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# IoT sensors in supply chain management — Raben Group case study

*Czujniki IoT w zarządzaniu łańcuchem dostaw — studium przypadku Raben Group*

## Abstract

Currently companies are facing the need to improve the efficiency of logistics processes by providing up-to-date information about storage and transport conditions to their customers. This necessitates the use of the Internet of Things (IoT) as well as processing and analysing large data sets. The authors asked themselves about the effects of implementation of IoT sensors which was the reason for taking up this topic. The authors put forward a hypothesis: The use of IoT sensors can positively affect the work and reduce costs in the company. To verify this hypothesis two objectives have been adopted. The first, of a theoretical nature, consists in setting out the definitional framework and possibilities of using the IoT in supply chain management. The second, of a practical nature, concerns the presentation of the implementation of the IoT and determining the potential effects and benefits for Raben Group. One of the most important achievements of this article is a literature review on the effects of IoT implementation. The implementation of IoT technology in Raben Group has allowed for achieving business results such as: increasing data quality, freeing employees from monotonous work, increasing system redundancy, increasing supply chain transparency and reducing costs. The article is an original approach to the effects of implementation of IoT sensors by indicating ones which are the most common in the literature as well as those observed by Raben Group.

## Keywords:

Internet of Things, effects of IoT, supply chain management

## Streszczenie

Obecnie przedsiębiorstwa mierzą się z koniecznością podnoszenia efektywności procesów magazynowania i transportu poprzez udostępnianie bieżącej informacji o warunkach składowania i przewozu swoim klientom. Wymusza to konieczność stosowania rozwiązań i technologii Internetu Rzeczy (IoT) sensorów, czujników oraz przetwarzania i analizy dużych zbiorów danych. Autorzy zadali sobie pytanie o efekty wdrożenia czujników IoT, co było przyczynkiem do podjęcia tej tematyki. Autorzy postawili hipotezę: zastosowanie czujników IoT może pozytywnie wpłynąć na pracę i obniżyć koszty w firmie. Aby zweryfikować tę hipotezę, przyjęto dwa cele. Pierwszy, o charakterze teoretycznym, polega na określeniu ram definicyjnych i możliwości wykorzystania IoT w zarządzaniu łańcuchem dostaw. Drugi, o charakterze praktycznym, dotyczy prezentacji wdrożenia IoT oraz określenia potencjalnych efektów i korzyści dla Grupy Raben. Wdrożenie technologii IoT w Grupie Raben pozwoliło na osiągnięcie wyników biznesowych takich jak: podniesienie jakości danych, uwolnienie pracowników od monotonicznej pracy, zwiększenie redundancji systemów, zwiększenie przejrzystości łańcucha dostaw oraz obniżenie kosztów. Artykuł jest oryginalnym podejściem do efektów wdrożenia sensorów IoT poprzez wskazanie tych najczęściej wymienianych w literaturze oraz zaobserwowanych przez Grupę Raben.

## Słowa kluczowe:

Internet Rzeczy, efekty wdrożenia IoT, zarządzanie łańcuchem dostaw

JEL: D3, L91, O32, Q56, P47

## Introduction

The need to analyse substantial amounts of data and information is characteristic of effective supply chain management today. An increasing number of physical objects involved in logistics processes are equipped with wireless sensors and communication devices resulting in an interconnected network of uniquely addressed objects, which is referred to as the Internet of Things (IoT). The IoT is currently a solution desired by enterprises as it provides the means to improve their operational efficiency, provides significant productivity gains across the supply chain, facilitates communication and data integration, which translates into competitive advantage. Consequently, there is a visible increase in interest in this issue among business theoreticians and practitioners. Authors put forward a hypothesis: The use of IoT sensors can positively affect the work and reduce costs in the company. To verify this hypothesis two objectives have been adopted. The first, of a theoretical nature, consists in setting out the definitional framework and possibilities of using the IoT in supply chain management. The second, of a practical nature, concerns the presentation of the implementation of the IoT and determining the potential effects and benefits for Raben Group.

