logistics 4.0 awareness (B=0.40; p<0.001) and perceived opportunities (B=0.28; p<0.001) positively and significantly predicted the level of Industry 4.0 integration, while perceived challenges, while less effective, were statistically significant (B=0.09; p<0.05). This finding suggests that employees' knowledge and awareness of Logistics 4.0 lead to a high perception of the opportunities offered by digital transformation, and that Industry 4.0 applications strengthen integration into logistics processes. While perceptions of challenges do not completely prevent integration, they do result in a cautious approach to the process.

Evaluation of the Findings from a Logistics Management Perspective

According to the overall assessment of the research findings, while awareness and integration of Logistics 4.0 and Industry 4.0 are not at the desired level, the digitalization experienced by employees can offer significant opportunities in logistics management. The high costs of technology investments, difficulties in integrating operating systems, ensuring data security, and the need for qualified employees can be cited as key challenges. The results indicate that logistics companies should focus on increasing employee awareness, strengthening technological infrastructure, and systematically planning change management processes when developing their Industry 4.0 roadmaps.

In this context, the integration of Logistics 4.0 and Industry 4.0 into logistics management requires a holistic transformation that is not limited to technological investments but also encompasses dimensions such as strategic vision, organizational culture, human resource competence, and process redesign. The research results provide guidance to business managers and policy makers by revealing both the challenges and opportunities of this transformation based on field data.

Conclusion and Recommendations

This research evaluates the operational efficiency achieved by implementing Industry 4.0 applications in the logistics sector in the context of transportation management, warehousing management, inventory management, order management, customer service organization, and cost management. Data was collected through fieldwork (surveys), their reliability was tested, and the results were interpreted according to the specified scales.

As many sectors worldwide transition to Industry 4.0, the transformation of the logistics sector, which is interconnected with all sectors, has become inevitable. The increasing share of technology and technological dependence in the life cycle has led to technology becoming an indispensable component of daily interactions, decision-making, and achieving competitive advantage. These changes have brought about digital innovations, including final delivery services, increasing the importance and sustainability of logistics. (DHL, 2018, p. 3).

Transportation management is the most crucial activity in logistics, as it accounts for a significant share of costs. In transportation management, the most important elements for increasing operational efficiency are route planning, determining driver performance, determining fuel consumption, and determining delivery speed. The use of Industry 4.0 applications increases operational efficiency in transportation management. Industry 4.0 applications enable monitoring of vehicle occupancy rates, tracking vehicle routes and durations, and monitoring customer delivery at the specified time. Real-time monitoring systems used by

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businesses are integrated with sensors to measure data regarding driver safety, increasing businesses' ability to intervene in problems and manage critical processes.

Route and route planning minimizes errors, increases transportation and delivery speed, service quality, and customer satisfaction. Furthermore, reducing route distances reduces fuel consumption. In warehouse management, order picking is the most important element of warehouse processes due to its high value in terms of labor and resources. This process, which accounts for over 50% of total warehouse operating expenses, involves significant time loss and therefore requires the most optimization.

Furthermore, the use of Industry 4.0 applications eliminates the need for non-value-added labor, saves on labor, and contributes to operational efficiency by minimizing labor costs. Warehouse management utilizes decision support systems, warehouse simulation, and big data analytics software to enable high-volume storage, increasing warehouse capacity and operational efficiency. By leveraging next-generation technologies, routine tasks are standardized, operational processes are improved, and adaptation to new processes is achieved, enabling customers to provide lean and sustainable logistics services with the necessary resources.

Providing real-time order tracking not only increases transparency between customers and the business, but also enhances operational efficiency by providing benefits such as order accuracy, streamlined order processing, and efficient order response.

With these systems, businesses can detect administrative problems before they occur, reduce intervention costs by increasing response speed, and increase customer satisfaction and loyalty. This increases the likelihood of businesses being preferred and gaining competitive advantage, thereby increasing customer potential. The ability to create customer-specific projects and meet individualized customer requests provided by Industry 4.0 applications also provides an advantage to businesses. The implementation of Industry 4.0 applications reduces error rates and lowers quality costs in businesses; increased automation minimizes labor costs and optimizes fuel consumption by increasing process efficiency. However, the high initial investment costs incurred during the installation and integration of these technologies prolong payback periods and make it difficult for businesses to achieve their profitability targets by reducing their total costs in the short term. In this context, the high capital requirements and limited availability of a skilled workforce are among the primary obstacles facing the Industry 4.0 transformation process. However, these costs are expected to decline in the medium and long term due to technological advancements and economies of scale. Therefore, it has become a strategic necessity for businesses to complete the necessary preparations for digital transformation in advance in order to gain a competitive advantage by reducing costs to reasonable levels.

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