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The Impact of Digital Transformation on Logistics: The Silicon Economy in The Context of Open-Source Platforms

Dijital Dönüşümün Lojistiğe Etkisi: Açık Kaynak Platformları Bağlamında Silikon Ekonomisi

Taner AKÇACI[a] Maide Betül BAYDAR[b]* Burcu YENGİL BÜLBÜL[c]

[a] Prof. Dr., Gaziantep Üniversitesi, İktisadi ve İdari Bilimler Fakültesi, Uluslararası Ticaret ve Lojistik Bölümü, Gaziantep / TÜRKİYE
ORCID: 0000-0002-5343-0894

[b] Dr. Arş. Gör., Gaziantep Üniversitesi, İktisadi ve İdari Bilimler Fakültesi, Uluslararası Ticaret ve Lojistik Bölümü, Gaziantep / TÜRKİYE
ORCID: 0000-0001-6805-1099

[c] Dr. Arş. Gör., Gaziantep Üniversitesi, İktisadi ve İdari Bilimler Fakültesi, Uluslararası Ticaret ve Lojistik Bölümü, Gaziantep / TÜRKİYE
ORCID: 0000-0001-9338-2172

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ABSTRACT

Digital transformation not only improves existing processes but also fundamentally reshapes business practices and competitive dynamics. With the Fourth Industrial Revolution, it is anticipated that logistics and supply chain management will gain an entirely new dimension through sensors, digital networks, and advanced automation systems. The acceleration of this transformation is increasingly driven by the role of open-source technologies. Open-source software and platforms accelerate companies' innovation processes while reducing costs, and at the same time facilitate the sharing of knowledge and technology across different industries. In this context, the German government's "Silicon Economy" (SE) project aims to build an open-source-based ecosystem in the field of logistics and supply chain management, enabling companies to advance their digitalization processes through common standards and interoperable solutions. SE is a digital ecosystem that allows the distribution, planning, control, and monitoring of material flows in the logistics sector, making possible new digital business models for logistics. The purpose of this study is to provide a conceptual review of digital transformation, open-source technologies, and the SE within a holistic framework, particularly in the field of logistics. By examining the relationship between usage of open-source and the logistics sector in the context of SE, the study offers a new perspective for both academic and industry stakeholders. At both international and national levels, the number of articles, reports, and datasets published about the project remains limited. Therefore, this study constitutes an important preliminary step toward a better understanding of the subject and its potential adaptation to different country contexts.

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ÖZ

Dijital dönüşüm, yalnızca mevcut süreçleri iyileştirmekle kalmayıp, iş yapış biçimlerini ve rekabet dinamiklerini de temelden değiştirmektedir. Özellikle Dördüncü Sanayi Devrimi ile birlikte, sensörler, dijital ağlar ve yüksek otomasyon sistemleri sayesinde, lojistik ve tedarik zinciri yönetiminin tamamen yeni bir boyut kazanacağı öngörülmektedir. Bu dönüşümün hız kazanmasında açık kaynak teknolojilerinin rolü giderek artmaktadır. Açık kaynak yazılımlar ve platformlar, şirketlerin inovasyon süreçlerini hızlandırırken maliyetlerini düşürmekte, aynı zamanda farklı sektörler arasında bilgi ve teknoloji paylaşımını kolaylaştırmaktadır. Bu noktada, Alman hükümetinin "Silicon Economy" (SE) projesi, lojistik ve tedarik zinciri alanında açık kaynak temelli bir ekosistem inşa ederek, şirketlerin dijitalleşme süreçlerini ortak standartlar ve birlikte çalışabilir çözümler üzerinden ilerletmesini hedeflemektedir. SE lojistik sektöründe mal akışlarının dağıtılması, planlanması, kontrolü ve denetimine dayanan, lojistik faaliyetler için yeni dijital iş modellerini mümkün kılan dijital bir ekosistemdir. Bu çalışmanın amacı, dijital dönüşüm, açık kaynak teknolojiler ve SE kavramlarını bütüncül bir çerçevede ele alarak, özellikle lojistik alanında kavramsal bir derleme sunmaktır. Çalışma, açık kaynak kullanımı ile lojistik sektörü arasındaki ilişkiyi SE bağlamında değerlendirerek, hem akademik hem de sektörel paydaşlar için yeni bir perspektif sunmaktadır. Hem uluslararası hem de ulusal düzeyde proje hakkında yayımlanan makale, rapor ve veri sayısı kısıtlıdır. Bu nedenle, çalışma, konunun daha iyi anlaşılması ve farklı ülke bağlamlarına uyarlanabilmesi için önemli bir ön adım niteliği taşımaktadır.