To the authors' knowledge, this is the first study of its kind dealing with the effects of the IoT in supply chain management. Although some literature has attempted to provide an overview of the IoT implementation in an enterprise, most studies have not specifically analysed the potential benefits and challenges of implementing the IoT in supply chains based on both literature and practical implementation. The study can be useful for researchers interested in the topic under analysis, business practitioners and organizations in the Transport, Forwarding and Logistics (TFL) sector and any other party interested in understanding in detail the impact of introducing the Internet of Things to improve supply chain management (SCM).

## Literature review — IoT in supply chain management

The concept of the Internet of Things (IoT) is one of the most innovative information and communication technology (ICT) solutions, combining sensory, communication, networking and information processing technologies within interconnected networks (Li *et al.*, 2015, Macaulay *et al.*, 2015). Hence, interest in the use of the IoT in

supply chain management (SCM) has increased significantly, both among business practitioners and scientists.

According to the Web of Science statistics (10.11.2021), there are major studies carried out on the concept of the Internet of Things — more than 16,495 records, while there are only 22 records for the phrase "Internet of Things in supply chain management". The research gap appears for the combinations of the "IoT" and "sensor" and "supply" and "chain" and "management" (0 records). The largest number of articles regarding the IoT and logistics deals with theoretical systematization of concepts based on bibliometric analysis techniques.

For instance, G. C. Nobre and E. Tavares (2017) conducted a bibliometric study to explore the literature on big data and IoT applications in relation to the circular economy. Although the literature study was based on 32,550 items in the field of big data and the IoT, it did not directly address SCM. Y. Bouzembrak *et al.* (2019) conducted a literature study relating to the use of the IoT in the food industry. In their analysis, they found that the IoT for food safety is a relatively new approach (the first article was published in 2011) and most of this research was conducted by Chinese universities, which mainly focused on using the IoT to track food products in the supply chain. In those studies, sensors were used to monitor mainly temperature, humidity and location. The most commonly used communication technologies were the Internet, radio frequency identification (RFID) and wireless sensor networks (WSN). More recent studies are concerned with combining the topic of the IoT with blockchain, a bibliometric analysis in this field was conducted by M. Kamran *et al.* (2000). They concluded that the interest of researchers in the field of BIoT (Blockchain in IoT) has been growing in recent years, as the number of citations of published scientific articles has been increasing rapidly since 2017 and is growing every year. The major research areas related to BIoT are computer science, telecommunications, engineering and chemistry. However, their research did not fully focus on the IoT in the context of SCM and logistics.

Studies based on bibliometric analysis that closely followed the topic of the application of the IoT in SCM were conducted by M. A. Rejeb *et al.* (2020). Based on the co-occurrence of keywords, the authors found that the literature of the IoT in SCM and logistics focuses on RFID technology, Industry 4.0 technologies, reverse logistics and covers various industries such as food and beverage, retail, construction and pharmaceuticals. They also pointed out that the positive impact of technology on SCM can be even greater if the IoT

is used in conjunction with blockchain, big data and artificial intelligence techniques such as machine learning, cognitive computing and neural networks. It is conceivable that combining these technologies with the Internet of Things will bring more value to organizations and streamline their operational processes such as monitoring, identifying and controlling products in the supply chain.

There are many definitions of the IoT highlighting its various dimensions and applications. According to B. Mehl (2018), the IoT is a technological concept in which multiple devices with the ability to be plugged in and out of the network are integrated to apply software and automation processes for smart applications. The flow of information can be implemented based on RFID readers that are connected to a network, which enables the transfer of data to identify an activity or process (Yadav *et al.*, 2020).

The IoT defined for logistics purposes is understood as a network of physical objects that are digitally interconnected to identify, control, and interact within the enterprise and/or supply chain (Chao *et al.*, 2007; Ben-Daya *et al.*, 2019; Kamble *et al.*, 2019; Rejeb, 2020). The essence of the IoT in SCM is to provide flexibility, transparency, tracking and sharing of information to contribute to effective planning, control and coordination of logistics processes (Ben-Daya *et al.*, 2019; Cui *et al.*, 2020).

The concept of the IoT is also explained based on the three essential elements that constitute it (Atzori *et al.*, 2010):

- 1) indirectly Internet-oriented software,
- 2) object-oriented devices and sensors, and
- 3) knowledge as a dimension of non-material systemization orientation.

