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Sustainability impact of digitization in logistics

Yasanur Kayikci *

Turkish-German University, Department for Industrial Engineering, Sahinkaya Cad. 86, 34820, Beykoz, Istanbul, Turkey

Abstract

Today, most enterprises are undergoing a digitization process with the fourth industrial revolution, named industry 4.0. The focus of the digital transformation lies mainly on production, therefore the terms such as "Factory of the Future" or "Smart Factory" are used similar with this concept. However, there are many reasons for considering the impact of digitalization in logistics and the importance of supply chain for industry 4.0. The key promises of this concept are enabling real-time full-transparency from suppliers to customers, small lot sizes, multiple product variants, connected processes and decentralized, autonomous management. These benefits cannot be achieved by production alone, but only along the entire supply chain. Moreover, logistics should gain a greater vision to fulfill the requirements of industry 4.0 as sustainably as possible in terms of using appropriate technologies and enhancing vertical and horizontal integration among the supply chain partners. In this respect, this study highlights the benefits of the digitization of logistics process and examines the sustainability impact of digitization in logistics. The study is pursued as a single case study within the FMCG companies and their transport service providers in Turkey and it is based on a qualitative method and on connected semi-structured interviews.

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Keywords: Sustainability impact; Digitization; Logistics, Industry 4.0., Digital logistics ecosystem

1. Introduction

The accelerated pace in digitization process with "Industry 4.0 (the fourth industrial revolution)" has transformed the business content and contributed an increasingly dynamic environment and market structure. During this digitization process, manufacturing processes have experienced rapid and escalating development, existing processes

* Corresponding author. Tel.: +90 216 333 31 23; fax: +90 216 333 30 04.
E-mail address: yasanur@tau.edu.tr, yasanur.kayikci@gmail.com

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and practices have improved, new technologies have introduced and the size and scale of industrial production have expanded enormously [20]. The core idea of Industry 4.0 is to use the emerging information technologies to implement Internet of Things (IoT) and services so that business process and engineering process are deeply integrated making production operate in a flexible, efficient, and green way with constantly high quality and low cost [17]. However, digital transformation lies mainly on production with respect to achieving the desired objectives towards “Smart Factory” such as real-time full-transparency from suppliers to customers, small lot sizes, multiple product variants, connected processes and decentralized, autonomous management. It is impossible to realize a smart factory unless the relevant logistics processes are also “smart” [16]. Digitization is an important instrument in realizing a reliable and sustainable future transport system and supply of goods [15]. Logistics gains a greater vision in terms of mass adoption of smart and connected digital technologies and applications (e.g. mobile, cloud, sensors, data analytics, machine learning, blockchain, IoT) and enhancing vertical and horizontal integration among the supply chain partners. This is likely to result in radical shift in ways of business thinking and implementation in logistics that has created a need for a new business paradigm toward a connected, smart, highly efficient and sustainable digital logistics ecosystem that is fully transparent to all the players involved - from the suppliers of raw materials, components, and parts, to the transporters of those supplies and finished goods, and finally to the customers demanding fulfillment [14]. However, the industry transformation of matter, energy and labor into goods, services, waste and ambient emissions, has generated high levels of economic wealth, simultaneously it results in increasing human interference with the biosphere, industrial activity produces about 22% in total final energy consumption, and about 20% in global CO2 emissions [18]. The ambition with the digitization of industrial sector should therefore be considered to transformative change towards more sustainable, resilient and just societies, as defined by the World Commission on Environment and Development [19]. Digital alone has the immense opportunity to reduce emissions from logistics by as much as 10 to 12% by 2025 [9] and to help decarbonize the global economy. Hence, the aim of the sustainable digital logistics ecosystem is to rethink digitally-based business models and redesign the way of business processes along the supply chain to sustainable development and to balance the sustainability in terms of economic, social and environmental dimensions and reflect the interconnections between them [7] [8] [9].

