Lappeenranta-Lahti University of Technology
School of Engineering Science
Industrial Engineering and Management
Master's Program in Global Management of Innovation and Technology (GMIT)

Master's thesis

Usage of modern sensors and network technologies in context of supply chain management

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ABSTRACT

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Industry-leading companies deploy the latest digital tools, invest in advanced analytical applications, and purchase the latest data visualization software. Creating a digital platform allows companies to manage information and material flows in real-time.

This study examines development trends and opportunities for using the Internet of Things (IoT) sensor technologies in terms of cargo transportation in Supply Chain Management (SCM). The main goal of this study is to identify and analyze the possibilities of applying modern sensor and network technologies in supply chain management. Relevant literature sources have been collected to define the concepts of SCM, IoT, and leading technologies related to IoT. This information has enabled the creation of a conceptual framework that includes analyzed IoT technology solutions and related 5G and LoRa networks.

Also, an expert survey was conducted with representatives of large companies to confirm the value of using and implementing sensor technologies in SCM. The results of the survey showed that companies see good prospects for the implementation of IoT technologies in SCM. However, some obstacles exist that do not allow companies to fully rely on and use these technologies as key tools for effective supply chain management.

Keywords: supply chain management, Internet of Things, Radio Frequency Identification, Wireless sensor networks, 5G Network, Low-power wide-area network.

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I would also like to thank specialists from the logistics and software industries for their time to answer the survey for the master's thesis. Thank you.

Arsenii Ogarkov

Saint-Petersburg, 28.11.2019.

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LIST OF ABBREVIATIONS

5G – Fifth generation

B2B – Business to business

B2C – Business to consumer

CRM – Customer Relationship Management

GPRS – General Packet Radio Service

GPS – Global Positioning System

GSM – Global System for Mobile Communications

IoT – Internet of things

LoRa – Long Range

LPWAN – Low Power Wide Area Network

LTE – Long Term Evolution (4G)

M2M – Machine to machine

OMS – Order Management System

PLM – Product Lifecycle management

RFID – Radio Frequency Identification

SC – Supply Chain

SCM – Supply Chain Management

TMS – Transportation Management System

WMS – Warehouse Management System

WSN – Wireless Sensors network

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1. Introduction

The world continues to change, and the rate of change is increasing, so ignoring the concept of general digitalization does not make sense. Why do we need digitalization? For companies - to increase their efficiency, stay "afloat" in frames of enormous competition. In a business context, an organization that wants to become "digital" should focus on automating processes in order to make them more efficient. A company that focuses on digitalization should aim to get a better return on these processes, through higher customer engagement, or by reducing costs and expenses at all stages of work. One of the most significant development trends in this regards seems to be artificial intelligence and different cases of using it to reduce costs and enhance product and process designs (Ghoreishi and Happonen, 2019a; Ghoreishi and Happonen, 2019b)

The logistics industry has historically been designed to minimize the likelihood of failure. This is justified for large projects where the cost of error is enormous, while digitalization makes it possible to foresee and predict such errors, thus conserving resources, which means increasing the efficiency of the company. Furthermore, against the backdrop of the development of digitalization, other technologies, one way or another connected with it, also receive more attention and attract more investments.

Sensor technologies are currently experiencing an active period of development. This is especially noticeable in the example of smartphones, tablets, wearable gadgets, and other electronics that are tightly integrated into our daily lives. Also, in various industries, logistics, IT, agriculture, and the military sphere, the need is ripening for the organization of reliable control systems and monitoring of distributed objects and their integration into a global network. Especially in logistics, trends are towards a higher level of automatization, process digitalization and enhanced process optimization (Minashkina and Happonen, 2018). Similar trends are observed all over the world and lead to the inevitable development of wireless communication technologies. Sensor technologies are tightly entering our lives, but at the same time, the question of device autonomy raises a sharp question, since the use of this technology often involves the rejection of all available wires and cables.

1.1. Background

Modern logistics is changing under the influence of many factors. The role of 3PL operators is changing in supply chains (Hemilä, Salmela and Happonen, 2007), and the requirements of consumers in B2B and B2C segments are increasing in terms of speed, quality, and transparency of processes. New market models (shared consumption economics, crowdsourcing, etc.) are changing the nature of logistics processes, architecture of chains, and fleet-level asset management

(Kortelainen et al. 2016; Kärri et al. 2017) reducing the number of links. New players enter the traditional market: these are start-ups offering more flexible pricing solutions for delivery using new technologies (for delivering the "last mile", freight rates, etc.), and large players from high-tech industries (autonomous transport, UAVs and other) (Kersten, Blecker and Ringle, 2015).

Logistics, however, lags in terms of digitalization compared with the areas of telecommunications, media, banking, and retail. There is still a lot of manual labor in most conventional logistics companies, and the available resources are being used inefficiently. Lack of organizational flexibility and accountability is a barrier to the effective development of logistics processes (Digital Transformation of Industries, 2016).

The digitalization of the logistics sector should be based on the creation of a reliable internal digital foundation in companies, the introduction of new business models and services. The problem is, that for digitalization, one needs proper IT tools, and as the literature work done by (Minashkina and Happonen, 2019) reveals, e.g., Warehouse Management Systems could definitely gain from some wide range large scale research to boost the system providers to see bigger picture for functions and features to be implemented into these systems.

Digital Logistics emerges as a response to the digital economy's global challenges to conventional transport and logistics industries, such as the rapidly changing, globalized and highly competitive trading environment, the complexity of the supply chain, rapid changes in customer expectations, and restricted infrastructure resources. In other words, rapid development means a need for logistics operators to have rapid expansion capabilities and flexible operational models (Happonen and Salmela, 2010), to be able to respond to these changes in our world.

At the same time, in the B2B sector, it may be promising to introduce technologies, including those using the "Internet of Things" achievements, which allow a potential customer to independently track relevant information about the proposal, namely, the goods being prepared for sale, by tracking the production cycle (manufacturing, shipment , transit time, estimated date of arrival at the warehouse, etc.), which will allow for more efficient procurement planning and, accordingly, their logistics support.

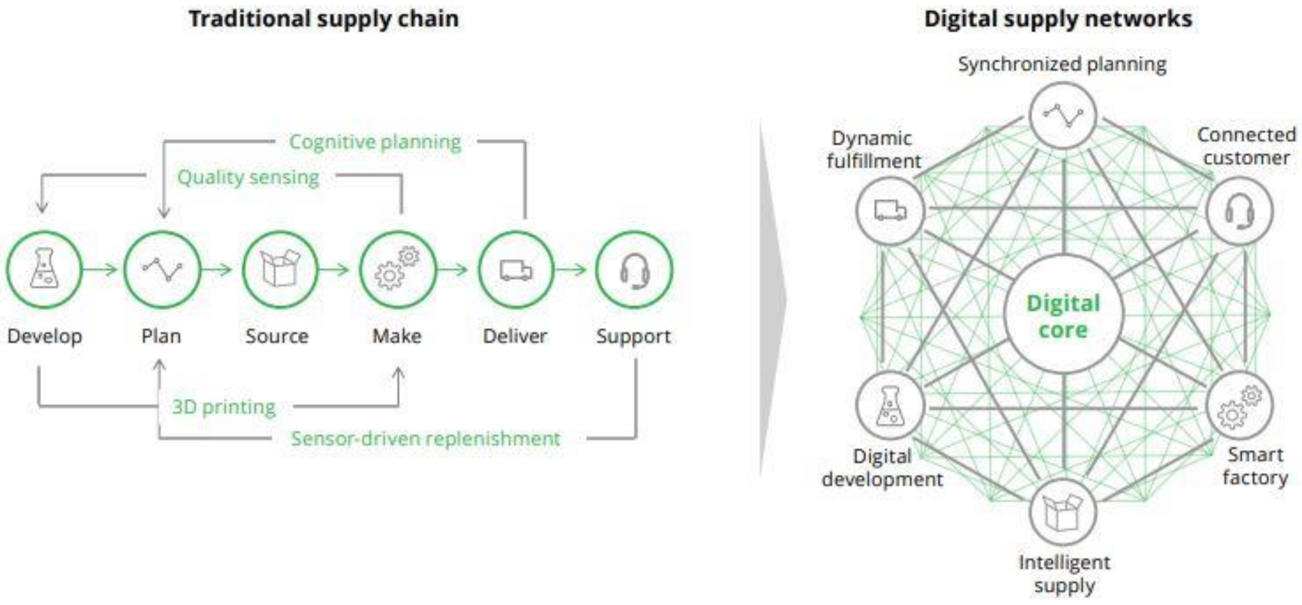

Figure 1. Moving from the traditional supply chains to the digital supply chain. Source: Mussomeli, Gish, and Laaper, (2016)

21st century supply chains are more complex and dynamic than ever before. How efficiently and profitably companies can schedule and ship the goods to customers - this is what distinguishes the giants of business from the laggards. For businesses that determine the real value of the business and the effects of a highly competitive global economy, several factors need to be managed better: such as stock, price, resources, and new product launch. In addition, it cannot occur without the best-in-class digital supply chain that will transform the world of modern logistics by working with IoT technologies.

1.2. The aims and objectives of the study

The purpose of this study is to analyze challenges and opportunities of introducing of applying modern sensor and network technologies in supply chain management. There is a sufficient number of studies determining the impact of IoT on SCM, however there is a lack of research aimed at the possibility of combining WSN and RFID sensor solutions in SCM even when some research exists for understanding the technical possibilities and limitations of the RFID tags themselves (Hämäläinen et al. 2007, Happonen et al. 2008). The paper will consider models for optimizing and protecting container traffic using technology. Also, besides RFID and WSN research, paper will include studies about the possibility of introducing technologies to ensure modern methods of network communication as 5G and LoRa. In addition, ways to ensure the efficient transportation of goods will be considered.

Thus, the research questions are formulated as follow:

RQ1: *Which are the areas in SCM that could be optimized by sensors and network technologies?*

RQ2: *How modern literature and expert opinion suggest that sensor and network technologies are relevant to be integrated into SCM?*

RQ3: *How utilizing RFID and WSN sensors technologies and 5G and LoRa network technologies influence internal SCM?*

1.3 Research outline

In order to answer the research questions, the following stages will be carried out:

1. Literature review, including definitions of SCM, IoT. Identification of problems that SCM can solve with IoT. Identification of current IoT technologies and communication in SCM. Identification of the main advantages and disadvantages of integrating IoT solutions into SCM.

2. A conceptual framework based on the article's analysis describing modern IoT solutions and communication was developed as a **qualitative analysis**.

According to Grant and Osanloo (2014) and Green (2014), the conceptual framework is qualitative research proposes a logical structure of interrelated concepts that helps to present a picture or visual representation of how ideas in the study relate to each other in a theoretical framework. The conceptual framework also provides an opportunity to concretize and define concepts within the problem.

3. Further, taking into account the fact that the conceptual framework was implemented mainly based on literature review and analysis of sources describing the solutions, it was selected an approach of the expert survey for representatives of companies working in the field of IoT solutions development, logistics business and cargo transportation.

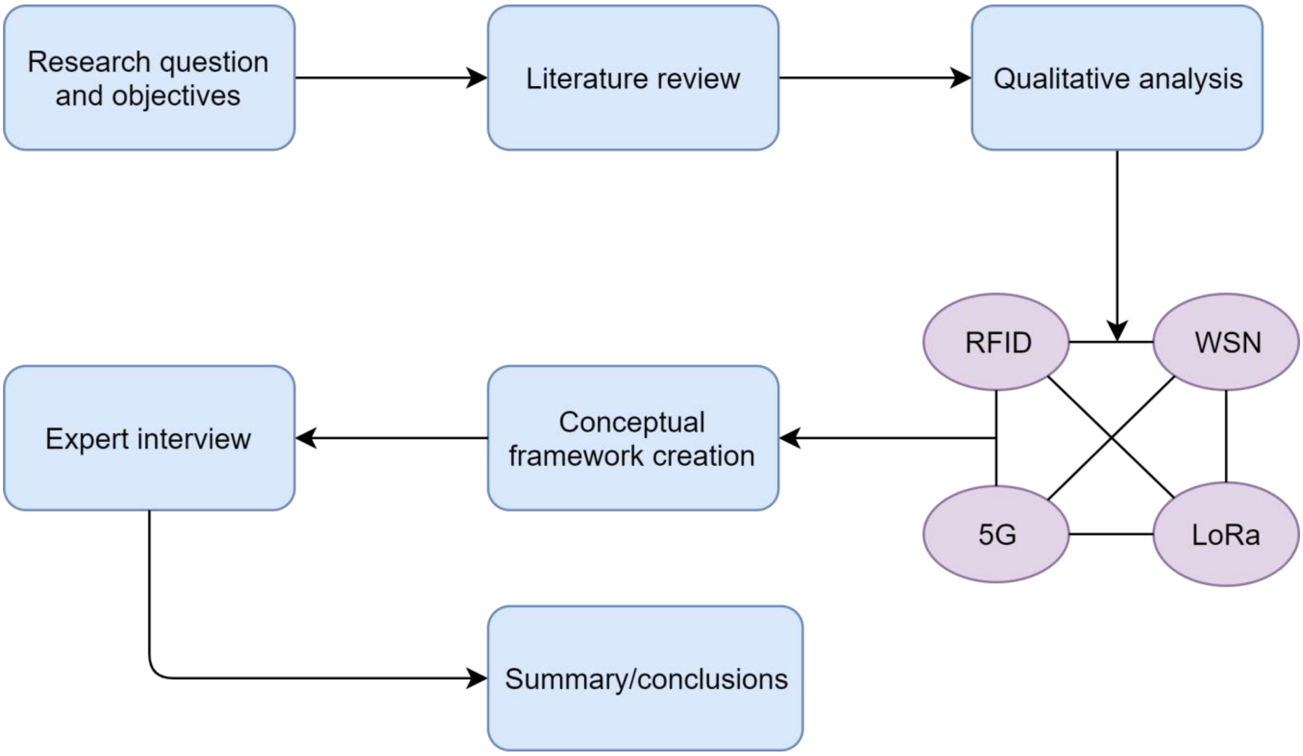

Figure 2. Research design.

2. Literature review on Supply Chain Management, Internet of Things and related technologies

2.1. Supply Chain management definition issue

The study of key works in the field of supply chain management and the interpretations of the word "supply chain management" by writers at different stages of development is important for our understanding of the evolution of the supply chain management concept. In the works (Oliver, Webber, 1982; Jones, Riley, 1987; Stevens, 1989), focuses on technology coordination and improved mutual understanding between partners while maintaining a given level of service. In the works (Ellram, 1991; Christopher, 1992; Cooper, Ellram, 1993; La Londe, Masters, 1994; Cooper, Lambert, Pagh, 1997; Lee, Ng, 1997; Croxton et al., 2001) emphasized the integration of key business processes. Finally, in (Mentzer et al., 2001; Gundlach et al., 2006) develops the idea of a marketing approach to supply chain management.

Table 1. Supply Chain management view based on previous research.