Internet-oriented elements include technologies and protocols that enable the creation of a network of physical objects and their accessibility on the Internet. These components are divided into gateway network (Wi-Fi, GSM/GPRS, LTE, Ethernet) and gateway (Embedded & Signal processor, OS, SIM Module, Microcontroller) (Koot *et al.*, 2021). The device-oriented part includes RFID, detectors, sensors that can be connected to the Internet. The systematics-oriented part addresses the issue of managing data produced by information sharing by smart objects that can be accessed through a web interface (Aggarwal *et al.*, 2013). M. Koot *et al.* (2021) distinguished 23 systemization-oriented elements calling them "Service Support & Application Support Layer", among them: virtual entity, IoT Service Management, virtual entity service, IoT Business Process Management, Business Process Execution, Business Process Modelling,

Management Capabilities, Specific Management, Device Manager, Quality of Service (QoS) Manager, Security, Authentication, Identity Management, Access Control, Encryption, Data Management, Data Governance, Data Quality Management, Data Mining, Analytics Platform, In Motion Analytics, Predictive Analytics, Statistical Analytics.

The IoT is also understood in holistic terms with an emphasis on the global dimension — such a definition has been formulated by L. Atzori (2010) and D. Giusto (2010), where the IoT is a global network in which objects are interconnected, controlled and optimized through wired links, wireless channels or hybrid systems.

In defining the concept of the IoT in logistics, its tasks are identified in relation to SCM, which include industrial-logistics automation enabling the integration and interconnection of RFID sensor networks for logistics management, supply chain information management and maintaining competitive advantage (Borgia, 2014; Piramuthu *et al.*, 2015) and increasing efficiency at all stages of the supply chain (Fan *et al.*, 2015). Companies have been adopting the IoT in their logistics business models for several reasons. Based on the literature (Aggarwal *et al.*, 2013; Maksimović *et al.*, 2015; Edirisinghe, 2019) the IoT can be useful to track products and know their current status and storage conditions. For instance, in the food and beverage industry, increasing traceability and control across the supply chain links is crucial for effective response to ensure product quality, which translates into competitiveness of companies by meeting consumer demands (Maksimović, 2015; Kamble, 2019). The use of the IoT by companies can help to improve the information flow, thus it helps better understand the needs of customers and work in partnership with them for better demand planning and the implementation of customer service strategies (De Vass *et al.*, 2018). Thus, the IoT helps minimize the information gap in a dynamic supply chain by capturing real-time data and information between supply chain links and collaborating companies.

Despite the existence of literature in the field of IoT and SCM, there remain many research areas related to, among others, the IoT deployment and its potential impacts that pose uncertainties and challenges for both researchers and business practitioners. Currently, the implementation of the IoT in the supply chain is an innovative solution (Rejeb, 2020; Rey *et al.*, 2021), yet fraught with some potential problems related to cost bearing, reluctance of organizations to invest, security and privacy issues.

## Systematization of the effects implementation of IoT in SCM

Implementing IoT sensors in the supply chain is still an innovative solution for many companies, not just logistics ones. This is related to the need to engage the resources of the information technology (IT) department — specialists who, in the current era of digitalization of processes, are highly burdened and sought after on the market. However, many companies are increasingly opting for this solution because of the achievable benefits. As G. I. Ivankova *et al.* (2020) point out, the choice of technology and the benefits obtained must be a product of energy efficiency, correctness of measurement over time and security layer. Energy efficiency refers to the choice of the power source used in the sensor, the possibility of easy replacement of the power source and the availability of current information on the charging level in order to take pre-emptive actions. When analysing the choice of sensor one should pay attention to the components from which it was made, to Long-Time-Drift among others, which is the possibility of its being upset during use, which can result in errors and falsifications. This is directly related to the correctness of the measurement over time. The security layer includes the issue of cyber-security, i.e. the security of transmitted data and channels of communication with production systems of a particular company.

According to A. Haddud *et al.* (2017) the IoT brings tangible business benefits. The adoption of the IoT has the potential to streamline operational processes, reduce costs and risks due to its transparency, traceability, adaptability, scalability and flexibility (Zhou *et al.*, 2015). Implementation of IoT solutions in an enterprise can improve the level of integration of internal business processes (Mann, 2015) by enabling the strategic redesign of all activities in an integrated manner to ensure improved productivity and operational efficiency (Ferretti & Schiavone, 2016).