This paper aims to examine the sustainability impact of digitization in logistics and also find out what are the digitization characters and associated technologies in logistics network, how the adoption of digitization changed the logistics processes and which benefits have been obtained through digitization. The study is based on a case study qualitative research approach incorporating Delphi panel carried out in four fast-moving consumer goods (FMCG) companies and two transport service providers conducted in Turkey.

2. Digitization in logistics

Digitization or digitalization means basically capturing an analog signal and converting it into digital form for the purpose of generating a digital representation that can be electronically stored or processed [1]. Digitization makes information and communication available anywhere, anytime, within any context, and for any user using any device and type of access. With the increasing use of computer technology, a greater proportion of recorded information has become digital, as in 1993, only 3% of the world’s recorded information was stored digitally, this figure had reached to 94% by 2007 [6]. The better information and transactions are captured and processed, the more systems get equipped with certain degree of intelligence, and the more these systems communicate with each other through interconnections, the higher is the level of digitization of a network e.g. an entire supply chain or a single logistics process. The digitization disrupts logistics processes partly or completely [8] but could also create intrinsic value for the industry and wider society. Building logistics network with digital technologies would offer a new degree of resiliency and responsiveness enabling companies to escalate the competition in effort to provide customers with the most efficient and transparent service delivery [14], as using analytic technology (e.g. hyperconnectivity, supercomputing, Big Data) obtains large-scale logistics data and applying complex algorithms into this data helps companies where they can save money, increase margins and operate more cost-effectively and environmentally friendly. According to white paper from the World Economic Forum indicates that digitization in logistics could provide $1.5 trillion in value through the year 2025 [9]. The digital logistics ecosystem is based on four key enablers: technology, process, organization and knowledge [6]. Integrating technology and applications with good knowledge management across organizations and business processes is critical to the success of digital logistics strategies. The digitization in logistics is based on six characteristics: cooperation, connectivity, adaptiveness, integration, autonomous control and cognitive improvement. The full implementation of wide range of digital technologies such as mobile, cloud, sensors, augmented reality, three-dimensional (3D) printing, data analytics, IoT and others, in logistics processes enables: integrated planning and execution systems, logistics visibility, autonomous logistics, smart procurement and warehousing, spare parts management, and advanced analytics [14]. A digital logistics designed with the aforementioned six characteristics and available technologies provides significant benefits to manage, plan and synchronize freight and logistics operations: real-time, full transparency along the entire supply chain, visibility and efficiency for transport chains and logistics center, high optimization potential through big data analytics, device and location independent information gathering through cloud computing, low management complexity through decentralized, autonomous decision-making, open intelligent user interface/software design for enabling horizontal and vertical collaboration, better automation through human-machine interaction, reducing failures in complex processes and enabling comprehensive consumer experience through augmented reality solutions (e.g. wearable computing) and more. In addition, these digital technologies allow the companies to timely react to disruptions along the supply chain and to adapt changes in logistics processes and even to predict possible risks by modelling the system with what-if scenario analysis.

The digitization of the entire process for plan, source, make, deliver and return will further improve logistics processes, optimize workflows and reduce lead times. Fig. 1 depicts a sustainable digital logistics ecosystem, which shows how digitization impacts logistics from the perspective of economic, environmental and social dimensions of sustainability. The sustainability dimensions should reflect:

- *Economic:* affordable system that operates efficiently, offers collaborative solutions and a mix of transport mode choices and supports the local economy.
- *Environmental:* reduced greenhouse gas emissions, pollution and waste, minimized consumption of non-renewable energy sources and uses technologies that reuses and recycles its components.
- *Social:* basic access needs of individuals/communities to be met safely and support good lifestyles, and with equity within and between generations.

