5G-Based Technologies in Logistics and Supply Chain

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The transport and logistics industry plays a crucial role in supporting the economy, but it faces various challenges, including high costs and the need for operational efficiency. To address these challenges, the industry is embracing digital transformation, and 5G networks are expected to play a significant role in this process.

Keywords: transport and logistics ; 5G networks ; digital transformation ; supply chain optimization

1. Introduction

The transport and logistics industry is a fundamental sector that acts as the backbone of a country's economy and plays an essential role underpinning other core sectors, such as manufacturing and retail. Challenges and opportunities facing the transport and logistics industry are also closely tracked and influenced by national and local governments, who are often responsible for investments in supporting transport infrastructures. As the movement of people and goods across the world increases, the industry is evolving to meet these demands. However, it faces challenges in doing so: significant pressure on the logistics industry, high capital and fixed operating costs, and differentiation strategies of companies. Despite growing demand, many firms are suffering from eroding margins. Therefore, the focus for the majority of the industry is on cost-cutting and improving operating efficiency. For many companies, investing in new technologies provides an opportunity to transform their operations and drive efficiencies. There is significant scope to do this since the industry as a whole is generally not as digitized as other verticals and because there is room to make improvements to currently under-utilized assets. For the industry to address these challenges and achieve efficiencies, it will need to adopt new technologies. The catalyst for digital transformation will be data—in particular, the generation of richer and more comprehensive data and the analysis of this data to produce insights for the decision-making process. The role of 5G networks and companion technologies mainly relies on the potential to help drive digital transition and address some of these challenges, helping to catalyze the digital transformation journey in logistics. As 5G is rolled out, it could have a significant effect on supply chains, the wider transport industry and society more generally.

The key benefits that 5G technologies can provide to the transportation and logistics industry are as follows:

- Device density and data volume: 5G technologies are able to connect and support more smart devices (from temperature-monitoring sensors to vehicles) than their predecessors, with a huge amount of data collected and shared through the network.
- Low latency: Latency refers to the end-to-end communication delay. Fifth-generation technologies have good latency performance so that data are captured in real time, allowing the highest mobile connection speed, even when the number of objects connected to the network is large. With faster speeds and a low time gap, smart devices can communicate faster with one another, close to real time, fostering the adoption of time-sensitive internet-of-things device applications relevant in the logistics and transportation field.
- Network slicing: Network slices are separate virtual networks that run on the same physical network infrastructure to meet different connectivity needs.
- Minimizing supply chain risks improving the visibility: With 5G implementation supporting a large number of sensors, it will help provide end-to-end communication and improve the supply chain visibility, which represents one of the biggest challenges in the logistics industry today.
- Faster and safer port operations: 5G technologies' performance allows fast and reliable connection, helping to create lean, secure and effective operations in ports.
- Enhanced communication, repairs and problem solving through virtual reality or augmented reality technologies.

However, to foster the actual market adoption of the innovative products and services, it is important to engage all the stakeholders involved and the potential final users in order to assess their real needs and highlight the impacts of the innovative solutions on their daily activities.

Moreover, an important aspect to consider is the sustainability of the innovative products and services, encompassing the economic (to ensure the long-term viability and profitability of logistics operations), social (to analyze the impact of logistics operations on people, workers, communities, and society as a whole), environmental (to minimize the environmental impact of logistics operations and promote ecological conservation), and operational (to ensure the efficiency, reliability, and resilience of logistics operations) dimensions. By considering these aspects of sustainability, logistics companies can create long-term value, mitigate risks, and contribute positively to the well-being of stakeholders and society.

2. Fifth-Generation-Based Projects

The global demand for freight transportation continues to increase in order to meet the requirements of the modern economy. One of the significant implications of this growth is the increased importance of data collection from various sources across the supply chain. Consequently, there is a need for connectivity solutions that can enhance the secure and reliable sharing of data. Several papers and European projects have highlighted the necessity for a technology infrastructure that integrates blockchain, internet of things (IoT), and cloud. This infrastructure supports data sharing while preserving data integrity and security [1][2][3]. To address these challenges and facilitate digital transformation in logistics and transportation, 5G technologies are gaining momentum [4][5]. Fifth-generation technologies offer key benefits to the transportation and logistics industry, including the following:

- Device density and data volume: 5G enables the connection and support of more smart devices, facilitating the collection and sharing of a massive amount of data through the network.
- Low latency: With faster speeds and reduced communication delay, smart devices can interact with each other in near real time, which is crucial for time-sensitive IoT applications in logistics and transportation.
- Network slicing: This feature allows the creation of separate virtual networks on the same physical infrastructure to meet diverse connectivity needs.
- Minimization of supply chain risks by improving visibility.
- Faster and safer port operations.
- Enhanced communication, repairs, and problem solving through virtual reality or augmented reality technologies.