* *Sorumlu yazar/Corresponding author*.
e-posta: betulaksoy@gantep.edu.tr

Introduction

Digital transformation has a significant impact on the development of logistics, one of the core sectors of the economy. All major economic trends are reflected in logistics, and fundamental digital technologies are already in use. The planning of logistics distribution systems is one of the most complex tasks of modern information technologies, and the high volume of e-commerce further increases this complexity. Therefore, logistics has become the first sector for the application of innovations such as the Internet of Things (IoT), 3D printing, big data, artificial intelligence (AI) algorithms, and others within Industry 4.0 (ten Hompel and Henke, 2020).

Open source represents one of the cornerstones of digital transformation by providing security, transparency, and independence in logistics systems, while the SE realizes this approach as a tangible platform, enabling new AI-supported business models and supply chain ecosystems in the logistics domain (Plevnik and Gumzej, 2025). This digital ecosystem, which is based on the automatic distribution, organization, planning, and control of material flows, ensures the execution of data trading while safeguarding sovereignty over data. Designed to counter oligopolistic developments, SE is described as a decentralized platform ecosystem that makes its core components publicly available as open-source for free use (ten Hompel and Schmidt, 2022). At its core, SE seeks to prevent the European logistics industry from being dominated by a monopolistic platform (Rotgang et al., 2023).

Many AI applications require large amounts of well-annotated data to achieve meaningful learning. Processed data gains value, giving rise to a data economy. Fundamentally based on the data economy, SE is a research project funded by the German government, aimed at the digitalization of the European logistics industry (Stodolka et al., 2023). It consists of more than ninety companies and focuses on safeguarding sovereignty over data usage through an open data space.

The SE is a modern economic concept that plays a major role in areas such as data sharing, automation, digitalization, logistics, and supply chains. This concept represents a digital platform that, through the use of new technologies, aims to create more efficient, transparent, and flexible processes. The design and implementation of the digital platform are intended to meet the diverse needs of stakeholders. In SE, labor is increasingly being transferred to machines through the digital platform. In logistics, this becomes evident in the planning, supervision, control, and monitoring of processes (ten Hompel and Henke, 2022).

This study provides a conceptual review of digital transformation, open-source technologies, and the SE concept within a holistic framework, with a particular focus on logistics and supply chains. The research addresses the ongoing digital transformation in the logistics sector, highlights the role of SE within the scope of open-source technologies, and discusses projects developed under the SE initiative. In this study, a review is conducted by interpreting data obtained from official project reports, academic articles, industry reports, and news sources. The research problem revolves around how open-source technologies contribute to digital transformation in the logistics sector, and what kinds of opportunities the SE approach -as an open-source initiative- offers within this transformation. However, the limited number of academic studies and datasets published on the project at both national and international levels makes it difficult to systematically examine the concept. In view of the limited data available in the literature, this study provides a guiding reference for both the industry and policymakers, while offering a strategic and innovative framework through its focus on the Turkish perspective.

Digital Transformation and Its Reflections in the Logistics Sector

Digital transformation is the process of creating new business processes and customer experiences -or transforming existing ones- through the use of digital technologies to meet changing business and market demands. This transformation encompasses a comprehensive integration process that redefines the rules regarding customer relations, innovation, competition, data usage, and value creation (Sehgal, 2023). In this process, advanced technologies such as AI, data analytics, the IoT, and blockchain are utilized to transform traditional business models and operations (Hvozdetska et al., 2023).

There are numerous studies related to digital transformation in the logistics sector. Karli and Tanyas (2020) examined digital transformation in logistics management bibliometrically through the concept of smart logistics. Ozdemir and Ozguner (2018) focused on Industry 4.0 and revealed the innovations that Industry 4.0 has brought to the logistics sector. Oztemel and Gursev (2018) collected data through surveys on how the effects of digital transformation are perceived in the logistics sector, drawing attention to the impact of information technology solutions on logistics. Turgut (2025) analyzed the effects of digital transformation on international logistics using a literature review method. Cichosz et al. (2020) examine the barriers faced by logistics service providers during the process of digital transformation through case studies. The study reveals that the main obstacles to digital transformation are the complexity of logistics networks and the lack of resources, while the most critical success factors are the leader's transformational vision and a supportive organizational culture.