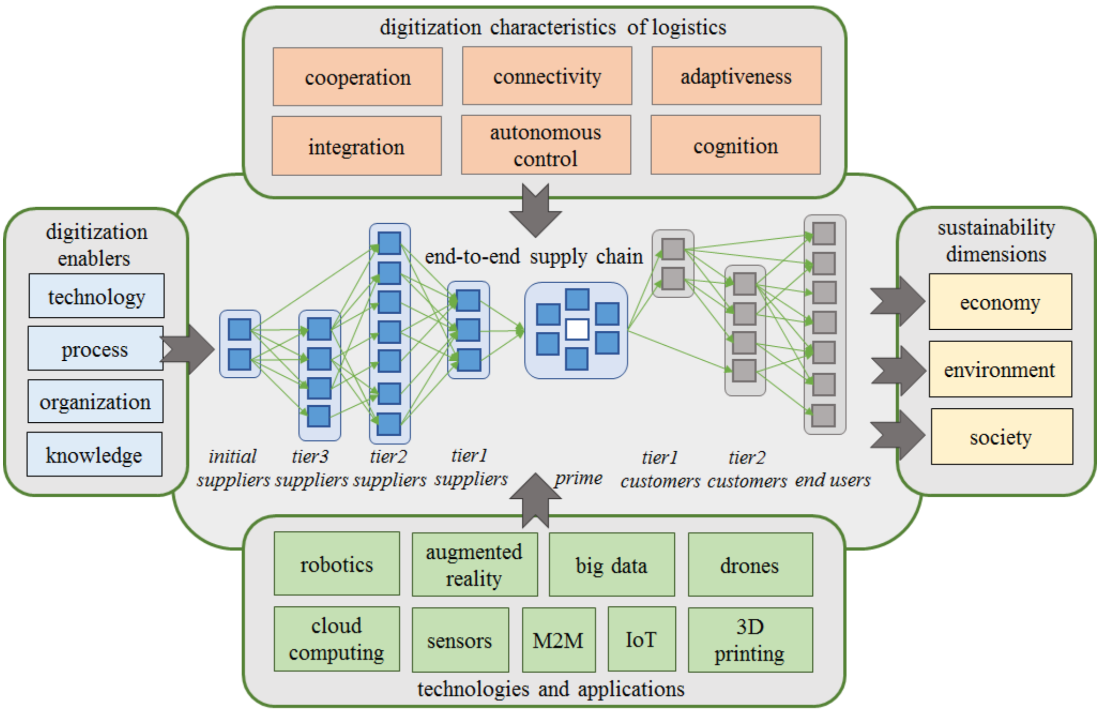

Fig. 1 Sustainable digital logistics ecosystem

The detailed descriptions of digitization characteristics in logistics are as follows:

- *Cooperation:* cooperative action (e.g. shared warehouse and transport capacities) through digitization has the potential to improve the efficiency and reliability of the logistics industry [9], this creates special needs for inter-organizational information exchange and data integration and an architecture to support virtual logistics clusters. The virtual service providers assemble several companies (or partners) into strategic alliances that allow sharing of their physical facilities to achieve utilization of logistics service beyond their own region of operation [12]. For example, the pooling of warehousing and transportation facilities over a widely geographical distributed area of operation through a digitally integrated cross-border logistics hub. A digital operating model is all about implementing digital capabilities along the organizational layers of governance, processes, data and performance management, and information technology. It allows for required levels of integration and standardization of processes [24].
- *Connectivity* refers the ability of a technology to act as an interface to other digital resources on the network, or to accept a connection from another resource [13]. Digitization through connectivity enables vertical integration from supplier to customer as well as horizontal integration among other competitors and other business partners along the supply chain in order to sustain end-to-end visibility. The technologies such as machine-to-machine (M2M), hyper-connectivity, super-computing and real-time big data analytics enable companies to match the supply and demand for underused assets and products. The cloud, in combination with mobile and social media, can dematerialize products or even entire industries. The logistics system is made more intelligent and increases productivity through self-regulating processes in order to avoid errors and unplanned interruptions. Moreover, 3D printing creates opportunities for manufacturing inputs that are biodegradable (e.g. cocopallet) or infinitely recyclable [5].
- *Adaptiveness*: Digitization refers an open dynamic adaptable system which is characterized by the fact that the components and their relations change over time and also it can be influenced by events outside of the system boundaries. The system of networked digital resources is both adaptable (system that can be changed by an external actor, e.g. through a graphical user interface) and self-adaptive (system that modify themselves in response to perceived changes in the environment, e.g. user-input or changes in the internal composition of the system) [13]. For instance, smart containers or smart bins are adaptable to different sensors to track and trace.
- *Integration* refers to the ability of system to connect, integrate, monetize and share any data, device, system and process in near or real time in the digital economy. In information technology, logistics systems integration is the process of linking together different computing systems and software applications physically or functionally, to act as a coordinated whole logistics flows. It adds additional value because of interactions between logistics subsystems. Three types of integrations are possible: (1) horizontal integration through value networks, (2) vertical integration and networked logistics systems, and (3) end-to-end digital integration of logistics across the entire value chain [17]. Software as a Service (SaaS) applications and other digital service platforms allow communication between back-end systems of organizations, thereby traditional data centers and enterprise services are seamlessly connected with cloud, mobile, and other application programming interface (API) digital ecosystems. Digitally enabled global logistics platforms are configured with this system logic to connect all users (e.g. shippers, logistics services) in order to sustain a real time operating environment. Those platforms consolidate demand from several shippers, optimizing the end-to-end logistics planning process and based on warehouse location and targeted delivery location, suggesting appropriate transport modes [9].
- *Autonomous control:* Digitization enables decentralized, autonomous decision making. Autonomous refers literally acting independently and without outside control. The machine-learning technologies (e.g. transvoyant) help to make predictive analytics. Daily many real-time events can be collected and analyzed from sensors, satellites, radar, video cameras and smartphones [2]. In logistics applications, algorithm tracks the real-time movement of shipments and calculates their estimated time of arrival, factoring the impact of weather conditions, port congestion and natural disasters. Adidas is implementing an omni channel strategy, allowing customers to buy in a number of ways (online and in physical store) and to get delivered in any way (at home, at the store or at a pick-up point) by using analytics.