Source	Definition
Oliver, Webber, 1992	Supply chain management covers the flow of products from the supplier, through the manufacturer and distribution channels to the end customer.
Ellram, 1991	An integrated approach to planning and controlling the flow of materials from the supplier to the end-user.
Cooper, Lambert, Pagh, 1997	Integrated philosophy of total flow control in the distribution channel from the supplier to the end-user.
Mentzer et al., 2004	Systematic, strategic coordination of traditional business functions within a particular company and beyond in the supply chain to improve the long-term performance of both each individual company and the supply chain as a whole.
Gundlach et al., 2006	A network of companies from suppliers to end-users who have a tendency to integrate supply/demand through the coordination of companies.
Borade and Bansod, 2007	SCM is the management of material, money, men, and information within and across the supply chain to maximize customer satisfaction and to get an edge over competitors.
Kappauf, Lauterbach and Koch, n.d., 2012	SCM is the observation and administration of logistical processes along the entire value creation chain, which includes suppliers, customers, and end consumers.

According to D. Lambert and J. Stoke (2007), SCM is defined as «integrating key business processes starting from the end-user and encompassing all suppliers of goods, services, and information that add value to consumers and other interested parties». In discovering this definition, the authors indicate that supply chain management is the combination of eight major business processes, namely:

Figure 3. Supply Chain management business processes. Adopted from Stock and Lambert, 2007

Due to the widespread adoption of the SCM paradigm, the Council of Supply Chain Management Professional (CSCMP), previous name CLM (Council of Logistics Management), has revised the definition of logistics in such a way that logistics is part of SCM as a broader concept. According to the definition of CSCMP, "logistics is part of the supply chain management process and represents the planning, implementation and control of the efficiency of the flow and stocks of products, services and related information from the point of origin to the point of consumption in accordance with the requirements of consumers" (Cscmp.org, 2019). This approach avoids the contradictions between the concept of logistics and SCM, which could arise because the concept of SCM appeared later.

It has to be remembered that the development of the concept of supply chain management has internal limitations predetermined by the task of continually reducing costs in the supply chain. According to B. Ferrari and B. Parker (2006), «the key competitive advantage is not in reducing costs or increasing economic efficiency, but in innovation». Organizations that are capable of constantly creating innovative products, developing innovative processes and business models can succeed in the long run. At the same time, since companies become global and dependent on external partners, the supply chain begins to play an increasingly large role in innovative strategies (Ferrari and Parker, 2006). Accordingly, one of the directions of development of supply chain management is the shift of priority from reducing costs in the process of creating a product in the supply chain to increase the cost of an innovative product created in the supply chain. In other words, the marketing approach progressively replaces the classical logistics approach to supply chain management (Jüttner, Christopher and Baker, 2007).

2.1. Challenges of supply chain management

A modern understanding of supply chain efficiency is to design supply chains that are highly cost-effective and sustainable. Supply chain actors are now aware of the need not only for internal integration of supply chain processes but also for coordination between other supply chain processes: suppliers and consumers, in order to provide a higher level of service to supply chain customers at a lower cost. The next challenges of SCM were analyzed and summarized according to (A.H Awad and Othman Nassa, 2010; Croxton et al., 2001; Bala, 2014).

1. Conflict

When the interests of the parties involved are contradictory or ambiguous, a dispute in a partnership exists. There is an internal conflict of interest in supply chains where the best strategy in the supply chain for the individual company may vary from the appropriate course of action throughout the whole chain. Conflict still often occurs in the allocation of revenue through rivalry. In addition, often inner, relational departmental or employee disputes can interact with performance.

2. Security

Information security is defined by the possibility of unauthorized access to the information system and confidential information leakage through information and communication networks or insiders. Stealing and loss of products leads to capacity stoppages, incompleteness, as well as unnecessary costs for ordering additional shipments. Trust increases information flow allows for quick decision-making and plays a vital role in supply chain management.

3. Delays

Delays in delivery and the selection of inefficient routes can have significant consequences and can result production stoppages in supply chains that use the "just-in-time" principle. This also has a negative impact on client satisfaction, as one of the most significant satisfaction variables is shipping deadlines fulfillment. Information delays influence on the simplicity of handling. When information is obtained after it is necessary, the data is worthless if a decision has already been made. Delays can decrease the efficiency of planning and lead to untimely monitoring.

4. Demand fluctuations

Unanticipated market swings result in surplus or insufficient inventory. Such difficulties may be caused by the «Bullwhip effect» associated with product promotion and forward sales. Problems arise at the operational level when the company's market demand changes too quickly and unpredictably (Wang and Disney, 2016). Even if production is able to react to unexpected changes in demand, it can cause side effects, for example, increased goods defects and losses. Changing information in the supply chain can reduce demand fluctuations, which will reduce the cost of inventory storage.

5. Imprecision

Predictive and manual data entry inaccuracies can occur, which can lead to mistakes in price, number of the order, destinations and stuff like that. The actual values and dynamics of functional parameters should be accurately reflected in logistic data. The information's higher precision reduces uncertainty and the need for unplanned actions. Data synchronization can resolve issues of low quality and accuracy of data among partners.

6. Lack of resources

There can be a lack of information lack of information when too little data is available to optimize the decision-making process. It occurs from too few factors being evaluated or from a poor flow of information between organizations and divisions. Inexperience and low knowledge, as well as low staff qualifications, result in low productivity of labor and high labor costs.

7. Under-utilization of resources

The high level of stocks is connected with high uncertainty, large batch sizes, fluctuating demand, seasonality, and a high level of service. In an uncertain environment, a high level of inventories helps to smooth out random fluctuations in stock consumption, and also prevents against two sorts of uncertainty: excess demand over the expected level within the functional cycle (the customer orders more than planned) and fluctuations in the duration of the functional cycle (due to delays in delivery, failures). Also for low value and quite certain demand items, it does not make too much sense to do to use complex algorithms to optimize their inventory amounts, if one could get more financial benefits by ordering in bulk and minimizing the amount of effort and resources used to work with these items (Happonen, 2011; Happonen and Salmela, 2011; Happonen, 2012). However, a high level of inventory may also have a negative impact on an entity's operations because it comprises increased storage costs and leads to risks of possible product quality loss and damage. Partial loading of the vehicle is a costly problem in freight transport. Incomplete vehicle loading is a costly problem in freight transport. Duplication of activities, which is due to barriers between companies, which hinder the efficient transfer of information, is also a problem.

Table 2. Classification of supply chain problems.

Problem	Source	Reason
Conflict	Relations	Different goals, conflicts of interest, competition for the majority of profits, interpersonal conflicts between departments, role conflicts, isolation of functional units
Security	Cargo, information	Losing, stealing, damaging. Information leakage.
Delays	Cargo, information	Delayed supply, inefficient transport route. Information delay.
Demand fluctuations	Stocks	Demand changes faster than production cycles, Bullwhip effect, seasonal variations
Imprecision	Information	Incorrect forecasting; manual data entry
Lack of resources	Stocks, Information	Demand exceeds supply. Measuring a small number of variables; weak internal information exchange between departments, organizations
Under-utilization of resources	Stocks, Cargo	High uncertainty, large lot size, fluctuating demand, seasonality, high level of service. Underutilization of vehicles

2.3. Internet of things applications in SCM

According to the Internet of Things Global Standards Initiative (Itu.int, 2019), the Internet of Things is a global infrastructure for the information society that provides access to high-tech services through the interconnection of physical and virtual things, based on current and incoming real-time information and communication technologies.

The Internet of things, to one degree or another, is already used in various industries - finance, logistics, construction, transport - for specific purposes, from the organization of the functionality of "smart homes" to the construction of "smart cities." Consider the application of this technology with specific examples. As part of the creation of a “smart home”, various sensors and software components are used to develop and maintain intelligent security services and services for optimizing the use of resources by households in order to automate as much as possible all systems inside the apartment: is the front door closed, is the iron turned off - all household information is displayed on the phone with a further opportunity to complete the action remotely via the same smartphone. Cameras and sensors at the front door allow us to identify a person, and when he appears at the door once again, send a signal to the owner. Sensors in the refrigerator notify the owner of the expiration of products or the exhaustion of food (Tareq Khan, 2019). To optimize urban traffic, sensors measure traffic congestion, calculating the need and potential location for the construction of a new interchange.

The benefits from the implementation of the Internet of things extend to the field of logistics, predicting a benefits not only for business but also for end consumers due to the possibility of introducing technology along the entire value chain: warehousing, transportation, delivery to the final consumer, etc., improving performance indicators, quality of service and safety (Phase and Mhetre, 2018). The Internet of things will allow us to track the physical and geographical characteristics of the system elements in real-time, measuring indicators, producing appropriate calculation of coefficients, making changes based on the situation. This technology minimizes human involvement, minimizing unpredictability and reducing costs.

It is no coincidence that it is in the field of logistics that the Internet of Things has high expectations. Tens of millions of objects are stored, moved, entered into and removed from the systems, interact with each other, which requires a monitoring and control system, debugged to automatism, allowing with the functionality of all elements of the system not only with the least losses but also with an increasing inefficiency. Unlike the automation systems currently used in logistics, the Internet of Things is a kind of “self-learning,” collecting and analyzing data throughout the supply chain to generate new ideas and ways to solve problems. The existing technologies, the growth of wireless networks, the development of Big Data, the cheapening of sensors, actuators, and other components are pushing industries and businesses to implement the Internet of Things (Heutger, Macaulay, and Kückelhaus, 2015).

In warehouse logistics (Tejesh and Neeraja, 2018), for both short-term and long-term storage of goods, premises are needed along with monitoring and control systems that have a significant impact on costs, efficiency, flexibility and other indicators that are reflected in the competitive advantages of logistics providers. Again, many goods pass through warehouses daily and are stored in warehouses, many of which require compliance with individual temperature and light conditions, have different physical and geometric characteristics, complicating the processes of warehouse logistics. In turn, for the warehouse providers themselves, every square centimeter of the warehouse and every minute of activating the mechanisms to minimize costs and maintain as many system objects as possible per unit of time are economically important. The Internet of things can offer a high coordination of pallets, forklifts, and other elements with the entire infrastructure of the building through, for example, RFID identification devices, which allow reading and saving information when an object passes through the same trucks, pallets, etc. In addition to the basic functions, smart sensors will help to save the consumption of resources, such as electricity, water, due to the automatic on/off function.

As a result of the above, we consider the classification of IoT applications in the transportation and storage of goods proposed by PWC (2017). Connected vehicles guarantee the transparency of geolocation, optimize the use of vehicles, and control driver behavior. Autonomous transport serves as an assistant to the driver, allows automatic taxiing. Security ensures identification of objects that are alien to the system, prevent theft and misuse of vehicles, and analyze incidents that have occurred. Asset tracking involves obtaining information about the condition of the goods, warehouse. A smart infrastructure transmits data on the state of its elements. Automation of warehouses allows tracking the load of tiers, loaders, their location.

The advantages of using this technology in transport (freight) logistics do not differ from the advantages used in warehouse logistics listed above. There are many vehicles of water, land, and air types that carry out not only single-mode but also multimodal transportation, the coordination of which is a very time-consuming process. Today, the Internet of Things allows to track containers with cargo, receiving information about the condition of the cargo and the location of the container, but theft and damage to the cargo still occur during transportation. The Internet of Things promises to make the process of monitoring the location of the container and the condition of the cargo more detailed and transparent, minimizing the possibility of losses. Consider the example of transporting a container using the multimodal method using air, road, and water transport described in the DHL report (Heutger, Macaulay and Kückelhaus, 2015). In real-time, information is transmitted to the responsible centers from all sensors installed on each object of this Internet of things system: airplane, cargo ship, truck, cargo itself. The sensors measure the speed of the vehicle, the presence of possible breakdowns, predict the time of arrival of the cargo or transport to the next intermediate port, and, if necessary, send a call command to the work crew to timely repair vehicle breakdowns or diagnose the cargo for damage. Sensors in the container measure temperature, humidity, determine the location of the cargo. DHL also monitors the driver's condition, determining whether a rest stop is necessary.

2.4. The basic model of the Internet of things

Firstly, consider the functioning of the Internet of things in its basic form, a five-level pyramid (Xuyang et al., 2016) (Pardini et al., 2019). At the lower tier, data is collected through IoT objects (things): sensors and sensors, counters, video cameras. On the second tier, the previously collected data is transmitted via fixed, mobile, and/or satellite communications. The third level is responsible for the aggregation, storage, and processing of data to compress or group them to transfer more structured data of a smaller volume to the next level. The fourth level - the platform - is responsible for device management, data analysis, and security. It is noted that the success of a particular technology depends on both technological advances and reliable business models. The business level at the highest level can manage the entire system. Based on the data obtained from the application layer, several business models can be built at this level (Xuyang et al., 2016). Supplement the definition with another variant of the basic explanation of the functioning of the Internet of things (Szilagyi and Wira, 2016). A «thing» in IoT can exchange data with other IoT objects through tags and sensors installed on it to coordinate actions and/or generate data that will be used at higher application levels (for example, data analysis or making "smart decisions"). Following the standards and protocols in the field of communication (for example, Bluetooth and ZigBee), data through the router (router) is sent from things to the cloud storage (cloud), following other protocols (for example, TCP / IP). The reverse process also occurs due to the two-way communication of the cloud and objects.

At the same time, things in IoT are not necessarily capable of independently performing the computational and communication functions that the chip can carry out (for example, an RFID tag, a sensor, a camera). Thus, anything can be an IoT object, as long as it meets the definition of "smart things" and is useful for the system: tags (QR code, RFID), devices (smartphone, thermometer), equipment (smart light, smart car) or the whole environment (smart city, smart home) (Kotis and Katasonov, 2013).

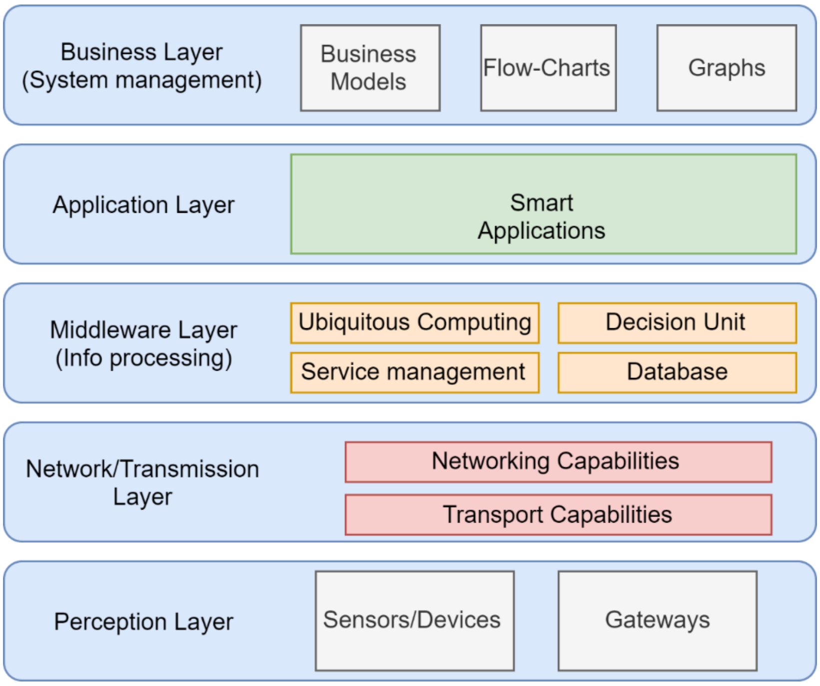

Figure 4. Architecture of IoT application (Xuyang et al., 2016).