As G. I. Ivankova *et al.* (2020) list, the most important effects of IoT implementation include:

- optimization of the applied assets,
- reducing security issues such as counterfeiting and theft,
- accurate monitoring of resources and workflow,
- clear visibility in real time and timely response to events,
- analysis of the flow of real data for adequate and quick decision making,
- reducing manual data processing to increase accuracy and to reduce time spent,
- identification of new opportunities based on the study of consumers behaviour patterns,
- improving quality of work with clients.

K. Rejeb *et al.* (2020) mention tracking as the most important advantage of the IoT, which should be understood more broadly as: the location of product, material and assets or information about the environmental conditions in which an asset is located. In turn, R. M. Rebelo *et al.* (2021), in their analysis of the literature, showed that most often in scientific articles we find information about the improvement of the functioning of areas in companies as a result of the implementation of IoT solutions. The key areas include:

- customer relationship management,
- customer service management,
- demand management,
- order fulfilment,
- manufacturing flow management,
- supplier relationship management,
- product development and commercialization,
- returns management.

W. Jiang (2019) argues that the most important supply chain layers that will be affected by the implementation of the IoT include tracking, monitoring and coordinated control. I. Sergi *et al.* (2021) emphasize in their article on IoT technology and sensor prototyping that the most important issue remains obtaining real-time information on the position of goods that will allow the final customer to track their delivery. Another important aspect pointed out by the authors is the information on temperature, humidity and acceleration to which perishable goods such as fresh foods are subjected.

It should be noted that the primary advantage of the IoT highlighted in all research articles (Chen *et al.*, 2021; Jiang, 2019; Rajeb *et al.*, 2020; Rebelo *et al.*, 2021) is the ability to obtain information about a particular object at any time (real-time information). The benefits of implementing the IoT in an enterprise are combined with the concept of digital supply chain (DSC), which can be defined as the strategic and operative exchange of information (financial, production, design, research, and/or competition) between members of the chain to enhance communications (Korpela *et al.*, 2017). DSCs enable business process automation, organizational flexibility, and digital corporate asset management (Chase, 2016). The goal of the DSC is ambitious: to build an entirely new kind of supply network that is both resilient to change and flexible (Schrauf & Berttram, 2016).

A. Haddud *et al.* (2017) analysed the individual benefits of implementing the IoT in the supply chain, which resulted in a ranking of their relevance. The results of their study indicate that the biggest potential benefit that companies can gain in the supply chain is: development of real-time SCM with reduction of data distortion and

improvement of business intelligence. The second most important benefit is performance management improvement by reducing delays in data collection, assessment, and decision-making. The next most important benefits of implementing the IoT in the supply chain were: better integration of cross-organizational business processes, transparency of local and international logistics operations, reliability, responsiveness, and increased agility through rapid real-time information sharing and streamlined process operations. However, the developed ranking of the benefits of IoT implementation is not comprehensive, because it does not include all the effects mentioned in the literature, and secondly, the study was conducted only on a group of researchers excluding business practitioners.

## Implementation of IoT sensors on the example of Raben Group

Raben Group is one of leading 3PL companies in Europe with branches in 15 European countries, 90 years of experience, around 1,300,000 m<sup>2</sup> of warehouse capacity, over 160 locations and over 10,000 employees. Company profile: contract logistics services, domestic and international distribution, fresh logistics, sea and air forwarding and intermodal transport for customers operating in various sectors. The implementation of IoT technology began in 2019 with the installation of

the first temperature and humidity sensors. As a result of the market research, a decision was made to apply sensors using the Sigfox network due to one-way communication, limited possibilities of remote interference (cybersecurity) and the costs of purchasing and maintaining the sensors (Table 1).