2.1. Fifth-Generation-Based Initiatives, Projects and Implementations

Several initiatives, projects, and implementations have been funded by national and European bodies to address the applications of 5G technologies in the supply chain, particularly in the port domain. By integrating 5G technologies with other companion technologies, such as artificial intelligence, big data, IoT, and autonomous vehicles, the development of port automation is expected to increase, providing a competitive advantage to innovative ports. The adoption of 5G implementations in port operations enables massive real-time data collection and analysis, leading to cost reduction and improved efficiency, thus enhancing competitiveness.

As part of the COREALIS program [6], the Port of Livorno in Italy hosted the project “5G Port of the Future” and the initiative “Logistics of the Future in Sustainable Smart Ports”. The objective of these initiatives is to demonstrate how integrated information from different devices and ships within the port area, coupled with improvements from augmented reality technologies and advanced control algorithms at a centralized level, can optimize loading and unloading operations and enhance personnel safety.

The Chinese Port of Ningbo-Zhoushan (NZP) [7], one of the world’s busiest ports, embarked on a pilot project in 2018 to adopt 5G technology. The pilot project focused on enhancing remote gantry crane operations, management, and video backhaul applications using the 5G network.

The 5G Infrastructure Public-Private Partnership (5G PPP) [8] is a joint initiative between the European Commission and the European ICT industry. Its aim is to provide solutions, architectures, technologies, and standards for next-generation global communications. The objective is to ensure European leadership in areas where Europe has the strength or the

potential to create new markets, as well as to improve the competitiveness of the European industry in global markets and open new opportunities for innovation. The 5G-PPP enabled system focuses on supporting new implementation scenarios for different market segments, providing optimized support for various services, traffic loads, and end-user communities. It involves stakeholders from different sectors, both public and private, to bring together the diverse competencies needed to achieve the project's goals. Among the 5G-PPP projects, several are particularly relevant:

- 5G-MoNArch— Mobile Network Architecture. The 5G Mobile Network Architecture for diverse services, use cases, and applications in 5G and beyond [9] is a project aimed at gaining knowledge and experience from using the 5G network slicing in a real-world environment, proving and improving the underlying technical concepts and methods. The overall goal is to provide a wireless infrastructure that can handle a large number of operations of the port's day-to-day work.

- 5G-EVE—European 5G validation platform for extensive trials. The 5G-EVE project [10] has the aim to implement and test advanced 5G infrastructures in Europe, to foster the adoption of AGVs, real-time image processing, 5G end-to-end facilities, and smart transport. The final goal is to interconnect four existing European sites (in Italy, Spain, Greece, and France) to form a unique 5G end-to-end facility, which is composed of various elements, such as 5G new radio, distributed cloud, MEC, and slicing [11].

- 5G-GENESIS. The 5th Generation End-to-end Network, Experimentation, System Integration, and Showcasing (5G GENESIS) project [12] has the aim to develop a set of end-to-end and experimental platforms (each one associated with a specific city) to facilitate 5G and related trials.

- 5G-SOLUTIONS. The 5G Solutions for European Citizens [13] project has the aim to validate that 5G is a prominent technology starting from five significant industry vertical domains in five countries to exploit the real commercial potential of 5G. In particular, the Norwegian pilot site aims at developing innovative use cases regarding smart solutions to optimize and improve operational efficiency and reduce logistics costs in the port.

- 5G-MOBIX. The 5G for cooperative and connected automated MOBIility on X-border corridors project [14] aims to develop and test automated vehicle functionalities using 5G core technological innovations along multiple cross-border corridors and urban trial sites, with a focus on truck platooning, vehicle remote control, highway lane merging, road user detection and urban environment driving.

- VITAL-5G. The VITAL-5G project [15] will create an open, virtualized and flexible experimentation facility comprised of an intelligent virtual platform, three distributed European 5G-testbeds in Antwerp, Athens and Galati (Danube), and associated vertical infrastructure, to enable the testing and validation of T&L Network Applications (NetApps) in real-life conditions, utilizing 5G connectivity. It will capitalize on recent 5G research (5G-BLUEPRINT, 5G-SOLUTIONS and 5G-EVE) by exploiting and developing the results for the T&L (transport and logistics) vertical, impacting large-scale actors and SMEs active in the T&L ecosystem. It aims to deliver three main innovation elements (the Vital-5g Service Portal, the Vital-5g Facility at T&L Sites, and the Vital-5g Open Online Repository&netapps) to be offered to third party experimenters through a joint commercialization approach with key consortium partners.