2.5. Benefits and barriers of IoT adoption in Supply Chain Management

Main barriers to the IoT integration

The growth of innovations in SCM is constrained by severe factors, including outdated or underdeveloped infrastructure, operational incompatibilities, high initial investment, outdated communication systems, slow process automation, the complexity of integration into existing systems, and the growing threat to cyber-security. Moreover, trains are in motion most of the time, and weather conditions are variable, making IoT implementation more difficult. According to a PwC report, low labor and energy costs, lack of accurate and detailed maps, bureaucracy in decision-making, and lack of uniform standards also hamper the development of IoT (PWC, 2017).

According to the research (Brous and Janssen, 2015), the complexity of IoT implementation is related not only to global factors but also to the individual characteristics of the company where the technology is implemented. The most critical factors in the survey were: lack of knowledge and skills of employees, lack of knowledge and commitment of senior management to new policies, relatively high investment in IoT infrastructure, lack of awareness of the benefits of improved products and services, regulations and standards (such as data privacy). Equipping all IoT system facilities with sensors, sensors, tags, and other equipment that collect information about a variety of factors (geolocation, temperature, pressure, speed, availability, etc.) generates a massive amount of information that needs to be stored, processed for further useful use and secure.

Because of the existence of many definitions of Big Data, let us characterize this term by the parameters highlighted in the study "Big Data Analytics for Wireless and Wired Network Design: A Survey": as high-volume, high-velocity, and high-variety data. They offer significant incentives for cost-effective decision-making and enhanced analysis through advanced processing which extracts data information and knowledge (Hadi et al., 2018). The Internet of Things has a very significant impact on the 3 BD parameters - volume, speed and diversity - which are becoming key areas of BD management within IoT.

These three variables, in turn, influence the vital criterion of data efficiency - waiting time. Yes, the data is transmitted in real-time, but due to its massive volume, the question arises: how real is this real-time? This refers to the time it takes to wait for a response after the data is transmitted, which is important to get before the data becomes outdated. There are three types (reasons) for the increase in waiting time: data delay - the time required to collect the data; analysis delay - the time required to evaluate the data and convert it into information to take action; and response delay - the time required to take action itself (Hackathorn, 2004). For IoT, the most significant delay is the delay in taking action or providing a response, as data within the system is not collected simply for statistics, but is transferred from one system object to another, often signaling deviations. Reaction times need to be kept to a minimum, otherwise, the whole point of IoT is meaningless: if the information about the temperature increase in the refrigerated drug container was received at 3:30 p.m. and the measures taken at 8:00 p.m., the entire batch may be damaged and destroyed.

Main benefits to the IoT integration

Despite existing barriers, transportation companies around the world are increasingly implementing certain elements of IoT (Čaušević, Čolaković, and Hasković, 2018). This is because data transfer technologies are becoming faster, safer, cheaper; sensors and transceivers are smaller, more affordable and less power-consuming; batteries are holding a longer charge to cope with the problem of not being able to charge them continuously; and cloud services are being developed to store vast amounts of data and manage Big Data. Besides, it is forecasted that the cost of maintenance and repair will increase due to the deterioration of the existing railway infrastructure and the increase in passenger traffic and cargo transportation, which already today makes it necessary to monitor complex operational and repair works of many heterogeneous elements of the railway infrastructure (Rabatel, Bringay, and Poncelet, 2011). For example, sensors transmit data on the location of the composition, its speed, mass, weather conditions, vibrations of the railway belt, which will allow to adapt the requirements to the operation and repair of the composition and its components and mouth. According to article (Jo, Kim and Kim, 2018), to estimate expediency of introduction IoT, it is possible to calculate, what share in structure of expenses for infrastructure maintenance in a working condition is necessary for human resources (inspection of a condition of an infrastructure manually that at introduction IoT it will be possible to automate), what on actually repair. This will allow us to roughly estimate how ineffectively the company's resources are being used now.

According to a study of the introduction of RFID technology in logistics and transport companies alone, the average percentage benefits of its introduction for the companies studied were as follows (Uckelmann, 2012):

- Time, physical and human resources for loading and unloading of vans/wagons/containers were reduced by 13%;
- Administrative overheads on incoming goods were reduced by 70%, and time spent on incoming goods was reduced by 90%;
- The number of accidents decreased by 54.3%, and the cost of claims and lawsuits was reduced by 29,7%.

Thus, it can be said that the introduction of IoT opens up a number of opportunities for the company in such areas as (Macaulay and Kückelhaus, 2019): monitoring of various characteristics and attributes of objects and processes, measurement of performance indicators, control and making changes without human intervention, automation of business processes, training from information provided by analytical systems, etc.

Consider in which of the articles and publications studied in the framework of this thesis, and there were barriers and disadvantages, as well as incentives and advantages of implementing the Internet of things technology (table 3 and table 4). To determine these factors, in addition to working with Internet portals and educational publications, the following articles and research papers were analyzed:

1. Mubarak A. On big data management in Internet of things / A. Mubarak // Department of Computer Science, University of Science and Technology. In this research paper, 85 pages describe the integration of Big Data technology into the Internet of things through a platform that combines foggy and cloud technologies, creating the effect of synergy between historical data from the Big Data platform and real-time data from many IoT devices. As part of the study, external and internal factors that influence the implementation of the Internet of things technology are studied, and the advantages and disadvantages of the technology are determined.

2. Sundmaeker H., et al. Vision and Challenges for Realizing the Internet of Things / H. Sundmaeker // CERP-IoT. - 2010. This research work was carried out by the Cluster of European research projects for the implementation of the Internet of Things CERP-IoT. On 230 pages, the complete process of the evolution of the Internet of things is analyzed, starting from the reasons for its origin, barriers to the introduction of technology, real cases of its implementation, analysis of technological, economic, information and operational aspects and ending with forecasts of the development of the Internet of things.

3. Berg M., Nordlindh M. Implementing Internet of Things in the Swedish Railroad Sector / M. Berg, M. Nordlindh // Department of Informatics and Media Uppsala University Sweden. - 2012. This research work is devoted to the study of the real implementation of the Internet of Things, the main purpose of which is to improve the logistics aspects of Swedish freight rail transport through the introduction of the Internet of Things, followed by the integration of technology into the European railway system. As in the case of this WRC, the main emphasis is on the initial stages of implementation, as the project is only getting ready for full implementation.

4. “Internet of Things” (IoT) in Russia [Electronic resource] // PwC report. - 2017. A study by the international consulting company PwC is dedicated to the analysis of the Internet of things market in Russia in some industries: electricity, healthcare, agriculture and livestock, cargo transportation and storage, smart city and smart home. The study includes an analysis of economic, informational, operational, and technological barriers and the advantages of IoT implementation, which are specific for Russia; economic assessment of the potential of IoT implementation in each of the industries; directions of development of IoT.

5. Fraga-Lamas P. Towards the Internet of Smart Trains: A Review on Industrial IoT Connected Railways / Fraga-Lamas P. // MPDI: Sensors Open Access Journal. – 2017. This article analyzes the industrial Internet of things through the case of IoT implementation in rail transportation, focusing on wireless network technologies, sensors, communication systems as tools for the effective functioning of the technology, offering various implementation scenarios and the architecture of the Internet of things, including the study of IoT-systems for monitoring infrastructure, operations, safety, forecasting in rail transportation.

6. Ferretti M. et al. Internet of Things and business processes redesign in seaports: The case of Hamburg [Electronic resource] / M. Ferretti // Business processes management journal. EmeraldInsight Database. - 2016. This article is devoted to the analysis of the real case of the implementation of the Internet of things technology in the port of Hamburg, including from a

logistical point of view, taking into account the railway infrastructure adjacent to the port. The article provides a rationale for the benefits of implementing IoT in terms of optimizing port business processes, despite the barriers inherent in the Internet of Things.

7. Macaulay J., et al. 2015 Internet of things in logistics DHL trend research / J. Macaulay // Cisco Consulting Services A collaborative report by DHL and Cisco on implications and use cases for the logistics industry. - 2015. - 29 p. Pioneering IoT companies prepared this study. They are the ones who are involved in the development of international standards and the architecture of IoT. The study analyzes the barriers and benefits of implementing IoT through a review of best practices in terms of operational efficiency, security, customer satisfaction, and business models. The emphasis is on cases in warehouse and transport logistics with the subsequent identification of key success factors.

The number in the columns corresponds to the study number. The signs “+” and “-” at the intersection of the factor stimulus or factor barrier indicate the presence or absence of mention of this factor in the study respectively.

Table 3. Incentives that influence the decision to implement IoT.

Study number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Mentions**
Data availability	+	+	+	+	+	+	+	7
Processing speed	+	+	+	+	+	+	+	7
Big Data Effect	+	+	+	+	-	-	+	5
The ability to store huge amounts of information	+	+	+	+	+	+	+	7
Technology accessibility	-	+	+	+	+	+	+	6
Rational use of resources	+	+	+	+	+	+	+	7
Error reduction	-	+	+	+	+	+	+	6
Generally accepted standardization	+	+	+	+	-	+	+	6
Cost reduction	+	+	+	+	+	+	+	7
Customer satisfaction growth	+	+	+	+	+	+	+	7

Table 4. Barriers Affecting IoT Decision Making.

Study number	1	2	3	4	5	6	7	Mentions
Security	+	+	+	+	+	+	+	7
Unwillingness to share information	+	-	-	+	-	-	-	2
Battery life	-	+	-	-	+	-	+	3
Infrastructure	-	+	+	+	+	-	-	4
Climate features	-	-	+	+	+	-	+	4
Lack of uniform standards	+	+	+	+	+	-	-	5
Knowledge, Skills	+	+	+	+	-	+	+	6
Regulations and Standards	+	+	+	+	-	-	+	5
Bureaucracy	-	+	+	+	-	-	-	3
High initial investment	-	+	-	+	-	+	-	3

From the tables, it can be seen that most factors are mentioned to some extent in most articles. It is worth considering that some of the articles have a specific specificity. Therefore they do not affect part of the factors (for example, battery life is a factor specific to industries such as rail transportation), which, however, does not indicate the insignificance of these factors.

The figure below shows the main benefits of IoT affecting SCM's business processes. Comparing figures two and the tables above, it can be noted that IoT implementation has a positive impact on most SCM processes.

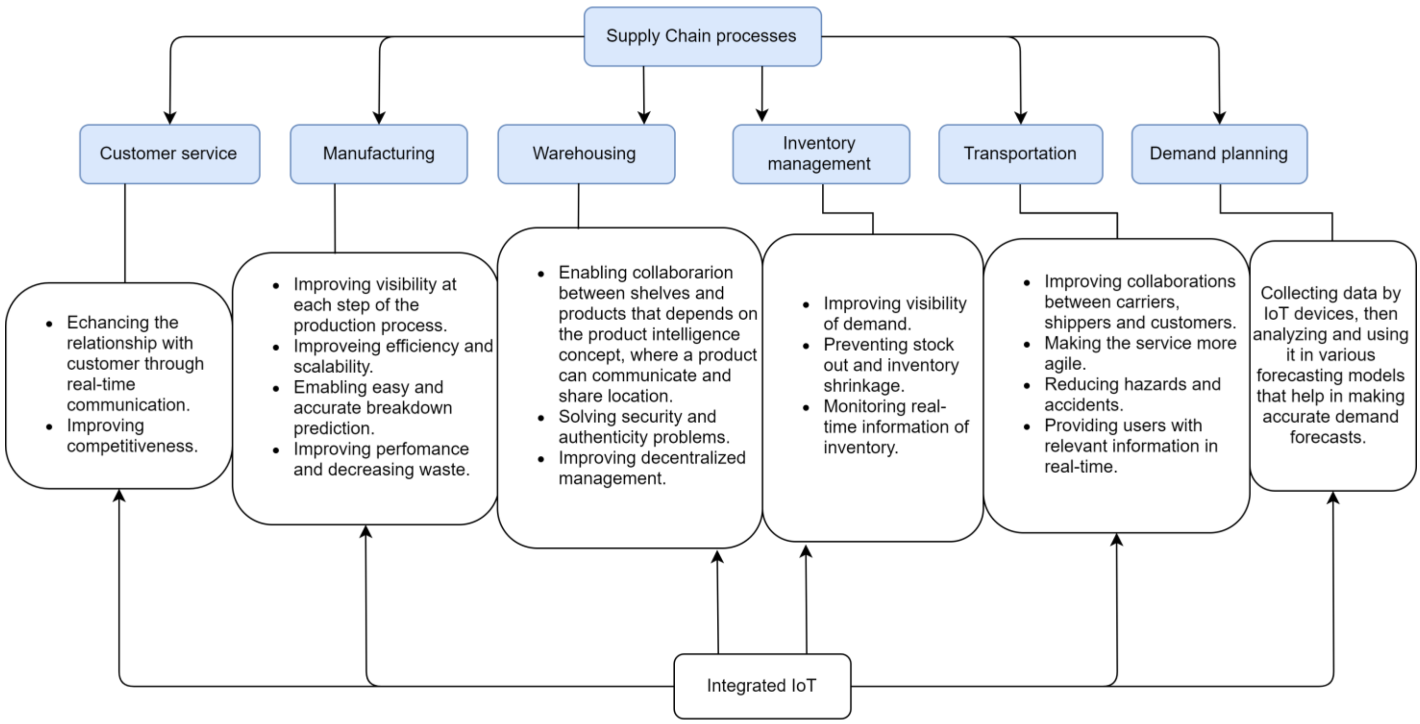

Figure 5. Benefits of using IoT in SCM processes. Adopted from Mostafa, Hamdy and Alawady, 2019.

2.6. Wireless sensor networks

Wireless sensor network is one of the main components of the concept IoT, and in many cases, they are traffic for future fifth-generation 5G communication networks (ITU, 2012). Today, WSN are developing rapidly due to the relatively low cost, deployment speed and application possibilities in conditions where it is challenging to use cable networks.

WSN technologies penetrate various spheres of human life, science, the physical security system, agriculture, robotics, industry, military affairs and much more (Buratti et al., 2009). Therefore, sometimes, the WSN is called the pervasive Sensor Network). The solutions of the WSN application are oriented both to users (people) and to control cars (mechanisms, cars, robots). The latter also includes devices with machine-oriented communication or M2M (machine-to-machine), which means communication between two or more devices without human intervention. The main tasks of the WSN can conditionally be classified as:

- **monitoring** of the initial state (for example, temperature, humidity, light, smoke, etc.; human body: the principal vital signs of various organs; technical systems, etc.);
- **processing** data obtained as a result of monitoring;
- **management,** i.e. impact on specific processes based on the obtained data.

Monitoring, as a rule, is associated with the use of various kinds of sensitive or measuring elements (sensors), which allow assessing the state of the controlled object. Processing involves the use of computing resources, either the sensor nodes themselves or dedicated nodes (servers), and the corresponding software that implements the solution of specific problems. Management involves the presence of particular actuators (activators), capable of receiving the command to do some work necessary to achieve the goal of the network. Wireless sensor network can conditionally be divided into three main elements:

1. Sensor node - this is an element of the WSN that can collect data from the environment using various sensors. It also can transmit the collected data using a radio channel to another network element, for example, for further processing of this data.

2. Gateway - this device and software that collect data from sensor nodes, process, store, and periodically update it. A server is also necessary for transmitting information (commands) to network nodes and individual executing devices.

3. Actuator (or activator) - is a device that performs certain actions based on the received data (commands) from the controller.