Table 1. Set of criteria for evaluation of sustainability impact of digitization in logistics in terms of sustainability implications

Sustainability Dimensions	Sustainability Criteria	Description	Source
Economy	(1) Logistics cost	Changes in logistics cost savings in terms of transport, warehousing, inventory carrying and administration costs	[21] [23] [18] [14] [9]
	(2) Delivery time	Changes in delivery improvements, cycle time, lead time	[21] [23] [14] [24] [9]
	(3) Transport delay	Changes in amount of delayed shipment	[21] [14] [9]
	(4) Inventory reduction	Changes in inventory volume	[23]
	(5) Loss/damage	Changes in amount of lost and/or damaged goods from damage, theft and accidents	[21]
	(6) Frequency of service	Changes in utilization rate (load factor), frequent intervals	[23] [15]
	(7) Forecast accuracy	Changes in demand uncertainties	[23] [14]
	(8) Reliability	Changes in logistics quality in terms of transport, inventory and warehousing e.g. perfect order, scheduled time deliveries	[21] [23] [18] [14] [9]
	(9) Flexibility	Changes in planning conditions e.g. percentage of non-programmed shipments executed without undue delay	[21] [14] [9]
	(10) Transport volumes	Changes in total transported freight volume	[21]
	(11) Applications	Suitable applications for digitization in logistics processes	[18]
Environment	(12) Resource efficiency	Non-renewable resources consumption in use of vehicles and transport facilities	[21] [18] [15]
	(13) Process energy	Changes in energy requirements	[18] [9]
	(14) Process emissions	Changes in fuel consumption, $CO2$ and other greenhouse emissions	[21] [18] [15] [9]
	(15) Waste	Changes in amount of recyclable waste	[18] [9]
	(16) Pollutions	Changes in air, noise and water pollutions	[21] [9]
	(17) Land use impact	Changes in land area devoted to transport facilities and rates of land loss	[21]
Society	(18) Development benefits	Open source appropriate technology implications for self-directed sustainable development	[18] [14]
	(19) Impacts	Social impacts generated through digitization in logistics	[18] [15]
	(20) Health	Changes in disease caused by transport side effect (pollution, noise…)	[21]
	(21) Safety	Changes in amount of accident related disabilities and fatalities	[21] [14] [9]
	(22) Labor patterns	Changes in labor intensity, employment schemes, and types of work	[21] [18] [15]
	(23) Acceptance	Socio-economic, community and market acceptance of digital applications	[18] [14]

