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Logistics 4.0 – digital transformation with smart connected tracking and tracing devices

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ABSTRACT

Tracking and tracing devices can provide real-time information from the supply chain and enable digital transformation in the logistics and supply chain industry. In this connection, Logistics 4.0 refers to the potential for information technology and smart connected assets to be used in logistics in the same way as the Industry 4.0 concept which has been applied in operations and manufacturing. This paper analyses current tracking and tracing-focused applications that can provide value for logistics operations through a case study approach.

This study employs an exploratory multiple-case study approach, which is based on interviews with development project stakeholders. The paper analyses three industrial case studies and how tracking/tracing applications are connected to value processes.

The findings of this study show that the value of Logistics 4.0, through the deployment of tracking/tracing applications, is delivered in terms of operational efficiency, visibility, transparency, and safety/security. The payback depends on the volume of transactions, the possibility of reusing the tracking tags, the duration of trips, and the supply chain structure. The paper provides insight into how Logistics 4.0 technology can enhance logistics performance value. Based on the analysis, the study proposes the following potential application domains: (1) intermodal tracking of the shipments for operations control, (2) asset management of containers, and (3) certification of the process steps and authenticity.

1. Introduction

Digital transformation in operations and supply chain management relies on the application of value-adding technologies. Studies in the field have shown that organisational structures need to support the efficient use of technology (Gölzer and Fritzsche, 2017; Roscoe et al., 2019). The capability to conduct data-driven decision-making and operations, and adapt supply chain accordingly is a feature highlighted in recent studies (Fosso-Wamba et al., 2020; Dubey et al., 2022). In this respect, data-driven operations management combines the value-creation mechanism with digital technologies.

Supply chain management, and logistics in particular, is a lucrative application area for the Internet of Things (IoT), which can offer opportunities to improve the efficiency of material flows. The development of logistics often aims to reduce transport costs, speed up operations, and improve the security of supply and the transparency of supply chains that are often global. The concept of Logistics 4.0 has been presented to describe the digitalisation of logistics and its implications (Winkelhaus and Grosse 2020). Logistics 4.0 comprises several enabling technologies, which are tailored according to customer needs and to solve problems, for example, achieving sustainability (Evtodieva et al., 2019), improving efficiency (Amr et al., 2019), or providing actual logistics data for simulations (Timm and Lorig 2015).

Closely associated with Logistics 4.0, digital transformation in this context has been studied and this has shown that the application of advanced technologies, such as big data analytics and IoT devices, can improve logistics operations. Hopkins and Hawking (2018) described in a case study how an organisation reduced transportation costs and greenhouse gas emissions by applying truck telemetry. Cishosz et al. (2020) studied logistics service-providing companies (LSPs) in Poland, and their analysis suggests that the key benefits companies seek from digitalisation are related to operational efficiency, improving customer service, building new visibility-based services and business objectives to become a platform operator.

This paper focuses on the Logistics 4.0 capabilities enabled by emerging tracking and tracing IoT devices. Recent developments in

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tracking devices in terms of technological maturity and cost reduction are enabling solutions for an increasing number of transport-related applications (Fritz and Schiefer 2009). In the past, smart tracking devices have been associated with vehicles, trucks, ships, and containers, but not necessarily with pallets, crates, or actual product packaging items (van Dorp 2002).

Today, tracking devices are often used with expensive items such as health and safety-related goods. Developments on the cloud computing side help users to build centralised repositories for tracking data and building hybrid systems, combining tracking information from various sources, and providing an up-to-date view of the movement of goods (Shamsuzzoha et al., 2013). Advanced tracking and tracing applications have been successfully implemented in many specific industries, such as health care, with well-known examples in medicine and blood supply chains (Coustasse et al., 2013), and with expensive goods such as gems (Cartier et al., 2018). The common background for both applications is that the end user wants to verify the origin of the product, and its value heavily depends on its actual origin.

Another perspective for the need to understand the possibilities is the emergence of technology. Smart tracker devices such as Apple AirTag are available for private consumer needs at a reasonably low price (Collins 2021). This opens up new application possibilities that can rely on a global mobile phone platform (Li 2021), and further research is needed on how these applications add value to logistics operations.

This paper, therefore, studies IoT sensors in the Logistics 4.0 environment. The research problem statement of the paper is as follows:

RQ – How can tracking and tracing focused Logistics 4.0 technology provide value for logistics operations?

Several reasons support the justification and importance of this study. The Internet of Things and especially new kinds of inexpensive sensors present a promising technology for building logistics systems based on data analytics and automatic real-time decision-making (Lagorio et al., 2023). There is a research gap in understanding the mechanisms of how IoT and other Industry 4.0 technologies can in practice change the organisation and self-organising features in the supply chains (Swierczek 2023). Hrouga and Sbihi (2023) also recognised the need for this type of study. This justifies the need for studies building an understanding of how technology can provide value for logistics and supply chain operations.