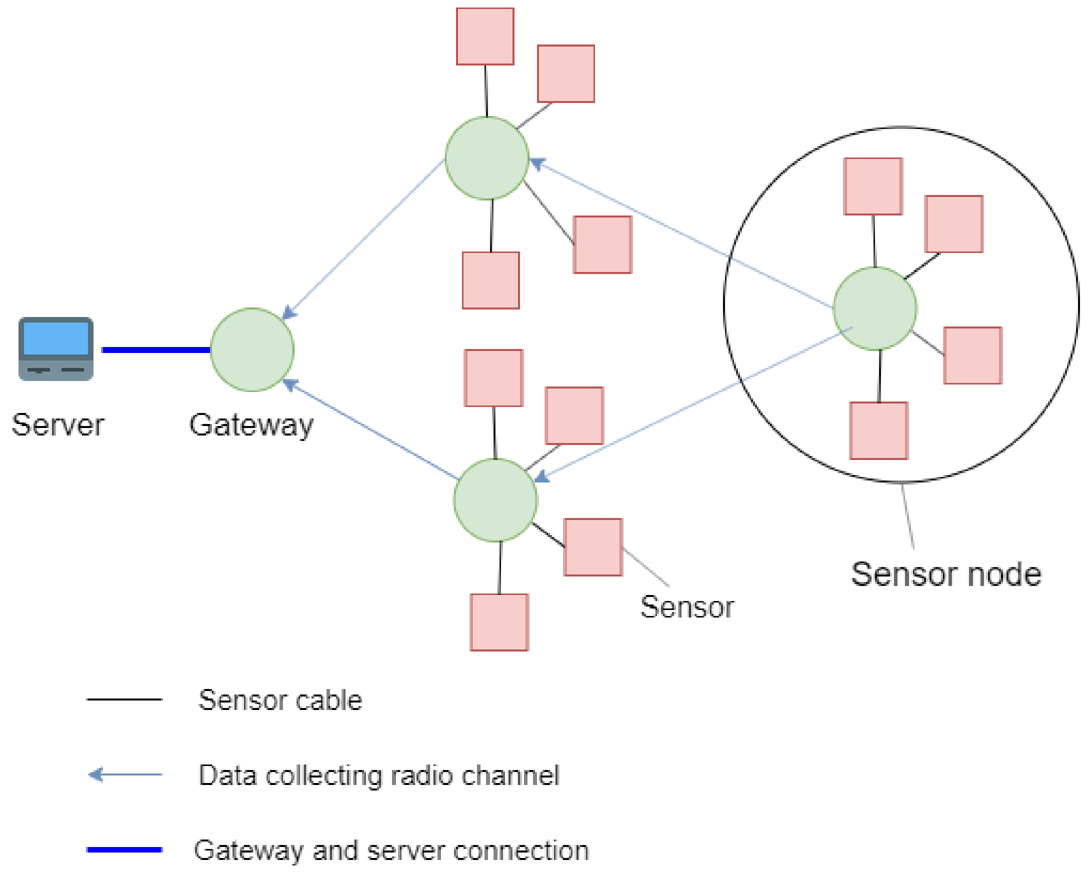

Figure 6. WSN communication architecture. Adopted from Buratti et al., (2009) and Baronti et al., (2007).

Let us consider the most well-known technology Zigbee standard of wireless communication:

According to (Baronti et al., 2007; ZigBee Alliance Std., n.d.): Zigbee is the technology based on the IEEE 802.15.4 short-range wireless standard, which is designed to be used in low-cost and cost-effective wireless data collection and management devices. Sensor network nodes are used in applications where small amounts of data need to be transmitted and where low power consumption, small size, and easy integration are required. One of the main advantages of the ZigBee/802.15.4 standard is the ease of installation and maintenance. The ZigBee specification features make it easy to deploy wireless personal networks. ZigBee-enabled devices have an extended lifecycle and are therefore suitable for supply chain cargo monitoring where periodic information updates are required. However, ZigBee applications offer low data rates of only 20-40 kbps and 250 kbps at 868/915 MHz and 2.4 GHz, respectively.

2.7. Radio Frequency Identification

Radio Frequency Identification is an automatic identification technology that uses tags to transmit data to the reader's RFID requests. In other words, RFID - is the wireless, non-contact use of RF electromagnetic fields for automatic transmission data for identification and tracking of tags associated with the assets (Finkenzeller, 2010 Ahson and Ilyas, 2008).

RFID tags, together with readers, antennas, and peripherals, form the physical layer of the RFID system. RFID tags use electromagnetic wave propagation and inductive and feedback to communicate with readers. The following are components of tags, including the RFID chip and its design (Finkenzeller, 2010; Ahson and Ilyas, 2008).

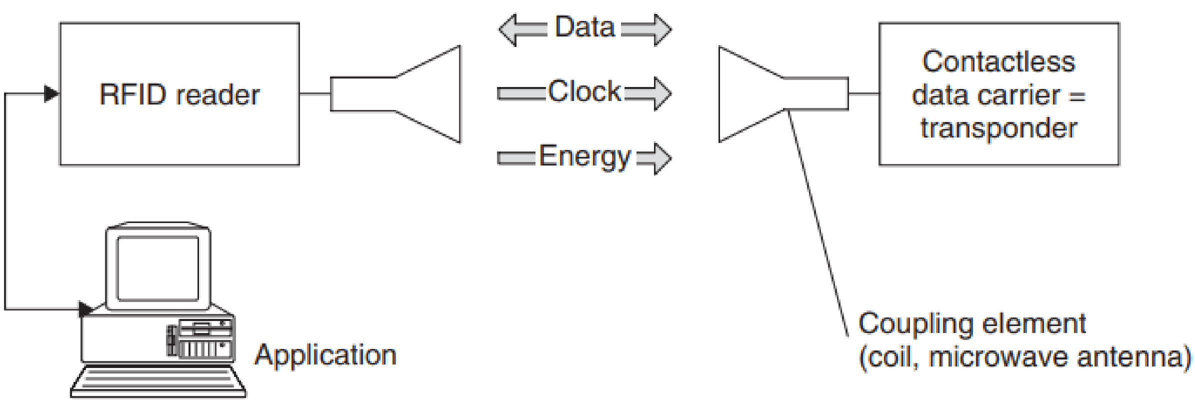

Figure 7. RFID communication architecture. Source: Finkenzeller, 2010.

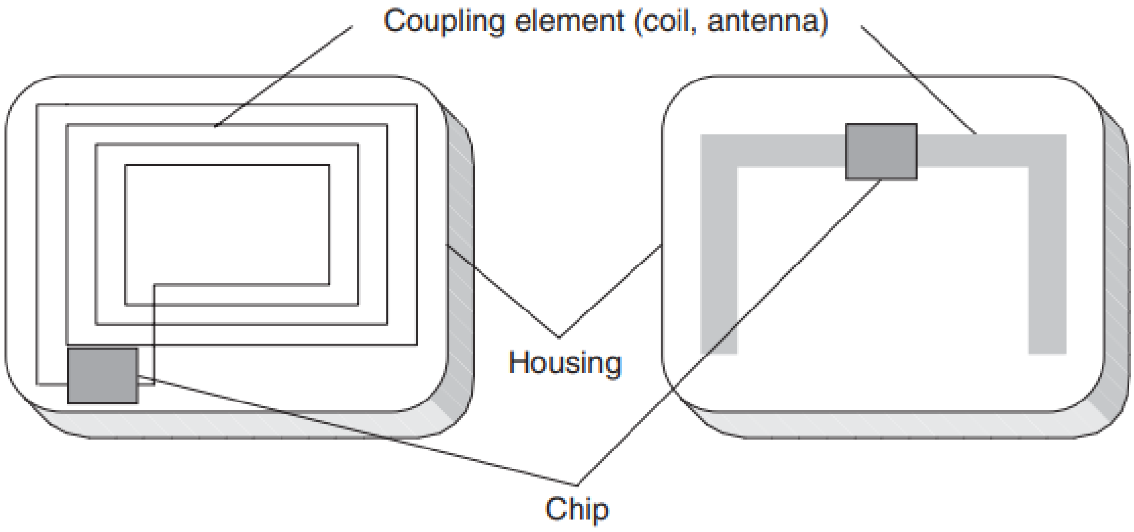

Figure 8. RFID transponder architecture. Source: Finkenzeller, 2010.

The concept of Industry 4.0 requires the personalization of products, which significantly complicates the process of monitoring the product life cycle (Yadgarova, Taratukhin and Skachko, 2015). To overcome identification problems, it is proposed to use rapidly developing RFID technologies. RFID is a technology that uses the electromagnetic spectrum to identify objects. In modern production, there is an active substitution of identification using an RFID barcode because RFID does not require direct contact with the tag. RFID systems consist of two main elements: an antenna and a transponder. The antenna generates an electromagnetic wave to activate the transponder. By activating the transponder, you can read or record data (Finkenzeller, 2010).

RFID classification

There are several classifications of RFID sensors: by the frequency of the generated electromagnetic waves, by the power source, and by the type of memory of the RFID chips. Depending on the operating frequency, type of memory, and power supply, the specifics of using RFID sensors depend. Frequency classification divides RFID sensors into low-frequency (LF), high frequency (HF) and ultra-high frequency (UHF). LF sensors exchange data with a tag at frequencies of 30 Khz-300KHz at short distances of no more than 2 meters. HF sensors operate at frequencies of 3MHz30MHz and are capable of working with transponders remote up to 30 meters. Furthermore, UHF sensors operate at frequencies of 300MHz-3GHz and read data at distances of more than 30 meters (Ahson and Ilyas, 2008).

RFID systems can also be classified by power source. According to this classification, transponders can be of three types: active, passive, and mixed BAP (Battery-Assisted Passive). In active RFID systems, transponders have their own power supply, usually in the form of batteries, which allows you to increase the reading radius of the tag and continuously transmit data to the transmitter. In passive RFID systems, tags are powered only by the electromagnetic field of the transmitter, which makes the system cheaper. In RFID systems with BAP transponders, tags use both power sources, which increases the reliability of data reading.

By type of memory according to Ahsan, Shah, and Kingston (2010), the tags may be divided into:

Table 5. RFID memory types

RO (Read-Only)	**WORM (Write Once Read Many)**	**RW (Read and Write)**
Data is written only once, immediately during manufacture. Such tags are for identification purposes only. No new information can be recorded in them, and it is almost impossible to fake	Where, in addition to a unique identifier, such labels contain a block of write-once memory, which can be read many times later;	Such labels contain an identifier and a memory block for reading a record of information. The data in them can be overwritten many times. Transponders can be made in a glass, plastic case, as well as in the form of smart cards and smart stickers.

This paper discusses the use of smart stickers. With this design, the RFID chip is delivered on a thin adhesive tape and consists of micro conductors and a chip. These tags are very thin and flexible so that they can be glued to almost any product.

RFID applications

Industry 4.0 requires customized products to enhance the user experience. The control over the life cycle of products is significantly complicated due to many modifications of customers. This may affect product quality and consumer loyalty. The use of RFID technologies can significantly simplify and improve the life cycle management processes of personalized products due to the features of data storage, recording and reading (Rashid et al., 2017).

Consider the main scenarios for the application of RFID technologies in various fields. Firstly, RFID technology can be widely applied in production. Attaching a radio tag to a product allows it to read and implement pre-recorded features of customer orders during its production, as well as save primary data about the state of the product during the assembly process. Moreover, RFID tags can be used by the cyber-physical system to recognize various tools, helping to build a flexible assembly process for products. Finally, due to the broad capabilities of RFID chips to store and provide data, PLM systems have direct access to product status data at each stage of production.

Therefore, the use of RFID technologies increases the transparency and controllability of technological processes, which is extremely important for implementing the strategy of using PLM systems (Kudriashov et al., 2016).

The second area where the implementation of RFID solutions is rapidly gaining momentum is logistics. Indeed, after the product has been manufactured, it must be delivered to a specific customer. The solution to this problem can spend an unacceptable amount of time and resources since it is necessary to identify each product and route it along a unique route (Fan et al., 2015). The use of RFID solutions offers excellent opportunities for automating these processes. Due to the fact that the RFID reader does not require direct contact with tags, it is possible to read information about each product, including the address of the recipients, from the entire transport pallet or container. Thus, there is no need for additional actions for identification, sorting, and delivery of goods. Besides, it is possible to individually monitor the condition of the goods at all stages of its delivery to the regiments of the store or the end consumer (Moatari-Kazerouni and Bendavid, 2017).

The third promising area of application of RFID technologies is the support and after-sales service of the released products. Since all critical information about the product's life cycle (by whom, how and where the product was produced, by whom and how it was delivered, when it was purchased, by whom and how it was serviced, etc.) can be stored in an attached RFID chip, its use greatly simplifies planning conducting routine maintenance, localizing problems associated with marriage and identifying malfunctions in the repair process for individualized products. Improving the quality of support and service increases the satisfaction of end-users, which is one of the main ideas of Industry 4.0 (Barenji, Barenji, and Hashemipour, 2014). Thus, RFID is one of the critical technologies for the development of PLM systems and the implementation of the concept of the fourth industrial revolution.

2.8. 5G network

According to the rule of ten years, about every ten years, mobile network technology changes (Davies, 2016). Accordingly, new services are emerging. Unlike 1G, 2G networks are now equipped with SMS, 3G Internet access and 4G video broadcasting services. 5G with new capabilities is already launched commercially and also in testing or initial stages in some countries. 5G is on the way to comprehensive development (5G map, 2019). Currently, 5G networks are being standardized and tested under the official name of IMT 2020. The main requirements for these networks are as follows (Osseiran, Monserrat and Marsch, 2016):

- The data transfer rate is higher than 10 Gbps, which is at least ten times higher than in LTE (4G).
- The capacity of the system is up to 100 million devices per square kilometer, which is about a hundred times greater than the current capacity of networks.
- Delay reduction of up to 1 ms, which is five times less than LTE, and this allows many delay-sensitive services to be implemented.
- Reduced power consumption by user devices, which increases the energy efficiency of the network.

Thanks to the above characteristics, it will be possible to create new services in medicine, entertainment, automotive, agriculture, education, and many other areas of life (Koucheryavy, Moltchanov and Harju, n.d.). 5G networks can improve existing services and provide new quality of services such as virtual and augmented reality and tactile internet due to very low latency (Koucheryavy et al., 2018). Another advantage of 5G networks is that they simplify the infrastructure of some systems. For example, the organization of city video surveillance requires the laying of several kilometers of cable, which requires a lot of time and labor. The 5G network allows you to implement high-resolution video surveillance without using wires. Existing technologies will not meet the requirements of 5G, which necessitates the development of new technologies. Along with new technologies, it is necessary to develop new methods of communication on which the quality of network functioning depends.