In the logistics, digital transformation refers to the integrated application of these technologies to enhance supply chain efficiency, reduce operational costs, and increase customer satisfaction. This transformation, by reshaping traditional logistics records, delivers significant improvements in efficiency, transparency, and resilience. Increasing competition in global markets and growing customer demands are pressuring logistics solutions to adopt digital innovations (Holloway, 2024). The key drivers of digital transformation in logistics include IoT, AI, blockchain, and big data analytics. These technologies enable real-time tracking, predictive analytics, and more efficient resource allocation within supply chains. In particular, IoT technologies are creating profound changes in logistics operations through applications such as asset tracking, inventory management, and predictive maintenance. Leading global companies such as Amazon, DHL, and Walmart have successfully integrated IoT-based solutions, significantly improving their operational efficiency (Holloway, 2024; Oliveira, 2024).

Today, the digital transformation of the logistics sector is accelerating with innovative technologies such as smart warehouse management, autonomous vehicles, and platform-based solutions. AI reduces costs and minimizes waste through routine automation and advanced demand forecasting, while also optimizing delivery routes and improving customer service. Blockchain technology enhances transparency and traceability in supply chains, supporting sustainability and ethical standards, particularly in critical sectors such as food safety and pharmaceuticals.

Another key component of digital transformation—robotics and AI-powered smart warehouse management systems—maximizes efficiency by optimizing processes from inventory management to order fulfillment. Finally, autonomous vehicles and drones hold the potential to revolutionize last-mile delivery, reducing delivery times and lowering operational costs. Digital transformation integrates all these technologies into a cohesive structure through digital platforms that strengthen collaboration among logistics service providers and encourage customized service models (Manjunadh and Manoj, 2024; Kott et al., 2024).

In 2021, Kern conducted a study on the digital transformation of logistics, technologies, and implementation practices, in which he reported a significant digitalization gap between digitally native large companies and industry players that refuse to adopt new technologies. According to the data presented on the state of digitalization across logistics infrastructure (ports, airports, warehousing), logistics execution (road, maritime, and air freight; courier, express, and parcel delivery), and logistics services and consulting:

- Ports and airports: Only about 3% of container terminals are (semi-)automated; digital transformation is slower compared to other areas.
- Warehousing: Approximately 30–40% use Industry 4.0 technologies such as sensors, robotics, automation, or predictive analytics.
- Road transport: Around 35–40% of companies employ technologies that optimize operations, such as transport management systems.
- Maritime transport: Only a few carriers use modern approaches (e.g., marketplaces), with digitalization progressing cautiously.
- Air cargo transport: The level of digital connectivity lags even behind maritime transport; solutions without clear cost advantages face challenges in adoption.
- Courier, express, and parcel delivery: While technologies are mature, their use remains in early stages.
- Logistics services and consulting: Only 50% of customers are satisfied with the IT capabilities of their third-party logistics providers (3PLs).

As a result, Kern (2021) argues that the level of digitalization among traditional sector actors is generally low to medium. However, an increasing number of companies are recognizing the impact of digital transformation and striving to adapt to contemporary requirements by overcoming barriers such as high costs, lack of standards, and uncertain benefits.

One of the prominent approaches in the digital transformation process is open-source technologies. By providing free access to software code, these models allow developers to build their own services on top of existing frameworks, fostering innovation and collaboration. Companies benefit from community contributions, reducing costs while enhancing organizational agility and innovation capacity, thus gaining strategic advantages from community-driven technological advancements (Kozlova and Komarovskaia, 2023).

Within this scope, the SE emerges as a digital ecosystem based on open-source software, enabling new digital business models for logistics activities that rely on the distribution, planning, control, and monitoring of material flows. Rooted in open-source solutions, SE integrates labor, machines, and algorithms to provide a robust alternative for the management, control, and supervision of logistics services in collaboration with the industry's new digital solutions. Designed as a decentralized platform ecosystem to counter oligopolistic market structures, SE makes its core components publicly available as open-source, ensuring secure and transparent data sharing while enabling the development of innovative business models through AI-driven autonomous control mechanisms and smart contracts.