An important part of the measurement quality of the sensors used during their lifetime turned out to be the analysis of the components/sensors to manufacture them. Sensirion electronic circuits (SHT11 and SHT21 — not recommended for new designs by Sensirion) were examined, paying particular attention to the stability of temperature measurements in the range of 0–60°C and relative humidity 20–80% RH. The humidity tolerance analysis of the SHT11 sensor indicates  $\pm 3\%$  tolerance, for SHT21 sensor the measurement tolerance is lower and it is  $\pm 2\%$ . The analysis of temperature tolerance data in the range from 0–60°C allows for concluding that it can take values of  $\pm 0.5$ – $1.5^\circ\text{C}$  for the SHT11 sensor, while for SHT21 sensors the tolerance is below  $\pm 0.5^\circ\text{C}$ . In order to obtain better data quality during operation, sensors should be selected with measuring systems having the smallest possible tolerance.

Sensors equipped with STH21 circuits were used also because of Temp. Long Term Drift  $< 0.02^\circ\text{C}/\text{year}$  and Humidity Long Term Drift  $< 0.25\text{ RH}/\text{year}$ , which were much higher for STH11 sensors at  $< 0.04^\circ\text{C}/\text{year}$  for temperature and  $< 0.5\text{ RH}/\text{year}$  for humidity. IoT sensors equipped with electronic measurement systems do

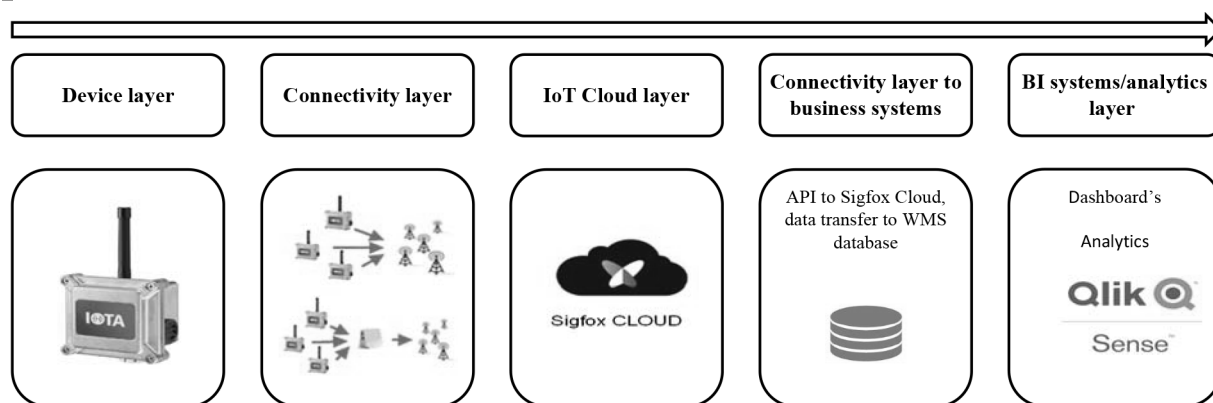
Table 1  
Comparison of Sigfox and LoRa WAN IoT Networks

Specification	Sigfox	LoRa WAN
Communication	Predominantly uplink, with limited downlink capability	Bidirectional
Rural range	30–50 km	15–20 km
Urban range	3–10 km	2–5 km
Packet size	12 bytes upstream, 8 bytes downstream	Max. 256 bytes, depending on network provider
Devices per access point	1M	100k
Messages per day	Up to 140 uplink (7 per hour), 4 downlink	Up to 84 upstream, 12 downstream, depending on provider
Cost structure	Based on number of IoT devices connected	Depends on network provider, or if you build your own network
Prototyping/starter kit costs	60–100 EUR	75–400 EUR
Radio module costs	5–10 EUR	10–35 EUR
Setup and API	Relatively simple	More complex, granular, better control and optimisation
Topology	Star	Star

Source: <https://przemysl-40.pl/index.php/2018/07/30/lorawan-i-sigfox-dwa-standardy-sieci-iot/> (accessed on 28.04.2021).