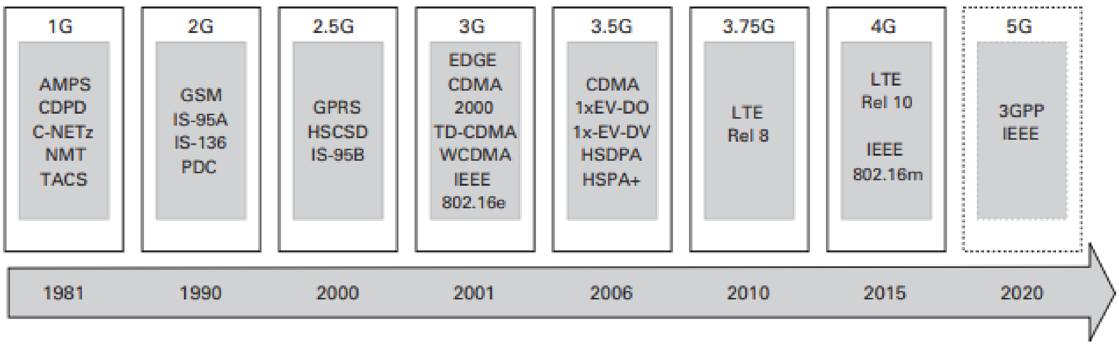

Figure 9. The development of mobile networks until 2020 (Osseiran, Monserrat and Marsch, 2016).

The main characteristics of mobile communication systems following generations are presented in Table 4.

Table 6. Characteristics of mobile communication systems (Adopted from Arasan, 2017; 5G map, 2019)

Generation	3G	4G	5G
Start of development	1990	2000	2015
Implementation	2002	2010	2018-2020 (test implementations and commercial utilizing)
Frequency	1.8 to 2.5 GHZ	2-8 GHZ	3-300 GHZ
Transmission speed	2 Mbps	2 Mbps – 1 Gbps	1 Gbps - Higher

2.9. LoRa (Long Range)

For several years, the IoT's huge potential to gather and analyze user device data for further decision making has not been unleashed due to technical reasons such as battery life, short-distance transmission, high costs and lack of necessary standards (PWC, 2017; Kucheryavy, 2013). However, on March 23, 2015, IBM Research and Semtech introduced a new energy-efficient WAN-based network that provides significant benefits over mobile and Wi-Fi networks through the ability to deploy IoT technology (ibm.com, 2019).

Using new specifications and a protocol for energy-saving WAN networks, which uses an unlicensed spectrum of wireless access, the technology can connect sensors that are located at a considerable distance from each other, while offering optimal battery life and requiring little infrastructure capacity. All this allows for improved mobility, security, bi-directionality, localization, and positioning, as well as cost reduction. Let us briefly list the key features of LoRa technology (Mekki et al., 2019):

- Wide range of work: up to 15-20 km in open terrain and up to 2-5 km in dense urban areas;

- Possibility to connect millions of nodes. Each LoRa base station can serve several thousand nodes;

- Long battery life (AA): more than ten years;

- Data exchange rate: from 300 bps to 50 kbps.

Because LoRa technology can provide a large area of coverage, it is often referred to as LPWAN (LoRa Alliance, 2015). A LoRa network consists of several elements (LoRa Alliance, 2015) (Fig. 9):

- Endpoints: LoRa network elements that contain sensors and actuators. Typically, they are located remotely.
- Base station (or gateway): The gateway collects and transmits messages from the endpoints to the transit system. This part of the LoRa network can be an Ethernet, cellular, or any other wired or wireless telecommunication network. The gateways are connected to a network server using standard IP connections. This site uses a standard protocol for data transmission, but the data can be connected and transmitted in any telecommunications network, public or private. Due to their similarity, LoRa base stations can be combined with a cellular base station. Thus, they can use the free capacity of the cellular backhaul network.
- Server: In the LoRa network, the network is managed by a server. The network server eliminates duplicate packets, manages the transmission schedule, and adapts the data rate. Based on how it can be deployed and connected, creating a LoRa network is a straightforward task.
- Remote Computer: The remote computer can monitor the endpoints or collect data from them, and the LoRa network is transparent to the user.

In a LoRa network, the nodes are usually composed in a star-star topology and form a transparent bridge with the base station. According to Haxhibeqiri et al., (2017) and LoRa Alliance, (2015), this type of construction consists of multichannel receiving and transmitting devices that allow to process signals coming simultaneously through several channels or several signals received from one channel. Thus, several similar devices provide the coverage area of the network and transparent bidirectional data transfer between the end nodes and the server. As a complete design, the LoRaWAN is a star topology with end nodes that, via gateways, form transparent bridges and communicate with the central network server. This architecture implies that the central server and gateways are controlled and owned by the network operator and the endpoints by the subscribers. Subscribers are provided with a transparent, secure, bidirectional way of exchanging information.

Messages from the endpoints are retransmitted to the network until they reach the server (Haxhibeqiri et al., 2017). The LoRaWAN protocol star topology is simpler and more economical to implement than the mesh topology. Communication with each endpoint is usually maintained separately and is bidirectional, but multicasting is also possible, and this is important, for example, in the case of software updates.

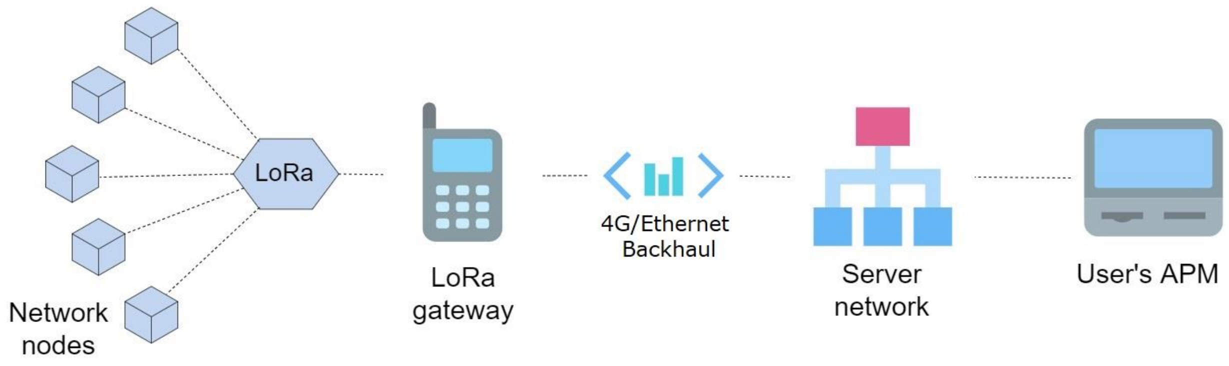

Figure 10. LoRa technology communication architecture (Adopted from LoRa Alliance, 2015).

3. Conceptual framework of IoT sensors solutions in SCM

3.1. Assessment RFID and WSN integration in Supply Chain Management

Today, every company is trying to modernize its production. Modernization can occur in various ways, but they all come down to increase the efficiency of its activities. The main reasons for automation are pretty commonplace (PwC, 2016):

- competition with other manufacturers;

- cost reduction at various stages of production;

- simplification of the processes implementation;

- increasing the effectiveness of activities.

As practice shows, without automation, it is impossible to develop and modernize any company, and automation should be comprehensive. This implies the introduction of new technologies and processes, as well as relevant tools, with which you can quickly analyze the activities of the company, monitor, and make operational decisions. The main point of automation is to solve complex problems using modern tools.

RFID and WSN in SCM

Most of the company's data today are available on the Internet, were recorded by people themselves, for example, by pressing keyboard buttons or scanning a barcode of a product, but the main problem with manual input is the human factor: people are limited in time, people are inherently mistaken. All of this leads to errors and inaccuracies in data later on, which in turn indicates that a person is not good enough to do this work, and if computers had all the data and information about things created without people's help, losses and costs would be significantly reduced, and planning, decision-making, and control processes would be effectively optimized.

In the work of D. Miorandi et al. (2012), it is shown that IoT technology can be considered at three levels.

At the single-component level, IoT is a collection of smart devices connected to the Internet. A smart device is an object with a physical embodiment, a unique identifier, address, characteristics, and a minimum set of communication functionality. A smart device has computational capabilities and allows you to initiate actions that affect our physical reality in which we live.

At the system level, IoT is a dynamic and distributed network system consisting of a vast number of smart devices that generate and then use this information. The so-called smart devices register physical phenomena and translate them into information flows, which are then transmitted to the Internet.

At the service level, IoT is a set of features offered to end-users in various fields. The architecture of IoT systems is a virtual model of the real world with specific methods for obtaining information from smart devices and its further dissemination to provide end-users as services.

From users, IoT will provide a large number of new services that will meet all the requirements and needs in various fields. The user will be able to receive a service that will correspond to his physical and mental state, environment and current conditions. IoT is a new concept of a combination of information and management, which is in a stage of rapid development; new models and new technologies are proposed that can identify, link, and control a vast number of objects, users, and not only in different areas.

Transport and logistics will become an important, if not the main, area of application of IoT technology (Pan et al., 2017). Examples of the use of the Internet of things in this area include tracking delivered, transported, or transported cargo, regardless of the type of transport used: truck, train, plane, or ship. This also includes the connection to the Internet of vehicles, so they can offer help to the driver or carry out preventive repairs and maintenance instead of the driver. On the other hand, IoT will bring lot of new IT, software implementation and technology knowledge requirements into the tables of solutions developers, as they have to be able to understand both the positives, but also the limitations of different IoT chip implementations, e.g. accuracy of GPS location information and time delays to get the location knowledge, in different use case settings (Lehtinen et al., 2008; Jahkola et al. 2017). Currently, any average vehicle purchased with a new one is equipped with more than 100 sensors. This figure will double when functions such as communication between cars, communication between a car and road infrastructure, and automatic driving become a prerequisite for safety and comfort. All this applies not only to private vehicles but also to railway transport and sea freight, where there is no possibility for downtime. Another application is technical assistance on the road, the ability to track the situation with conventional vehicles. Some applications can be straightforward, but very expensive, for example, tracking the location of free emergency service vehicles. Automatic route planning systems for company vehicles and technical personnel are also required depending on the situation on the road. This mobile category is distinguished by the fact that geolocation plays an important role here. Most of the geolocation data comes through GPS navigation. The Internet of things is based on data such as resources and time, and in this case, spatial coordinates.

Modern logistics is based on information and communication technologies that support the implementation of business processes and provide communication between users in the supply chain. In SC, it is important to ensure the identification of objects and communication between participants in the entire process. Identification technologies applied to various objects used in logistics have led to the emergence of smart containers, pallets, packages, packaging materials, vehicles, shelves, forklifts, infrastructure, ports, terminals, and the like (i-SCOOP, 2019). Already today, systems such as RFID, GPS, and WSN are widely used in logistics and supply chains:

• RFID systems provide automatic object identification and data reading over a wireless network. RFID tags can be active, passive, and semi-passive and contain a large amount of data about the objects on which they are located. RFID tags are used for marking transport and handling equipment, logistics units, individual items, and shelves in retail, particular types of goods (money, gold, medicines, dangerous goods), mail, location, and movement in warehouses, identification cards, etc.

• GPS systems allow you to position objects in real-time. GPS devices receive satellite signals, determine their position in space and time, store location data and transmit them to the system user. GPS is utilizing at most segments of logistics activities, providing information on the exact location and time, showing a certain object. GPS devices are located on vehicles of all types of transportation, semi-trailers, containers and individual cargoes, industrial and reloading equipment, any devices that workers use in business processes.

• WSN provides data collection and transmission among sensor nodes, gateways, and network operators. The sensor node consists of a set of active and passive sensors and can transmit, save and process the collected data. Sensors are used to identify objects and determine their physical characteristics - characteristics of goods, transport and handling equipment, containers, places in warehouses, sales objects, equipment, transport infrastructure, and others.

The use of these systems allowed us to develop new business models and the concept of the digital supply chain, in which the company can automatically manage business processes and communicate with its customers and suppliers. In logistic systems, there are various models of connecting via the Internet. For example, the IoT solutions that facilitate communication of all participants and objects. According to studies published in the Internet of Things in Logistics (Macaulay, 2019), just five years ago, in 2014, 75% of companies used IoT solutions, compared to 15% in 2012. The development of IoT and a broadband communication network will allow creating a virtual model of the logistics business, uniting all participants, which will contain data on objects available for viewing in real-time. In the work of A. Whitmore (2014), logistics is mentioned as the first and key industry for the application of IoT technologies. The reason for this is that logistics depends on the quality of the logistics network, the connectivity of all participants in the supply chain, fast and reliable information received from anywhere and at any time of the day. Logistic decisions are made based on available information and affect all other participants in the supply chain. IoT combines identification technologies (RFID, GPS, and WSN), artificial intelligence, advanced analysis of large volumes of data, software applications and decision-making systems at different levels of management. From software systems in logistics (WMS, TMS, OMS, CRM) they will start to extract the maximum result, since high-quality data and reliable information about the current state of objects in the network will be used.

Through IoT in the field of SCM, the following processes can be covered:

- Real-time monitoring of vehicles and trans-shipment facilities, logistics units, goods, and people;
- Measuring resource efficiency and planning according to current status;
- Logistic control of activities and processes, response to deviations and application of corrective actions to achieve the set objectives;
- Analysis of all data in order to analyze the existing state and identify opportunities for new ideas;
- Automation of business processes for the elimination of manual work, along with improved quality and reduced costs;
- Optimization of staff, system, and facilities, their coordination and integration.

In logistics, the introduction of IoT technologies allows solving such urgent problems for the industry as reducing freight costs and delays, increasing transparency of transportation (including using RFID tags), and minimizing the impact of the human factor. Vehicles connected to the Internet and remote monitoring of the fleet will reduce operating costs by optimizing the repair and maintenance of equipment (Macaulay, 2019).

Nowadays, there are various systems for protecting containers and trailers from unauthorized access, but all of them have some shortcomings. A model of the IoT system is proposed, which will allow controlling cargo using a combination of radio frequency identification RFID and GPRS communication. The system will automatically determine the location of the trailer and container, optimizes the use of transport. Each such device, using GSM / GPRS / GPS telematics devices, will send to the system server comprehensive information about the location of the cargo and the safety of the seals. All actions with cargo and electronic seals will be recorded in the system with the exact location of the event and time. To conduct operations with this data, it is necessary to create an application that will provide users with various options for accessing this monitoring system data, including using web interfaces and mobile devices.

According to Phase and Mhetre (2018), the introduction of IoT and its applications in supply chain management has grown to the degree that has not only helped track and in-transit goods but has also influenced efficient inventory management and minimized supply chain losses. This has culminated in economic benefits for businesses on a large scale and has helped to expand supply chain business activities across large geographic areas. From basic product recognition systems to a complex network of physical devices working in a coordinated manner, IoT implementation has given greater visibility in the manufacture of products as well as supply chains to distribute the finished goods to the end-user.