The Potential of the Silicon Economy for the Logistics Sector

In international trade, many problems arise from the inefficient exchange of information in logistics and supply chain flows. Bureaucratic costs can increase the overall value of a shipment, while identifying the source of defective products is often impossible. In recent years, however, sensors have reduced dimensions, sensitivities, and costs, making configuration

easier. As a result, it has become possible to identify and locate any asset, and—more broadly—to collect data in unprecedented quantities. Furthermore, advances in fields such as data mining and machine learning enable the extraction of meaningful insights from sensor data, allowing decision-making processes to be automated. When these advancements are combined with the extended connectivity of IoT devices and the enhanced version of the Internet of Services (IoS), it becomes possible to build fully automated and self-adaptive systems. These technologies, often referred to as the "Logistics 4.0" revolution, optimize overall supply chain performance (Perboli et al., 2018).

IoT, as the core data source of the SE, enables cyber-physical systems such as smart containers and pallets to be securely connected via NarrowBand IoT or traditional networks (ten Hompel and Henke, 2022). The continuous networking of load carriers, real-time monitoring of environmental data, and sensor-based recording of logistics and production systems all contribute to the scalability of platforms like SE. Nevertheless, despite technological progress, the number of IoT devices in logistics remains limited. This is because, although technically feasible, these technologies are constrained by costs and energy requirements. It is precisely at this point that SE provides ideas for the modularization and standardization of IoT devices (Kerner et al., 2022).

One example of such an application is the Temp2Net device, which is particularly used in cold chain transportation to monitor load carriers that lack temperature control. In containers especially, this device provides functions such as temperature monitoring, data recording, remote access, warning and alarm systems, data analysis, and reporting.

In addition to the Temp2Net project, the SE also focuses on the Pixel2Net project. The Pixel2Net device is used in operations such as image-based inspection, object recognition, and classification. In Germany, a company called Futura GmbH collaborated with the Fraunhofer IML logistics institute to develop a technical model. The aim is to conduct pest control—an industry with a market share worth billions of dollars and of great importance for certain sectors—through IoT technologies. With nearly zero error, rodents are detected by a sensor and safely captured. The mode of the trap can be adjusted according to the desired time and location (Futura, 2024). Together with sensor, IoT, and blockchain applications, “Track and Trace” technologies provide information about the location, condition, and ownership of raw materials, intermediate goods, and final products throughout the supply chain (Schulte and Schipp, 2022).

Currently, the control systems of automated guided vehicles (AGVs) are generally limited to manufacturer -specific solutions, making it impossible to manage vehicles from different brands within the same system- in other words, AGV control remains vendor-dependent. Within the scope of SE, the libVDA5050++ project, carried out in cooperation with the Verband der Automobilindustrie and the Verband Deutscher Maschinen-und Anlagenbau, has established an interface standard for communication between AGVs and control systems, and offers an open-source implementation of this standard (Silicon Economy, 2025).

The SE project, initiated by Fraunhofer IML in 2020, aims to develop open-source, federated, and AI-supported digital ecosystems in the logistics sector, laying the groundwork for new business models through applications such as autonomous control, secure data sharing, smart contracts, and automated billing. In contrast, traditional logistics structures are often based on closed systems, manual processes, and limited data integration-factors that constrain both operational flexibility and innovation potential. As emphasized in the work of ten Hompel and Henke (2022), the SE approach, through AI-enabled autonomous management, fosters supply chain ecosystems that are more dynamic, flexible, and efficient than conventional models. In this context, SE plays a transformative role in the shift from traditional logistics paradigms to digital, open, and collaborative ecosystems.

When examining the literature on the SE, ten Hompel and Schmidt (2022) analyzed the potential of transitioning to SE for supply chains, its architectural structure, and the challenges encountered during this process. Schmidt et al. (2022), on the other hand, discussed the concepts of open source and the platform economy in detail, explaining the role they play within the SE context. Leveling et al. (2022) developed a reference architecture for SE, in which components such as the IoT agent, logistics broker, and blockchain broker function as intermediaries.

SE not only contributes to the digitalization of operations but also positions countries as significant actors in cross-border trade, where technology and commerce are dynamically applied. In her study "Technological Advances Shaping Azerbaijan-Turkey Logistics", Baghirova (2024) emphasized that blockchain-enabled smart contracts facilitate automatic and secure agreements between parties.

In addition to advancements in logistics services, the SE is also applied in financial supply chain management. According to Schulte and Schipp (2022), SE is used to better manage financial risks, enable new financial approaches, and automate processes throughout the financial supply chain.