Figure 1

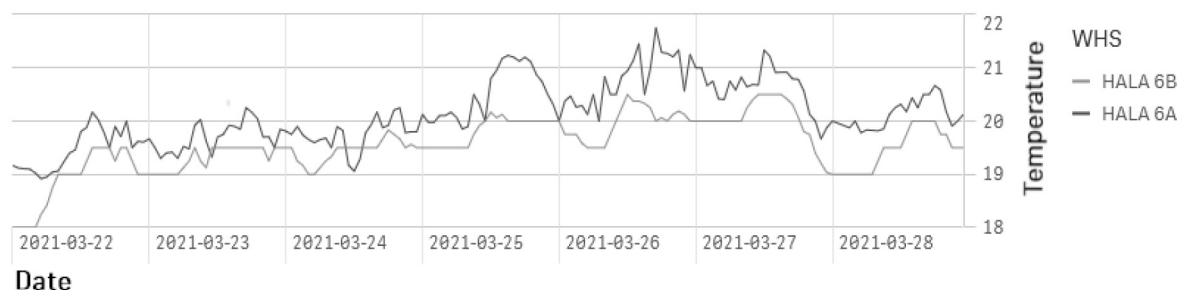
Communication architecture of IoT sensors in Raben Group



Source: own study.

Figure 2

Line chart of the average temperature in the two halls located in Robakowo/Poland, one week



Source: own study.

not require adjustment, only calibration in climate chambers. One of the goals of using IoT sensors was to build a system that was secure and not vulnerable to cyberattacks. In order to minimize data transmission risks, a decision was made to select sensors that provide one-way communication with structured messages. In the first step the data go to the Sigfox network operator (cloud) and only in the second step the data are downloaded to Raben Group systems with the use of Application Programming Interface (API), transfer of structured data with the use of Electronic Data Interface (EDI) messages and their saving in the Warehouse Management System (WMS) database. This communication architecture provides the maximum level of system security (Figure 1).

The data are presented on a dashboard prepared in Business Intelligence (BI) class software. Such data presentation allows for a quick reaction in case of deviations. There is a one hour delay in the measuring system, which is due to a decision to limit the number of data transmissions of the

measuring system in order to minimize energy consumption — which resulted in a longer interval between service actions. Figure 2 shows the temperature diagram for the 12th week of operation in 2021 for hall 6A (maroon) and 6B (green) located in Robakowo near Poznań.

The hall stores products intended for storage at room/ambient temperature (15–25°C). The temperature was not exceeded in any range.

## Results and discussion

In the article, the authors adopted two objectives to verify the hypothesis: The use of IoT sensors can positively affect the work and reduce costs in the company. The first, of a theoretical nature, consisted in defining the definitional framework and possibilities of using the IoT in supply chain management. The second, of a practical nature, regarded the presentation of the

implementation of the IoT and determining the potential effects and benefits for Raben Group.

The first objective was accomplished directly in part one "IoT in supply chain management" by the literature review and partially in the section on the effects of IoT implementation. The second objective was accomplished by discussing the effects of IoT implementation in the second part of the article and confirmed by case-study research of IoT sensor implementation in Raben Group. Based on the case-study research we can conclude that the implementation of the technology allowed for business outcomes in the form of:

- increase in data quality, reduction of errors associated with reading and copying of results by employees to .xls sheets,
- relieving employees from monotonous work related to preparing and sending reports on temperature and humidity to internal and external customers (by automating the process),
- increase in the redundancy of the system through the possibility of using multiple sensors, which clearly increased the resistance of the supply chain to interference,
- creating the ability to react more quickly when deviations are detected,
- increasing supply chain transparency (through the ability to share data with the customer online),
- possibilities to reduce losses in case of large temperature fluctuations (also thanks to prediction and correlation with weather data),

- restricting the movement of administrative staff in the warehouse to take readings from analogue devices during the pandemic,
- reducing operating costs in the process of recording temperature and humidity data,
- reducing costs by eliminating the need to calibrate analogue equipment.

The historical data collected can be used for further forecast/prediction analyses related to, for instance, the insulation of walls and roofs of warehouses in a particular climate zone, and the costs of heating or cooling the facility. Determining the cooling or heating curve of a warehouse will allow for reacting early and avoiding losses. Having real-time data through the use of IoT technology significantly reduces the risk of loss at the storage stage of the supply.

In the world literature, we find many studies on the need and validity of using the IoT in supply chain management. Many researchers point out that the possible effects are often presented rather haphazardly or as an addition to technical and technological studies. However, the authors noticed a lack of studies on the effects of implementations supported by case studies, which was one of the reasons for taking up the subject. They have also noted a lack of classification of the effects of IoT sensor deployment, both in terms of the supply chain and more broadly concerning the business, which will be the subject of further research by the authors.