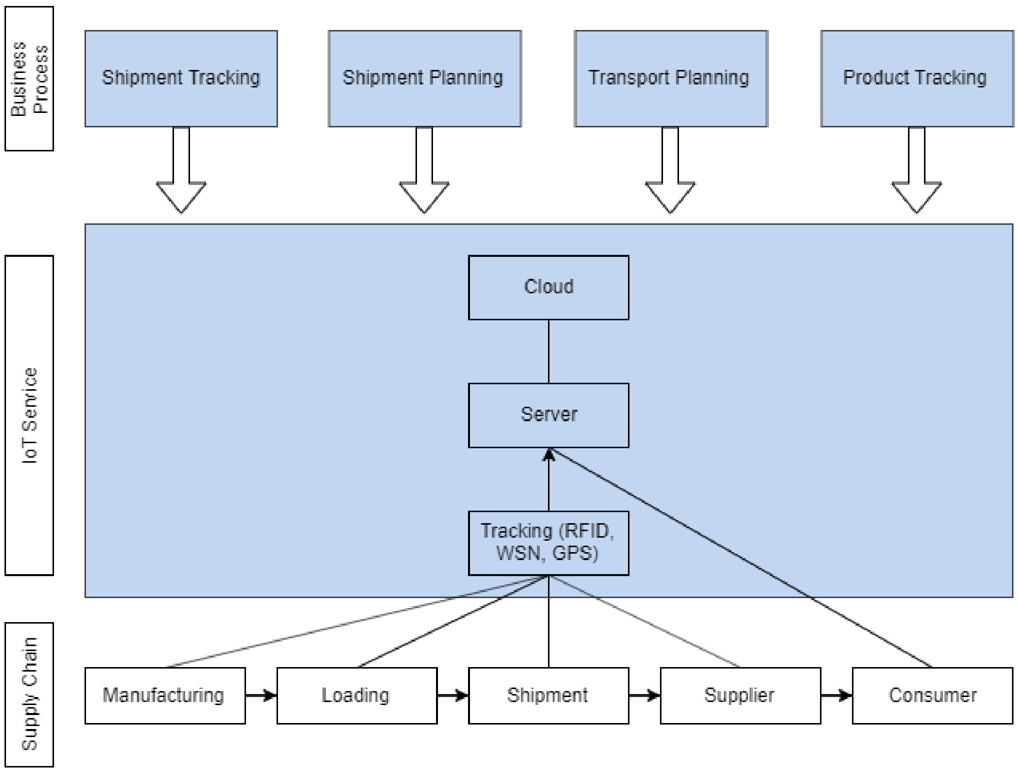

Figure 11. Supply chain with integrated IoT architecture (Phase and Mhetre, 2018).

As it was mentioned earlier, wireless technologies have great functionality and are applicable in various conditions. When designing a pressure sensor, for example, it is essential to note that the sensor itself may be at some distance from the reader or in a place that is difficult to reach. The electronic power board of the pressure sensor can be equipped with a transceiver module, antenna and RFID tag (Fig. 11). The signal from the pressure sensor installed in the metal housing is transmitted to the microcontroller, which processes the received information and digitally transmits it through the transceiver to the receiver of the RFID tags. Then, with the help of radio-frequency identification technology, the information is transmitted to the reader and then goes to the server, where it is promptly analyzed, and then commands are given to the actuators.

According to (Xu, He, and Li, 2014), to better identify and track cargo in real-time, RFID technology can be assimilated with WSN. Emerging wireless intelligent sensor technologies will further facilitate the implementation and deployment of manufacturing services and applications. Through the integration of RFID-based smart sensor data, more powerful IoT applications can be created that is suitable for industrial environments.

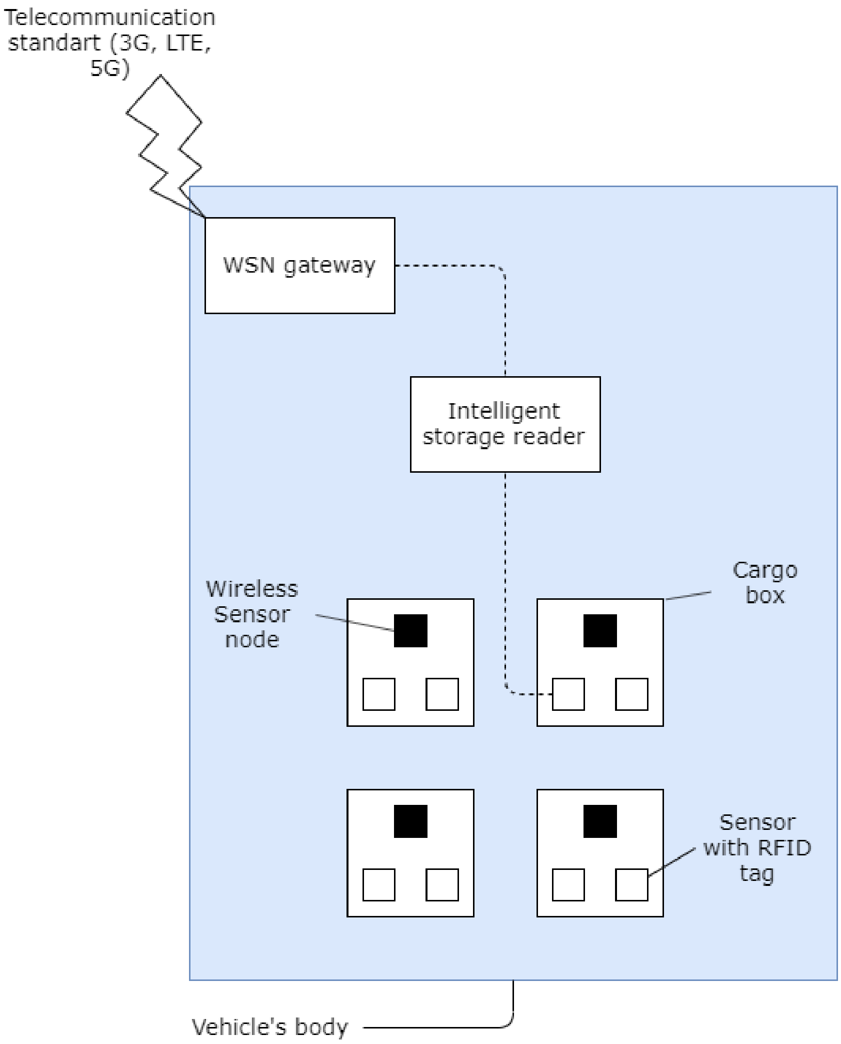

Figure 12. RFID and WSN monitoring system concept (adopted from Le, 2018)

If one of the routers fails, its tags are "picked up" by neighbors, and the tags themselves are warned about a possible failure. The coordinator also receives notification and information about dangerous temperature rises recorded on one or a group of routers to take appropriate actions. In this way, the proposed solutions can help optimize the construction of the WSN network by using RFID tags for more efficient operation within cargo transportation security control systems.

3.2. LoRa application

To ensure effective application-specific monitoring, there is a need for wireless components with stand-alone power supply, low power consumption, long-range, and long service life. Such requirements are met by elements of low-power LPWAN networks, which are a new type of network for the transmission of small packets of telemetry data from various devices, sensors, sensors over long distances. LPWAN technologies are an essential part of IoT and demonstrate the most rapid growth. Among all comprehensive LPWAN technologies, the open standard LoRaWAN developed jointly by Semtech and IBM, is favorably distinguished [1]. It is based on the use of the LoRa modulation method patented by Semtech at the physical level, which is a kind of spectrum expansion method and provides record-breaking values of the communication channel budget (up to 168 dB).

LoRa technology is one such solution, which will allow us to use the advantages offered by various "smart" devices more effectively today. It is a technology that is designed to fill the gap between short-range technologies (WiFi, ZigBee) and mobile technologies (3G, LTE). To conclude, will be as a quote Thorsten Kramp, Master Investor IBM Research: " The Internet of Things is already changing our world – from better traffic control on our highways to greater energy efficiency in buildings and manufacturing operations, to reduced crime on our city streets," said Thorsten Kramp, Master Investor IBM Research (ibm.com, 2019). Technologies such as LoRaWAN help significantly increase the penetration, range, and durability of sensors, which form the basis of the intelligent world.

Table 7. Comparison of wireless networks (adopted from Salazar, 2017)

	LoRa	**Bluetooth**	**Wi-Fi**	**ZigBee**	**3G**	**GSM/GPRS/EDGE**	**LTE**
Frequency range	433-868 MHz	2,4 Ghz	2,4/5 Ghz	868-2,4 Mhz	2100 Mhz	900 Mhz	2500-2700 Mhz
Data transfer rate	up to 100 kb/s	up to 1 mb/s	up to 1 gb/s	up to 250 kb/s	up to 2048 kb/s	14,4/171/473 kb/s	up to 326,4 mb/s
Range of operations	up to 20 km	up to 100 m	up to 100 m	up to 200 m	in the coverage area	in the coverage area	in the coverage area
Security	34 and 128-bit encryption	34 and 128-bit encryption	-	AES128 and the applied level of security	-	-	-
Number of connected devices	up to a few thousand devices per network	8 devices on one network	up to 128 devices per net	Around 65000 devices per network	no limit	no limit	no limit

3.3. 5G application

The future of IoT is associated with the development of fifth-generation telecommunication networks (Liberg et al., n.d.). Ongoing 5G developments are categorized by network resources organization to accommodate a broad set of services considered into three categories. Enhanced mobile broadband (eMBBB) will have to provide wireless transmission of vast amounts of data to virtual and augmented reality devices, telemedicine, and ultra-high resolution video. Ultra-reliable, ultra-reliable, and low-latency communications (URLLs) will be deployed in autopilot machines and aircraft. Massive machine-type communications (mMTC) will ensure the operation of intelligent automatic monitoring systems (Cheng et al., 2018).

As 5G technologies prepare to serve multiple IoT applications with expanded capabilities (Lee and Lee, 2015), there is an increasingly major difference between their operation's consumer and industrial scenarios (Atzori, Iera, and Morabito, 2010). Simultaneously, the IoT industrial segment is a relatively recent trend intended to improve connections between companies (Li, Xu, and Zhao, 2014).

Using 5G communication, industrial users are looking for wide-ranging and efficient interactions that outweigh the potential of 4G broadband mobile technologies (Figure 13). Some IoT industrial scenarios, however, have certain requirements that current 3G and 4G networks are not able to fulfill, such as industrial production control and road safety systems, communication among devices and operators, logistics and facility monitoring, automotive, power, etc. (Thierer and O'Sullivan, 2015).

The benefits of using the Internet of Things technology for logistics extend across the entire value chain, including warehousing, freight, and final delivery. They also have an impact on operational efficiency, security and customer service. Unmanned transport (cars, subways, trains) is increasingly penetrating our lives. The global market for cars connected to the network is growing: according to ABI Research (Abiresearch.com, 2019), by 2025, about 67 million cars will use 5G services, of which 3 million will be self-propelled cars. The first tests of 5G communication networks on unmanned vehicles may take place in Moscow this year. The effect of using 5G and IoT systems in ports should ensure the robotization of loading and unloading operations (due to remote control of devices via 5G communication channel), as well as reduction of production costs and improvement of logistics quality. The use of 5G and IoT systems in industry will allow for even greater robotization of production in new industries, which will lead to lower production costs and injuries, improved product quality and increased production flexibility (Huawei, GSA, HKT, 2019). The introduction of 5G and IoT systems into agricultural production is promising

(Kota and Giambene, 2019). Sensors integrated into the Industrial Internet of Things (IIoT) system will ensure the operation of unmanned aerial vehicles agricultural machinery, remote physical condition monitoring animals, as well as environmental monitoring, natural disaster warning and automated response to emergencies.

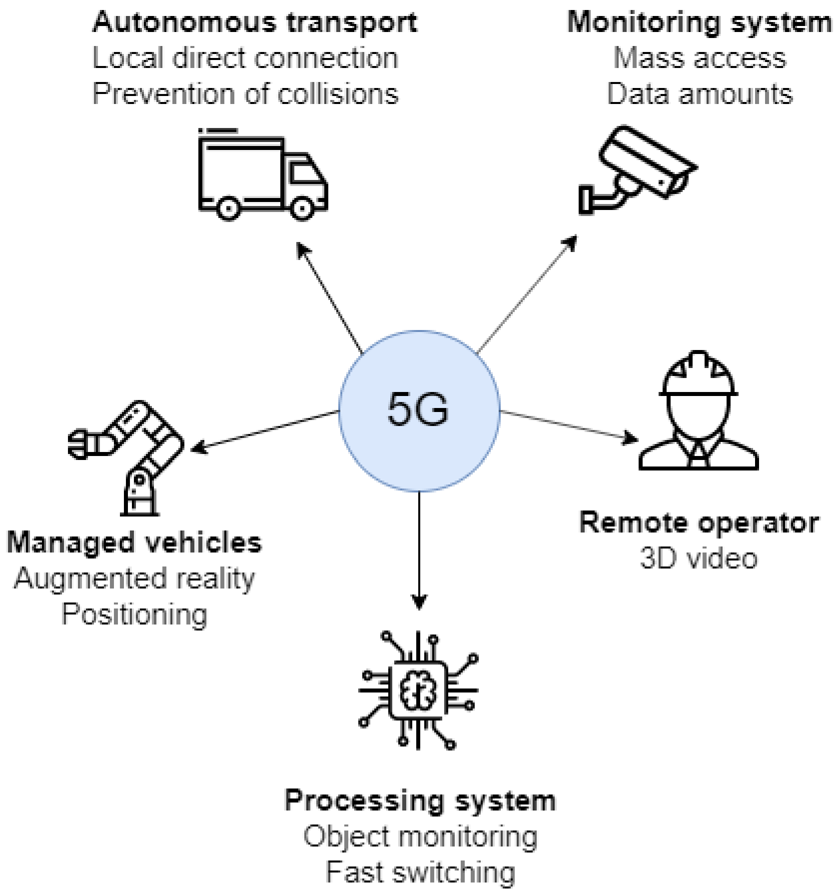

Figure 13. Examples of 5G applications for production automation.

In order to meet the basic requirements for the industrial Internet (World Economic Forum, 2015), the following fundamental principles must be observed: interoperability, virtualization, decentralization, real-time interaction, focus on improving the quality of services and modularity (Hermann, Pentek, and Otto, 2015), that together may ensure the necessary quality level of perception of the service. For instance, a multi-year program called "Industry 4.0" was supported by European countries in the context of automation of manufacturing processes, quality assurance and loading and unloading procedures (Varghese and Tandur, 2014).

While the research on industrial Internet applications is speeding up globally, it is obvious that 5G technologies will become a main discussion in addressing the needs of Industry 4.0 (Wang et al., 2016). In this sense, support for network connections in quite far regions is particularly challenging (Galinina et al., 2017), which may require specialized software systems for production and distant control services (Haerick and Gupta, 2015). At the same moment, modern digital cloud systems can be used for the tasks of tactile control to arrange VR or AR services (Moskvitch, 2015).

3.4. Possible sensor solutions for safe transportation

Automation of automobile weights are gradually ceasing to be the prerogative of large enterprises with a massive flow of transport and are increasingly used in small and medium-sized enterprises (PEMA, 2013). The peculiarity of such technical solutions is that they are located at the intersection of technology, automated control system, video monitoring, information systems, and access control system, and therefore, even an experienced engineer cannot efficiently deal with such a task. RFID can help specialists of enterprises facing the task of optimizing the process of weighing to approach this task more systematically and comprehensively.

Automation of the weighing process on an automobile scale is a complex of hardware and software (Fig. 1), which provides automation of routine processes, previously performed by the operator manually:

- Entering the weight into the software and database;
- Reading the vehicle number and entering it manually;
- Monitoring the vehicle's position on the scale;
- Control of traffic through the scales, etc.

In practice, companies most often want to automate the weighing procedure on their vehicle scales to avoid the following problems:

- Possibilities of making mistakes by the operator of scales, especially at recording of readings of scales;
- The possibility of abuse by staff when loading or receiving cargo;
- Lack of digital documentation of the weighing process and, as a consequence, the complexity of claims work with counterparties;
- High labor costs in the process of shipment or acceptance of goods;
- Insufficient carrying capacity of weights, which is typical for enterprises connected with seasonal cycles (agricultural sector, etc.);
- Inadequate process of transport movement through the scales.