- *Cognition:* Logistics functions undergo a fundamental change with the development of technologies such as artificial intelligence (AI), robots, drones for handling domestic and international movement of goods. Those technologies and applications such as autonomous mobile robots, unmanned ground vehicles, unmanned aerial vehicles and self-driving vehicles deeply impact the present and future success of logistics and improve the logistics industry, moreover autonomous vehicles have greater potential to reduce accident and enhance the road safety [25]. *Self-driving trucks* are testing by automotive manufacturers including Daimler, Volvo and Scania, Google's driverless car has made a lot of progress [11], and moreover Uber realized the first delivery operation with driverless autonomous vehicle. Amazon is exploring the viability of delivery of small parcels by drone technology and developing flying warehouse blimp for the large delivery. In addition, picking process with *autonomous forklifts* is improving productivity in warehouse logistics, however this technology has reached "a level of maturity" in warehouse operations. A white paper of World Economic Forum [9] indicates that autonomous truck will make $30 billion economic impact as a result of savings in fuel costs, maintenance costs, employee costs and insurance, whereas drones will achieve $20 billion of business impact from faster and cheaper last-mile delivery services in both rural and urban areas.

Table 2. Key sustainability impacts of digitization in logistics across various digitization characteristics of logistics

Sustainability Dimensions	Sustainability Criteria	Digitization Characteristics of Logistics					
		Cooperation	Connectivity	Adaptive-ness	Integ-ration	Autonomous Control	Cognitive Improvement
Economy	(1) Logistics cost	+++	+++	++	+++	+	+
	(2) Delivery time	+++	++	++	++	+++	++
	(3) Transport delay	+++	+++	-	+++	+++	+
	(4) Inventory reduction	++	++	+	+++	+++	+++
	(5) Loss/damage	+++	+	n/a	+++	+	+++
	(6) Frequency of service	++	++	+	+	+++	+++
	(7) Forecast accuracy	+++	+++	++	+	+++	++
	(8) Reliability	+++	+	+	+++	+++	++
	(9) Flexibility	+++	+++	++	+	+++	++
	(10) Transport volumes	+	+	-	++	+	++
	(11) Applications	++	++	+++	++	+++	+
Environment	(12) Resource efficiency	+++	++	+	++	++	++
	(13) Process energy	+	+	++	+++	++	+++
	(14) Process emissions	+	++	+++	+++	+++	+++
	(15) Waste	++	+++	+++	+++	++	+++
	(16) Pollutions	++	+	+	++	+++	++
	(17) Land use impact	+	+++	+	+	+	+
Society	(18) Development benefits	+	++	+	+	++	++
	(19) Impacts	++	+	+	++	+	++
	(20) Health	++	+	++	++	++	++
	(21) Safety	++	++	++	++	+++	++
	(22) Labor patterns	+	+	+	+	-	-
	(23) Acceptance	+	+	+	++	+	+

Relative impact: + less/poor ++ moderate +++ high/excellent, no impact, n/a no available evidence yet

3. Research Design

This research uses a case study methodology to evaluate the sustainability impact of digitization in logistics, which focuses on understanding the dynamic present within a given setting [3]. The case study is pursued within FMCG companies and their transport service providers in Turkey, as FMCGs have inherently been affected by the changes in consumer behavior, especially the rise of digital, so that they are ready to adapt quickly [22]. A descriptive sustainability evaluation is performed to qualitatively identify implications of digitization on the three sustainability dimensions of logistics: economy, environment and society as defined by the WCED [19]. The evaluation is based on a defined set of criteria for which identified implications are described. The social indicators can necessarily only be dealt with in a qualitative fashion since the digitization technologies are still being developed, whereas the other economy and environment indicators can be quantified through costs, energy and CO2 emissions, however all sustainability dimensions are qualitatively evaluated in this study, the reason for this is the difficulty to collect representative data. The criteria are obtained from studying relevant literature as well as expert opinions as a comprehensive sustainability evaluation of digitization in logistics has not been performed yet and also existing studies on sustainability dimensions are based more on transport rather than on logistics [21]. An aspect has been selected valid to become a criterion if a digitization in logistics related sustainability implication has been associated with the aspect, see Table 1. At the end, 23 relevant criteria are determined, where 11 out of 23 indicate the economic dimension, 6 criteria point to the environmental dimension and the rest of 6 criteria refer the social dimension of sustainability. In order to evaluate the impact of digitization from logistics perspective, the aforementioned digitization characteristics are also considered while deciding on the listed aspects.