## References/Bibliografia

- Aggarwal, C. C., Ashish, & N., Sheth, A. (2013). The Internet of Things: A survey from the data-centric perspective. In: Managing and mining sensor data. Springer. [https://doi.org/10.1007/978-1-4614-6309-2\\_12](https://doi.org/10.1007/978-1-4614-6309-2_12)
- Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. *Computer networks*, 54(15), 2787–2805. <https://doi.org/10.1016/j.comnet.2010.05.010>
- Ben-Daya, M., Hassini, E., & Bahroun, Z. (2019). Internet of Things and Supply Chain Management: A literature review. *International Journal of Production Research*, 57(15–16), 4719–4742. <https://doi.org/10.1080/00207543.2017.1402140>
- Bouzembrak, Y., Klüche, M., Gavai, A., & Marvin, H. J. (2019). Internet of Things in food safety: Literature review and a bibliometric analysis. *Trends in Food Science & Technology*, 94, 54–64. <https://doi.org/10.1016/j.tifs.2019.11.002>
- Borgia, E. (2014). The Internet of Things vision: Key features, applications and open issues. *Computer Communications*, 54, 1–31. <https://doi.org/10.1016/j.comcom.2014.09.008>
- Chao, C. C., Yang, J. M., & Jen, W. Y. (2007). Determining technology trends and forecasts of RFID by a historical review and bibliometric analysis from 1991 to 2005. *Technovation*, 27(5), 268–279. <https://doi.org/10.1016/j.technovation.2006.09.003>
- Cui, L., Gao, M., Dai, J., & Mou, J. (2020). Improving supply chain collaboration through operational excellence approaches: an IoT perspective. *Industrial Management & Data Systems*, 122(3), 565–591. <https://doi.org/10.1108/IMDS-01-2020-0016>
- De Vass, T., Shee, H., & Miah, S. J. (2018). The effect of "Internet of Things" on supply chain integration and performance: An organisational capability perspective, *Australasian Journal of Information Systems*, 22, <https://doi.org/10.3127/ajis.v22i0.1734>
- Edirisinghe, R. (2019). Digital skin of the construction site: Smart sensor technologies towards the future smart construction site. *Engineering, Construction and Architectural Management*, 26(2), 184–223. <https://doi.org/10.1108/ECAM-04-2017-0066>
- Fan, T., Tao, F., Deng, S., & Li, S. (2015). Impact of RFID technology on supply chain decisions with inventory inaccuracies. *International Journal of Production Economics*, 159, 117–125. <https://doi.org/10.1016/j.ijpe.2014.10.004>
- Ferretti, M., & Schiavone, F. (2016). Internet of Things and business processes redesign in seaports: The case of Hamburg. *Business Process Management Journal*, 22(2), 271–284. <https://doi.org/10.1108/BPMJ-05-2015-0079>
- Giusto, D., Iera, A., Morabito, G., & Atzori, L. (2010). *The Internet of Things: 20th Tyrrhenian workshop on digital communications*. Springer Science & Business Media.
- Haddud, A., DeSouza, A., Khare, A., & Lee, H. (2017). Examining potential benefits and challenges associated with the Internet of Things integration in supply chains. *Journal of Manufacturing Technology Management*, 28(8), 1055–1085. <https://doi.org/10.1108/JMTM-05-2017-0094>