2.2. Literature Review

Supply chain optimization through the development of innovative, technology-based solutions is gaining importance in addressing the continuously growing requirements of the modern economy. In their literature review, Del Giudice et al. [16] explore the capacity of digitalization and new technologies for sustainable and innovative development in shipping and seaports. The focus is on the development of innovative business models that can achieve environmental, economic, and social goals. The review, covering publications from 1969 to 2020, highlights that the literature primarily focuses on environmental externalities.

According to Uusitalo et al. [17], several key enabling technologies for port automation are ready for adoption. These technologies include autonomous vehicles, augmented reality, cloud computing, big data analytics, and artificial intelligence. The authors emphasize that new 5G communication networks will play a crucial role in integrating these technologies and enabling their practical implementation. In contrast, Wi-Fi-based networks are considered insufficient for the scope of port automation use cases.

In the realm of smart supply chains, Gerasimova et al. [18] analyze transnational smart supply chains from a service design perspective. Their study focuses on the integration of blockchain technology and smart contracts in logistics processes. From the study, there emerge the critical role of IT strategic planning to boost and make effective the IoT-driven business processes redesign, the need for collaborating with high-profile technological partners to design suitable

IoT infrastructures, and the relevance of project management to support business processes redesign via the IoT. Similarly, Philipp [19] investigate the potential of blockchain technology and smart contracts in optimizing value chain operations and fostering the implementation of business models.

The Port of Hamburg serves as a case study in the work of Ferretti and Schiavone [20], which examines how IoT technologies have redesigned business processes in a smart port. The study concludes that the adoption and effective utilization of the IoT-driven business processes redesign rely on port-specific factors, such as management practices and infrastructure investments, as well as stakeholder-related aspects like strategic partnerships and IT choices. The study highlights the critical role of IT strategic planning, collaboration with technological partners, and project management in supporting business processes redesign through the IoT.

The implementation of IoT technologies and the smart port concept are also evaluated in the context of the Port of Le Havre by Rajabi et al. [21]. The authors explore how IoT technologies facilitate data collection, monitoring, intelligent decision making, and logistics and transportation management in ports.

In their analysis of the Port of Livorno in Italy, Cavalli, Laura, and Giulia Lizzi [22] discuss the benefits of introducing 5G, augmented reality (AR), and AI-based use cases. These advancements contribute to economic, social, and environmental benefits, such as reducing transit time, decreasing vessel and unit operations, maintaining safety conditions, minimizing environmental impact, and enhancing system automation and service flow.

The experience of the Port of Oulu in Finland confirms the strong link between the value proposition of the port ecosystem and various technological components, including 4G/5G wireless connections, fixed optical fiber connections, sensor networks, big data storage, digital twin technology, and analytics powered by artificial intelligence and machine learning [23]. The authors propose an innovation of the “4C Typology” business model layers (connection, content, context, and commerce) due to the influence of digitalization.

Ahokangas et al. [24] focus on the Port of Oulu as a use case to develop a multi-stakeholder engagement process for the introduction of a 5G-enabled common data platform and associated regulatory challenges. They emphasize that enhanced situational awareness can bring value to multiple stakeholders in the ecosystem through an optimally hybrid data platform with centralized connectivity. They also highlight the need for widespread approval from regulatory bodies to achieve industry-level legitimacy and scalability of solutions, particularly for local and private 5G network deployments.

Examining the port of Motril-Granada in Spain, Seisdedos and Carrasco [25] analyze the role of innovative technologies in improving the quality and effectiveness of port operations. Beyond enhancing operational efficiency, these technologies encourage the integration of new players, such as private companies, research institutions, technological centers, and universities, into the existing port ecosystem, fostering the emergence of innovative SMEs and startups.

In their work, Henríquez et al. [26] underline the significance of technological innovation adoption in seaports for business models. They demonstrate how IoT technology’s “building blocks” are associated with the adoption of policies and strategies that increase standardization, cooperation, and information sharing among ports and stakeholders. Furthermore, the investment in an IoT-related infrastructure is expected to lead to additional knowledge-intensive investments.

These studies collectively demonstrate the growing interest in leveraging digital technologies, such as IoT, blockchain, AI, and 5G, to optimize supply chains, enhance port operations, and foster sustainable development. By embracing these innovative solutions and integrating them into business models and processes, ports and stakeholders can achieve various economic, social, and environmental benefits, driving positive transformations in the maritime industry.

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