4. Case Study

After determining a list of criteria for sustainability impact of digitization in logistics, a case study is pursued among FMCG companies and transport service providers. For this study, four FMCG companies and two service providers were selected as they are investing in digital transformation and adapting the last digital technologies and applications in their processes and operations [4] and they are also cooperating each other for logistics activities. The following research question was asked every company logistics expert to fulfill the evaluation table.

"*How do you evaluate the sustainability impact of digitization in logistics processes and operations in respect to digitization characteristics of logistics*?" Please indicate your evaluation with the following statements on a 5-point relative impact scale: + *less/poor* ++ *moderate* +++ *high/excellent, no impact, n/a no available evidence yet*.

The evaluation process is pursued first of all with the remote session and the logistics expert of each company received the research question by email and fulfill the table in order to assess own perception, then all experts were invited to participate in a Delphi panel for achieving consensus on evaluation of sustainability impact of digitization. Their task was to sort, analyze and evaluate listed criteria and recommend of the most impacted sustainability criteria of digitization with at least two-rounds. They came to consensus with respect to sustainability impact and digitization characteristics of logistics, as seen in Table 2.

5. Result and Conclusion

This study explored the sustainability impact of digitization in logistics and also answered what are the digitization characters and associated technologies in logistics network, how the adoption of digitization changed the logistics processes and which benefits have been obtained through digitization. The most existing literatures pointed out the sustainability implications of digitization from solely transport perspective and they failed to employ a broad case of logistics. Therefore, this study represents a new approach to understand the sustainability implications from logistics perspective. Digitization in logistics has still not reached the maturity level, as it is still in an early maturation phase. For this reason, sustainability implications can be improved and changed over the years with the maturity level of digitization.

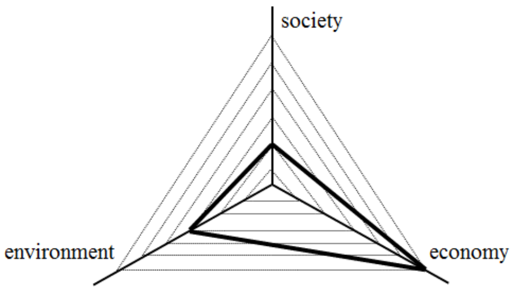

Fig. 2. Sustainability implications of digitization in logistics

The study result showed that the using digital technologies and applications in logistics within FMCG companies and transport service providers had a huge sustainability impact, especially the sustainability impact of digitization with respect of economic implication was more important than the other dimensions (see Fig. 2), although evaluation of some impacts of criteria were unclear from participants. In terms of logistics cost, delivery time, delay, inventory, reliability and flexibility issues, a great potential of digitization in logistics can be seen. Beside this, study showed that the social implications of digitization (improved health outcomes, lover accident rates) have generally poor impact. Safety and health matters could be improved with the digitization in logistics, whereas digitization was seen as potential threats with respect to labor patterns, therefore the acceptance of fully digitization was also less. The environmental implications of digitization had most impacts on reducing waste, pollution and emission of greenhouse gases. Digitization is expected to create far more value for society than economy, in this instance, businesses, regulators and policy-makers will need to collaborate to maximize value for business and wider society [10].

The study has limitations that restrict the generalizability of the results, as the study were conducted using only six digitization characteristics of logistics as well as Delphi study was pursued with the participation of six companies. Furthermore, quantitative part is missing in the study which was assessed only qualitatively on the three sustainability dimensions: economy, environment and society.

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