Also, there are cases when automation of scales is either redundant or inapplicable:

- Very little traffic flows through the scale;
- Insignificant cost of operator errors;

- Scales portable.

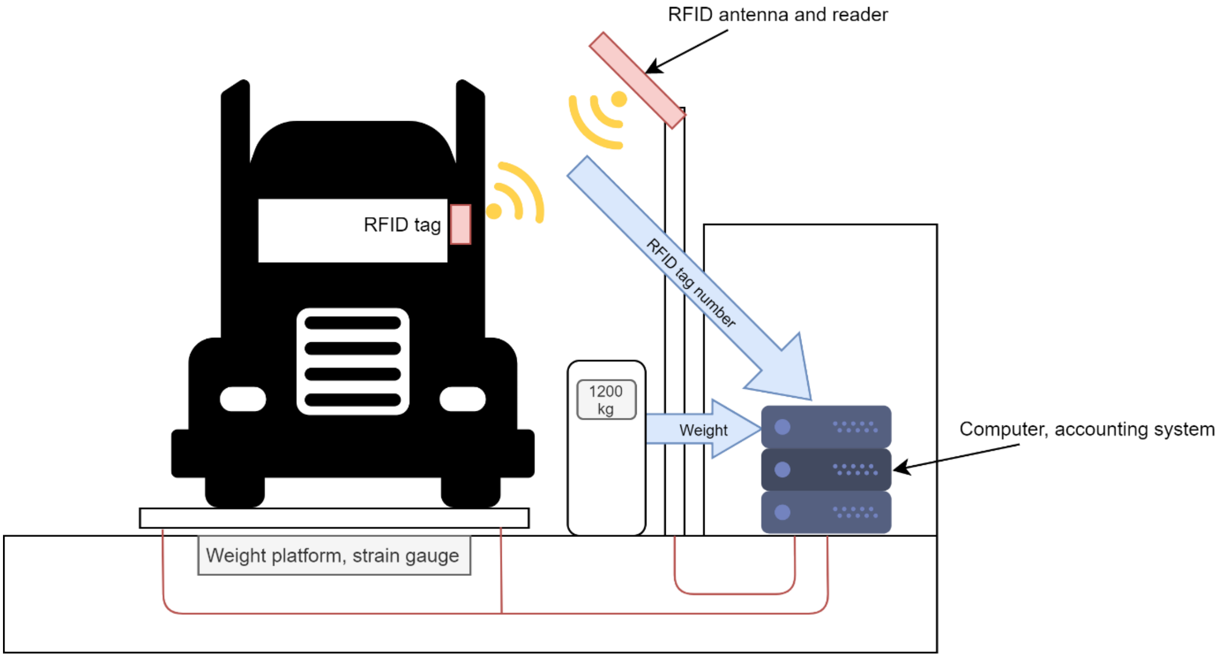

Figure 14. Concept of RFID implementing in weight checking.

3.5. Summary of conceptual framework

A framework demonstrated below allows us to understand the potential use of the technologies analyzed. The use of RFID tags integrated into the WSN, as well as the use of modern SCM communication methods as LoRa and 5G, can become more transparent, reliable and efficient.

In real-time supply chains, it is necessary to carry out comprehensive monitoring of logistics business processes, i.e., the movement of all resources (material, financial, etc.), implemented utilizing integrated means with additional tracking and identification technologies. Such monitoring provides a transition from the technology of control over delivery execution to the technology of operative management of critical processes based on information interaction.

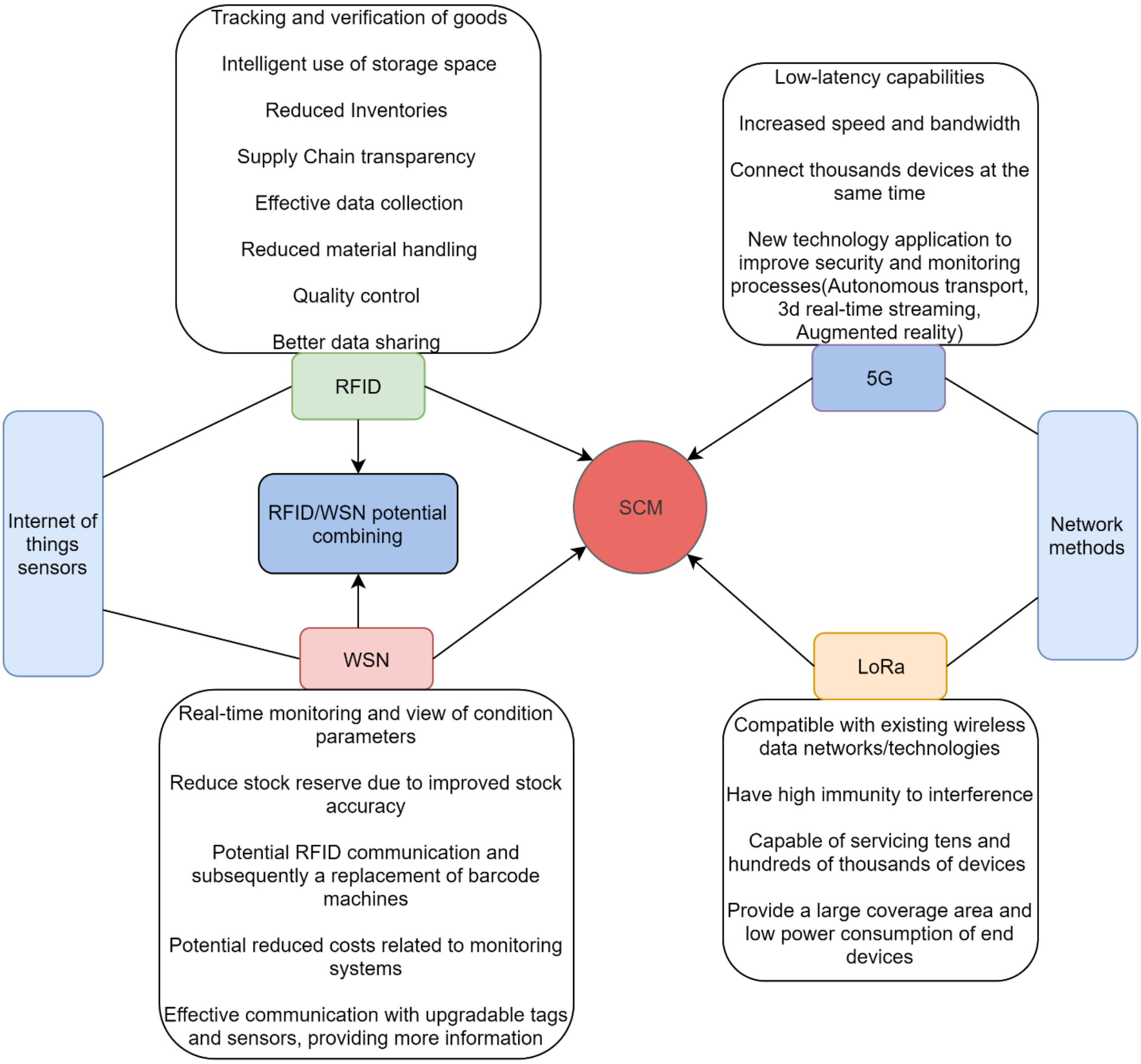

Figure 15. The conceptual framework of analyzed solutions in the SCM.

IoT wireless networks, in a broad sense, represent a transparent chain of all levels of the IoT model (Minerva, Biru, and Rotondi, 2015). However, for regulating the development of various IoT wireless networks, it is not necessary to reproduce all the elements of such a model, it is possible to specify the critical levels of interaction and abstract interfaces between these levels, to which the requirements for a system approach to the development of IoT services can be formulated.

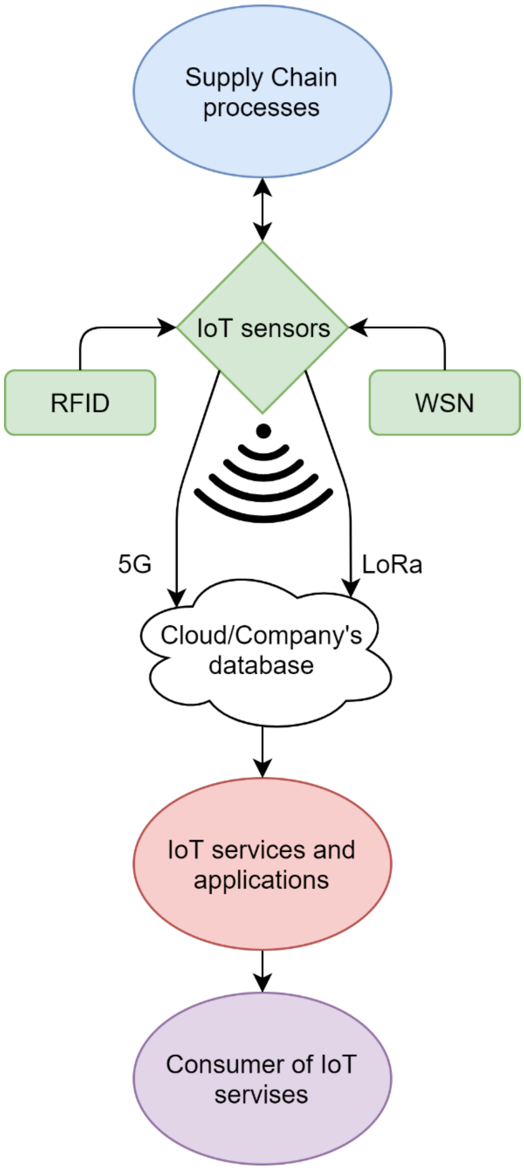

Figure 16. The conceptual framework of an IoT wireless network architecture.

4. Expert survey

Expert survey as a research method is one of the main qualitative methods of obtaining information in empirical studies. The survey involves the creation of a questionnaire where the researcher records the answers of experts (PONTO, 2015).

In this case, the following was conducted a specialized interview where the main source of information is a professionally competent person whose work is closely related to the subject matter to be studied or whose theoretical knowledge, life experience allows for sufficiently authoritative answers. The participants in such surveys are experts that can provide a balanced assessment of the issues of interest to the researcher (Kabir, 2016).

The results of the survey will allow us to determine the expert opinion on the relevance and maturity of technological innovations for logistics and supply chain management of companies. The companies were identified by business areas, namely, those carrying out global activities in logistics and supply chain, development of IoT solutions, cargo transportation. Companies for the survey were preliminarily analyzed on their activities and the possibilities of using sensor technologies.

This expert survey was an integral part of the study because it allowed objectively considering the arguments in favor of the effectiveness of IoT sensor solutions on SCM.

4.1 Responders review

Table 8. Responders review

Position	Business field	Experience	Country
Senior project and analytic manager	Company «A» - is the largest private railway operator in terms of transportation volume and market share in the segment of railway transportation of crude oil and petroleum products.	12 years	Russia
Senior financial specialist	Company «B» - Provides a full range of services in fields such as freight and railway infrastructure rolling stock maintenance, long-distance and regional passenger transport, container transport, logistics, research and development, as well as other activities, including the implementation of large-scale projects on railway construction and infrastructure development abroad.	25 years	Russia

Analyst	Company «C» - production of its line of telematics equipment.	5 years	Russia
Region sales manager	Company «D» - the largest managing company of the international business format cash&carry (small wholesale trade).	16 years	Russian department
Senior logistics manager	Company «E» - is an international industrial holding company, a leader in the production of construction materials in Russia.	10 years	Russia
Procurement specialist	Company «F» - a public engineering company that manufactures machinery and other equipment for gas, oil, and other raw material power plants.	3 years	Russian department
Development manager	Company «G» - develops industrial digitalization technologies, invests in products, and develops the industrial internet of things and artificial intelligence.	7 years	Russian department
Project manager	Company «H» - is a group of companies, one of the largest universal logistics operators in the CIS.	5 years	Russian department
Logistics manager	Company «J» - has become one of the leading players in the automotive logistics market in Russia, expanding the range of services from transportation of finished vehicles and components to the organization of complex supply chains for leading Russian industrial enterprises	5 years	Russian department

The expert survey was aimed at identifying which technologies are relevant enough for SCM representatives and whether they use these technologies. The main question for the survey was formulated as «What are the development trends and opportunities for using IoT sensor technologies and modern network technologies in the context of supply chain management»?

4.2 Experts answers

1. What are the development trends and opportunities for using IoT sensor technologies and modern network technologies in the context of supply chain management?

«Ideally, the digital supply chain should have processes in place with appropriate technology that monitor inventory levels in real-time: equipment failures, interactions with counterparties, cargo locations and use this information to schedule and perform operations at higher levels of productivity. Such technologies as RFID, wireless sensor networks, cloud computing, modern communications tools play an important role in the digital supply chain. In addition, blockchain

technologies may provide information that processes become traceable and visible of the supply chain». – company's «C» analyst.

«For several years now, digital delivery chains have been at the center of discussions, especially in digital projects such as the Internet of Things and artificial intelligence, which help to increase the efficiency of delivery chains themselves. For example, their potential applications are application solutions that help to monitor mechanisms and determine the need for repair or complete replacement of a particular node. Moreover, new software solutions already allow businesses to raise the efficiency of warehouse storage to an unattainable level. Automation using digital algorithms also helps to make production processes more efficient and cost-effective. The most striking example is the food industry, which, on average, loses about 30 percent of its output due to incorrect storage and transportation conditions. The development of 5G networks will also contribute to the development of the Internet of Things, when it will be possible to simultaneously connect multiple gadgets directly via cellular communication.» – company's «G» development manager.

«In 2017, we saw an increase in the number of devices and connectivity options, and this trend is likely to continue. In particular, we will see further development of networks based on Low Power Wide Area Networks (LPWAN), such as NB-IoT, Sigfox, and LoRaWAN. These technologies extend the battery life of devices that should run for up to several years without recharging while providing reliable connectivity over long distances». – company's «E» senior logistics manager.

«Radio-frequency identification is becoming a modern trend in many areas of the market. Radio-frequency identification is used to track goods, values or even people in real-time, which increases productivity, competitiveness, speed, and efficiency of any part of the market». – company's «B» senior financial specialist.

«Recently, RFID (Radio Frequency Identification), wireless sensor networks WSN (Wireless Sensor Network), NFC (Near Field Communication) and M2M (Machine-to-Machine) inter-machine communications have been developed, together with the Internet, providing a simple connection of various technical devices ("things"), the number of which can be huge». – company's «A» senior project and analytic manager.

On the question, *«Does your company use sensor technology in its supply chain management?»*, five representatives answered «Yes», two answered «No», one answered *«We are using such technologies, but itis on the process of testing and subsequent implementing»* - logistics manager; the last one *«Yes, but at this stage it takes time to determine the value of these technologies»* – company's «A» senior project and analytic manager.