- Ivankova, G. I., Mochalina, E. P., & Goncharova, N. L. (2020). Internet of Things (IoT) in logistics. *IOP Conference Series: Materials Science and Engineering*, 940(012033). <https://doi.org/10.1088/1757-899X/940/1/012033>
- Jiang, W. (2019). An intelligent supply chain information collaboration model based on Internet of Things and Big Data. *IEEE Access*, 7, 58324–58335. <https://doi.org/10.1109/ACCESS.2019.2913192>
- Kamble, S. S., Gunasekaran, A., Parekh, H., & Joshi, S. (2019). Modelling the Internet of Things adoption barriers in food retail supply chains. *Journal of Retailing and Consumer Services*, 48, 154–168. <https://doi.org/10.1016/j.jretconser.2019.02.020>
- Kamran, M., Khan, H. U., Nisar, W., Farooq, M., & Rehman, S. U. (2020). Blockchain and Internet of Things: A bibliometric study. *Computers & Electrical Engineering*, 81(106525). <https://doi.org/10.1016/j.compeleceng.2019.106525>
- Koot, M., Mes, M. R., & Iacob, M. E. (2021). A systematic literature review of supply chain decision making supported by the Internet of Things and Big Data Analytics. *Computers & Industrial Engineering*, 154, <https://doi.org/10.1016/j.cie.2020.107076>
- Korpela, K., Hallikas, J., & Dahlberg, T. (2017). Digital supply chain transformation toward blockchain integration. *Proceedings of the 50th Hawaii International Conference on System Sciences*. Waikoloa, HI, January, 4182–4191, <https://doi.org/10.24251/HICSS.2017.506>
- Li, S., Xu, L., & Zhao, S. (2015). The Internet of Things: A survey. *Information Systems Frontiers*, 17(2), 243–259. <https://doi.org/10.1007/s10796-014-9492-7>
- Macaulay, J., Buckalew, L., & Chung, G. (2015). *Internet of Things in Logistics*. Troisdorf: DHL Customer Solutions & Innovation.
- Mann, J. (2015). *The Internet of Things: Opportunities and applications across industries*. International Institute for Analytics, Enterprise Research Service. [www.sas.com/content/dam/SAS/en\\_us/doc/research2/iiia-internet-of-things-108110.pdf](http://www.sas.com/content/dam/SAS/en_us/doc/research2/iiia-internet-of-things-108110.pdf)
- Maksimović, M., Vujović, V., & Omanović-Miklićanin, E. (2015). Application of Internet of Things in food packaging and transportation. *International Journal of Sustainable Agricultural Management and Informatics*, 1(4), 333–350.
- Mehl, B. (2018). *What is IoT? Here are the definitions from industry experts*. Access Control Experts. <https://www.getkisi.com/guides/internet-of-things-iot>
- Nobre, G. C., & Tavares, E. (2017). Scientific literature analysis on Big Data and Internet of Things applications on circular economy: A bibliometric study. *Scientometrics*, 111(1), 463–492. <https://doi.org/10.1007/s11192-017-2281-6>
- Piramuthu, S., Rizzi, A., Vignali, G., & Volpi, A. (2015). Benchmarking of RFID devices for apparel applications: An experimental approach. *International Journal of RF Technologies*, 6(2–3), 151–169. <https://doi.org/10.3233/RFT-140064>
- Rejeb, M. A., Simske, S., Rejeb, K., Treiblmaier, H., & Zailani, S. (2020). Internet of Things research in supply chain management and logistics: A bibliometric analysis. *Internet of Things*, 12(100318), <https://doi.org/10.1016/j.iot.2020.100318>
- Rey, A., Panetti, E., Maglio, R., & Ferretti, M. (2021). Determinants in adopting the Internet of Things in the transport and logistics industry. *Journal of Business Research*, 131, 584–590. <https://doi.org/10.1016/j.jbusres.2020.12.049>
- Rebelo, R. M. L., Pereira, S. C. F., & Queiroz, M. M. (2021). The interplay between the Internet of Things and Supply Chain Management: Challenges and opportunities based on a systematic literature review. *Benchmarking: An International Journal* — ahead of print. <https://doi.org/10.1108/BIJ-02-2021-0085>
- Schrauf, S., & Bertram, P. (2016). *How digitization makes the supply chain more efficient, agile and customer — focused*. PWC Report. <http://www.strategyand.pwc.com/media/file/Industry4.0.pdf>
- Sergi, I., Montanaro, T., Benvenuto, F. L., & Patrano, L. (2021). *Sensors*, 21(2231). <https://doi.org/10.3390/s21062231>
- Yadav, S., Garg, D., & Luthra, S. (2020). Selection of third-party logistics services for Internet of Things-based agriculture supply chain management. *International Journal of Logistics Systems and Management*, 35(2), 204–230.
- Zhou, L., Chong, A. Y., & Ngai, E. W. (2015). Supply Chain Management in the era of the Internet of Things. *International Journal of Production Economics*, 159(2015), 1–3, <https://doi.org/10.1016/j.ijpe.2014.11.014>

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