Stodolka et al. (2023), starting from the question of how multi-stakeholder participation can be integrated into the design of digital services, investigated the supply and demand of European inland port logistics. As a result, they proposed the Stakeholder Onboarding Model, which aims to ensure the effective involvement of stakeholders in projects and, ultimately, to improve overall performance.

The Turkish Perspective in the Silicon Economy

One example that demonstrates the potential and application areas of SE in the Turkish context is projects aimed at the digitalization and standardization of logistics processes. The eCMR project can be cited as an example of SE, which is an open-source initiative. This project aims to enable the standardized management of all documents related to every type and mode of transportation - including their preparation, modification, transmission, and archiving (Open Logistics Foundation, 2024a).

Another project carried out within the SE is the NE:ONE project, which aims to improve exchanges among different stakeholders in air cargo transportation by digitalizing them on an open-source basis. The NE:ONE project is a server software package built upon the IATA ONE Record standard, designed to enhance efficiency, collaboration, and transparency in the air cargo transportation sector (Open Logistics Foundation, 2024b). Frankfurt-based Lufthansa Cargo aims to implement this standard within its IT infrastructure to increase data exchange and operational efficiency (Air Cargo News, 2023). Turkish Airlines' Turkish Cargo has evaluated the project as a step toward initiating piece-level planning and operational processes in the air cargo industry. Following the earthquakes in Türkiye on February 6, 2023, problems arose in piece-level planning for relief shipments; therefore, Turkish Cargo aimed to optimize cargo capacity and improve communication among stakeholders by using the IATA ONE Record standard (Aeroportist, 2023).

The Stakeholder Onboarding Model is a framework designed to ensure that stakeholders joining a project, platform, or ecosystem are systematically and strategically integrated into the process. It focuses on clarifying roles and responsibilities, aligning expectations, and strengthening the environment for collaboration. The reflections of this model can be seen in mega projects such as Istanbul Airport and Kanal Istanbul. During the construction of the airport, numerous domestic and international stakeholders -including government institutions, companies, environmental groups, and investors- were involved.

In addition, Arkas Logistics, one of Türkiye's largest logistics companies, has been using IoT-based smart sensors and systems at ports to enhance operational efficiency. Through smart port management, it can effectively manage ship traffic, loading and unloading operations, and container collection processes. Given its wide customer base, supplier network, government relations, and business partners in the logistics and transportation sector, Arkas Holding can leverage the The Stakeholder Onboarding Model to strengthen stakeholder engagement in its projects and secure their successful implementation (Arkas News, 2025).

Conclusion

Logistics is an indispensable component of global trade, encompassing not only the physical movement of materials and products but also the exchange of information and financial processes within a vast networked structure. In advanced industries such as logistics, digital transformation emerges as the primary driver of innovation. In particular, transformation related to data and information exchange has become the key to significant developments based on AI and autonomous systems (Moshood et al., 2021).

Within the context of Industry 4.0, the SE is positioned as a platform economy in which individuals, businesses, autonomous vehicles, and IoT-based devices interact with one another. Through projects aimed at modularizing and standardizing such devices, SE reveals the potential that, within the coming years, AI applications in logistics may globally manage, monitor, and plan material flows. The integration of new technologies—such as 5G and the development of new open-source IoT devices—has the power to form the core components of tomorrow's digital infrastructure (ten Hompel and Henke, 2022). As the effects of digital transformation spread more widely, the need for various industries to adopt emerging technologies continues to grow. Given that the logistics sector is one of the most affected domains, this study has examined the concept of the SE and its reflections on logistics. By accelerating digital transformation in logistics, SE enhances the efficiency of supply chains and logistics processes, ensures greater security and speed, and thereby facilitates global integration. These innovations pave the way for the sector's evolution into a more sustainable, autonomous, and digitally based structure.

SE can be considered an exploratory, dynamic, multidimensional domain characterized by high uncertainty. As decentralized platforms such as SE are still in the early stages of development, new research areas are emerging at both theoretical and applied levels. In particular, an in-depth analysis is required of the impacts of open-source-based digital ecosystems on logistics enterprises of varying scales, across the dimensions of competitiveness, cost-effectiveness, and sustainability. Furthermore, identifying the technical, organizational, and cultural barriers encountered in the adoption of open-source technologies will provide a critical contribution to accelerating this transformation process.

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