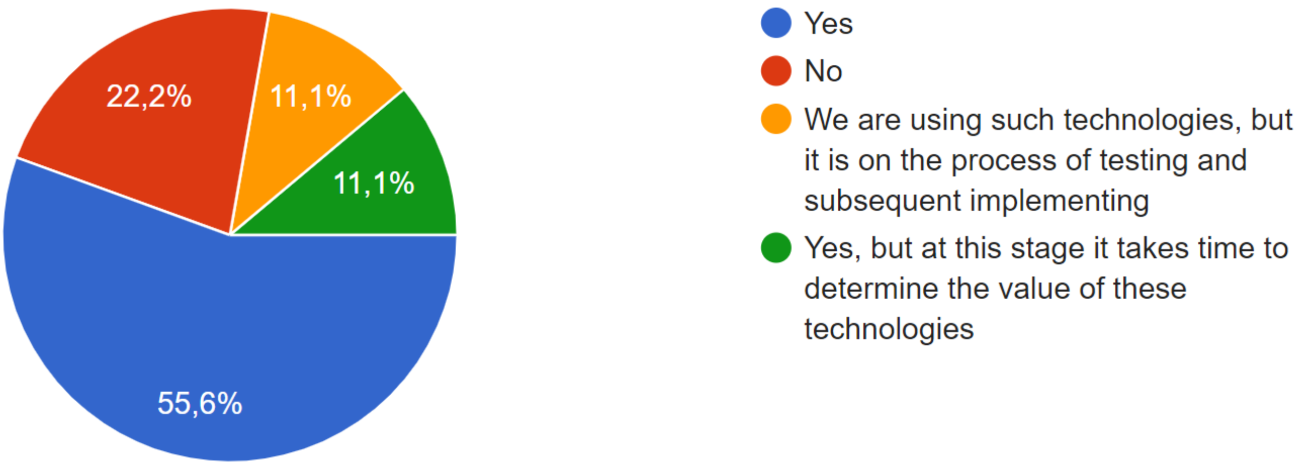

Figure 17. Using sensor technology in its supply chain management.

To the question, *« Does your company consider using or testing new IoT-based technologies? »* eight representatives answered «yes,» and one answered, «No, this way is too risky at the moment. Only after a couple of successful cases, it will be a reason to take a closer look» – company's «E» senior logistics manager.

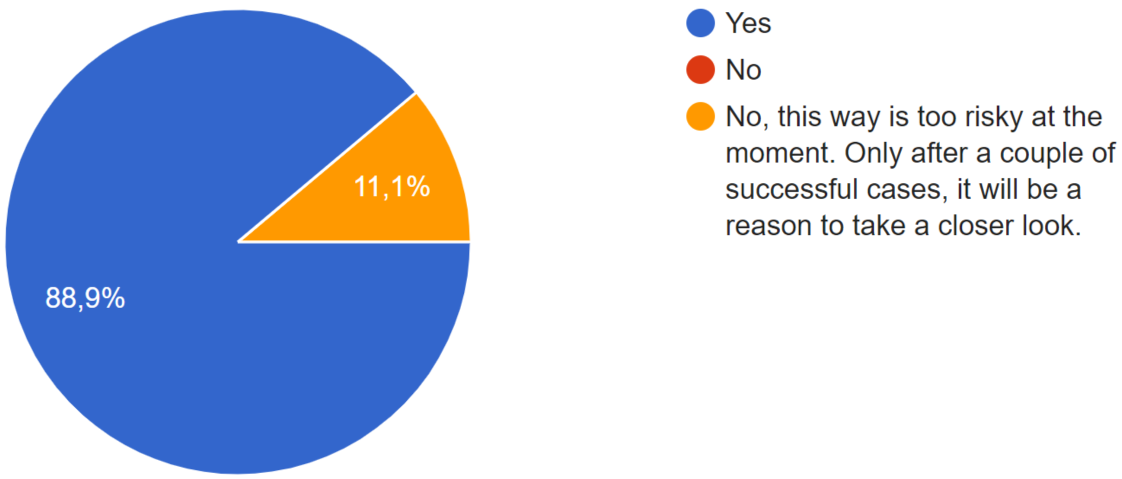

Figure 18. Possibility of using or testing new IoT-based technologies.

On the request to *« Evaluate the possibility of using technologies such as RFID and WSN, LoRa in your company,»* six representatives answered «high,» two answered «Medium,» and the last one answered « LoRa is the most interesting option due to the longest work area» – company's «D» region sales manager.

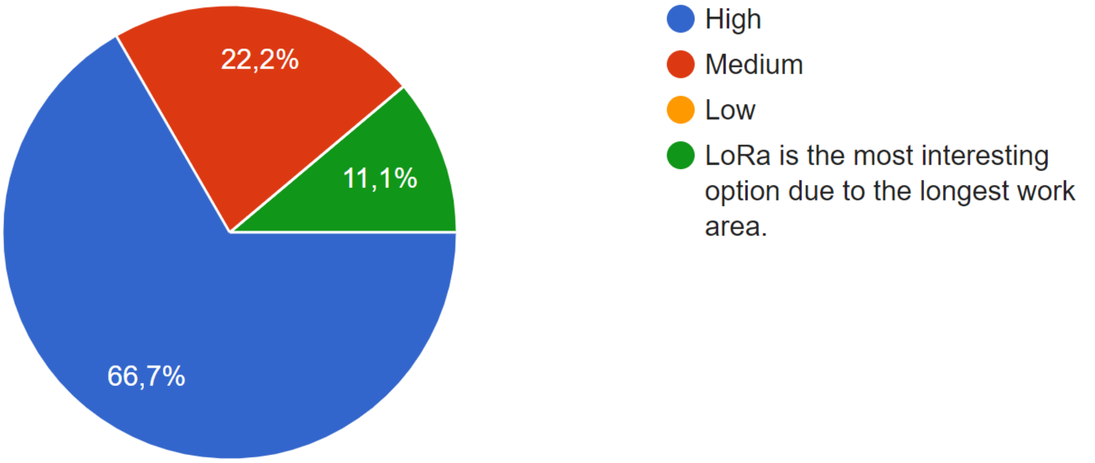

Figure 19. Possibility of using the possibility of using technologies such as RFID and WSN, LoRa.

To the question, *«Do you agree with the statement that IoT technologies have a more positive impact on SCM than negative?»*, eight representatives answered «yes», and one answered « Despite benefits using IoT, there are enough problems: security issues, the diversity of different protocols and the lack of generally accepted standards» – company's «B» senior financial specialist.

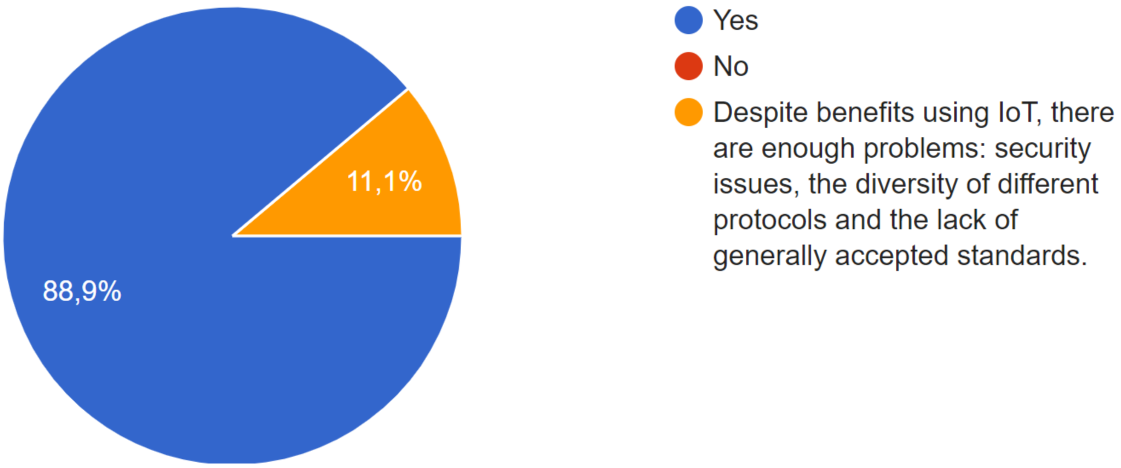

Figure 20. Opinion on the statement that IoT technologies have a more positive impact on SCM than negative.

On the question, *«Do you agree that 5G technologies will lead to the development of IoT and subsequently SCM processes?»*, five representatives answered «Strongly agree», three answered «agree», and one answered « Agree, the first 5G pilot zones will appear in Russia at the end of 2019» – company's «C» analyst.

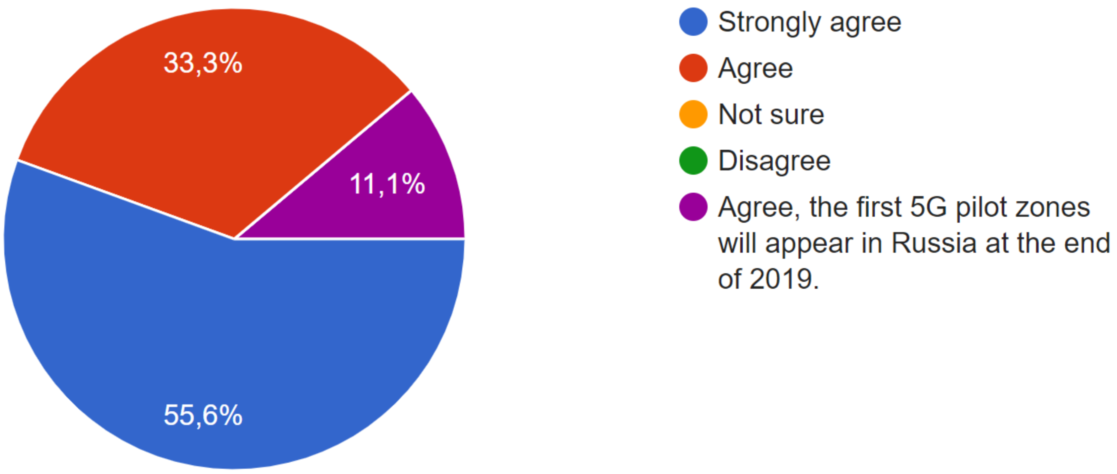

Figure 21. Opinion on the statement that 5G technologies will lead to the development of IoT and subsequently SCM processes.

Additional information from companies

«The Russian IoT market is at an early stage of development. It is characterized by a lack of awareness among business customers about technologies, which also lack an understanding of how to ensure the economic effect of their implementation. Among the benefits expected from IoT is an opportunity to increase the efficiency of processes, including by ensuring transparency, as well as to reduce risks, downtime and production costs. The IoT is perhaps one of the closest innovations to reality, which has already been implemented and actively influences our lives. The direction is perspective, as a huge number of spheres really need this technology» – company's «D» region sales manager.

«Automobile manufacturers, road authorities, infrastructure operators, city authorities and telecommunication companies understand that SCM is one of the main industries for IoT. It is too early to conclude the impact of IoT on our industry, but some pilot sectors have launched services based on large volumes of data collected from the transport sector, and most service providers and authorities are taking advantage of this amount of information. The transition to IoT has not yet been made, but business models are already developing the marketplace necessary to make a full transition to IoT» – company's «C» analyst.

«Tracking the goods from the moment of purchase to delivery is a significant indicator for the customer. Traditional monitoring consists of scanning the order between delivery points. RFID tags simplify the tracking process: they connect to the cloud and send location data more often than when scanning» – company's «F» procurement specialist.

«For the Russian logistics and supply chain management industry, the integration of IoT has certain obstacles, for example, it is necessary to address several issues on the part of the government to specify standards of use that would allow the use of the IoT everywhere, including in logistics. Also, there are many technological innovations that are "tied" to the IoT. Such technological innovations are AI, robots and automation. These innovations cannot be applied as effectively as they could be in the IoT» – company's «B» senior financial specialist.

Thus, according to the results of the expert survey, it is possible to observe that companies have a favorable opinion about the sensor technologies of the Internet of Things and its adaptation in SCM. However, some of them expressed concern that technologies are incipient, and in order to see each company with such technologies now requires close cooperation, along with it has been kept in mind a significant level of competition in the supply chain between different players and competitors and general investment availability. The findings of professionals involved in their daily professional work in the study of the state and dynamics of public opinion can provide a reliable and accurate picture that is not inferior in its reliability to mass surveys.

The method of the expert survey allowed to empirically confirm the importance and interest of modern sensor technologies because these solutions allow us to solve the optimization processes of companies in SCM.

5. Conclusion

This study was conducted to respond to the above research questions:

RQ1: Which are the areas in SCM that could be optimized by sensors and network technologies?

RQ2: How modern literature and expert opinion suggest that sensor and network technologies are relevant to be integrated into SCM?

RQ3: How utilizing RFID and WSN sensors technologies and 5G and LoRa network technologies influence internal SCM?

Thus, the main idea was to identify the challenges faced by today's SCM industry and how these problems can be solved with the help of sensor and network technologies.

The study provided a literature review, a conceptual framework, and an expert survey in order to fulfill the above research questions. The conceptual framework was created to understand the direction of the development of modern IoT sensor technologies, which can positively influence the current SCM problems. It was also necessary to specify trendy communication technologies as 5G and LoRa. Besides, the concept of RFID implementing in automobile weight checking was proposed.

5.1. Key Findings

This study identifies weaknesses in SCM that need to be optimized using the Internet of Things. The advantages and barriers of implementing the IoT were identified. Also, considered were sensor technologies IoT, providing effective optimization of supply chain processes. Among these technologies, RFID and WSN were highlighted as a way to organize the monitoring of supply chain processes. Moreover, monitoring systems can be combined using RFID tags with WSN technology by organizing a more efficient way of monitoring. Also, how the data is transmitted is particularly essential for the construction of a sensor monitoring system. LoRa and 5G technologies are highlighted as the most promising ways to organize network communication because of their characteristics and to expand opportunities for improving business processes. According to the results of the expert survey, the majority of respondents noted the use of sensor technologies in their field, as well as a positive impact on SC processes. However, some experts noted that there are concerns with the complete transformation of supply chain processes using IoT.

5.2. Discussions

As shown above, modern digital technologies and tools (IoT, Cloud Services, etc.) are used as a point and method of access and transfer of information between supply chain agents. Moreover, the joint application of digital technologies and logistics practices provides significant advantages, as it allows access to data on cargoes and various IoT at any time from any point in the supply chain. It also provides the ability to quickly obtain information and prevent supply chain disruptions, as well as to monitor the performance of the entire supply chain. The Internet and related technologies create new opportunities for more efficient management of business processes in the supply chain. In particular, the Internet can change supply, production and distribution processes. In each area and process, the Internet can change the type and role of communications between different partners, creating value for the entire supply chain and developing new business models.

Thus, the implementation of modern logistics concepts and technological solutions based on digital technologies provides companies with ample opportunities to reduce costs, improve service quality, increase customer satisfaction, and other competitive advantages. These benefits derive from the effect of digital technology on the various supply chain business processes. Digital tools allow companies to work with business partners to improve forecasting and scheduling, resulting in lower rates of inventory (meaning lower costs and better service). These technologies can also be used to communicate with customers, which leads to improved customer service and satisfaction, allowing companies to receive and share information throughout the supply chain, making the order fulfillment process more efficient. Possession of the latest technologies by modern companies will increase competitiveness and lead the company on the path of sustainable growth.

While the introduction of modern digital technologies has great potential to reduce costs and increase efficiency, the concept creates cultural and technical limitations in its implementation in practice. Cooperation is based on trust and commitment, which requires companies to overcome security concerns, confidentiality, standardization and skills and knowledge of employees, and high initial investments.

In summary, it is safe to say that, despite the challenges posed by the digitalization of the transport sector, IoT is a rapidly developing technology that allows the logistics industry to move to the next stage of development.

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