This study employs an exploratory case study approach, where we compare three companies aiming for Logistics 4.0 implementation and evaluate the application requirements and value expectations. The next section of this paper reviews prior work in the literature, and then IoT tracking technology is presented. Following this, application areas are presented, and finally, a cost estimation approach is presented to evaluate the operating costs and the benefits of using IoT tracking systems for logistics operations.

2. Technology overview

In this section, previous work on Logistics 4.0 will be reviewed from the conceptual angle first, then from the tracking and tracing perspective, and finally from the point of view of IoT solutions.

2.1. Logistics 4.0

The concept of Logistics 4.0 has its roots in Industry 4.0, which was introduced by a German initiative to use digitalisation to improve the competitiveness of traditional manufacturing industries (Lasi et al., 2014). The key idea of Industry 4.0 was to implement high-level smart automation, robots, cyber-physical systems, and information technology in general to produce next-generation competitiveness in manufacturing and operations. The Industry 4.0 concept has links to intra-logistics conducted within the factory and the management of operations, but the focus was never on transportation or inter-logistics types of activity. Industry 4.0 is perhaps a more mature concept and its implications have been studied empirically in manufacturing and industrial services (Sony et al., 2021).

The technological advances in information systems can be applied to logistics and supply chains in a very similar way to that proposed in Industry 4.0, which is the initial reason for the introduction of Logistics 4.0 (Kucukaltan et al., 2022). The concept itself can imply several enabling technologies to solve logistics problems cost-effectively, and has been understood in different ways (Evtodieva et al., 2019; Amr et al., 2019). The authors have emphasized different parts. For example, according to the literature review of Winkelhaus and Grosse (2020), the key Industry 4.0 technologies are the Internet of Things (IoT), cyber-physical systems, big data, cloud computing, mobile-based systems, social media-based systems, and other information system technologies. Other authors, such as Wang (2016) have included other technologies to be a central part of the concept, for example, big data and data mining and cloud computing can be also associated with Logistics 4.0. During the COVID-19 pandemic, the digitalisation of logistics, including IoT, Artificial Intelligence (AI), blockchain, cloud computing, and Augmented Reality (AR) has been seen also as a driver for building resiliency to supply chains (Gupta et al., 2022). Generally, the technology adaptation has been linked to logistics innovation capability developments (Wang et al., 2020).

Logistics 4.0 has also been linked to a digital twin type of thinking, where a virtual model, for example, a simulation or a model for an execution plan, is connected to a real logistics execution system (Timm and Lorig, 2015). This approach emphasises the linkage between real space - actual events in the supply chain, and virtual space - the simulation model of reality. Logistics 4.0 has been also linked to objectives to improve the sustainability of an organisation. The model proposed by Nantee and Sureeyatanapas (2021), for instance, links the technology-enabled improved operational efficiency and visibility to enhance economic efficiency and also social and environmental sustainability.

Scholars also examine Industry 4.0 considering industry-specific features. In this respect, Jagtap et al. (2020) analysed Logistics 4.0 from the point of view of the needs of the food industry. This paper concluded with a very similar list of enabling technologies to those in other papers such as Winkelhaus and Grosse (2020). Szymańska et al. (2017) asked whether Logistics 4.0 is just another buzzword and not so much a novel contribution despite packaging existing solutions under a new conceptual umbrella. Meanwhile, Strandhagen et al. (2017) in their conceptual paper studied Logistics 4.0 as an enabler of sustainable business models and considered new needs to cover environmental parameters as performance indicators. The definition of Logistics 4.0 adopted in this paper is based on Winkelhaus and Grosse (2020), which is defined as "the logistical system that enables the sustainable satisfaction of individualised customer demands without an increase in costs and supports this development in industry and trade using digital technologies." By taking this approach, one does not need to rely on certain enabling technologies, but the focus is on various customer demand fulfillment needs supplied by digitalisation technologies.

One of the most complete theoretical frameworks of Logistics 4.0 was proposed by Dallasega et al. (2022), presenting a metrics-based maturity model of organisations. This model comprises three main aspects: (1) building organisational capabilities, (2) interconnection and material flow transparency, and (3) autonomisation-related aspects. However, this model has been empirically tested in three continents, with the current state-of-the-art knowledge of the business impact of Logistics 4.0 being largely based on surveys. Bag et al. (2020) concluded that the technological capabilities and environmental parameters are stronger firm performance-driving parameters than organisational capabilities in Logistics 4.0 implementation, and that Logistics 4.0 related capabilities have a significant effect on performance. Further research on Logistics 4.0 technology which employs non-survey approach would therefore provide further insight into how they help create or enhance firm

Table 1
Comparison of asset tracking technologies.

Sensor name	Contact range	Battery life	Price range	Description
T1 - QR codes, barcodes	Visual contact with the reader	–	€0.01 each	Passive sensor - Requires a separate reader system to be installed on-site
T2 – RFID	1 cm–10 m	–	€0.2–0.8 each	Passive sensor - Requires a separate reader system to be installed on-site
T3 – BLE (Bluetooth low energy) Beacon	Bluetooth range 10–60 m	1–48 months	€10–50 each	Active sensor - Compatible with different reading systems
T3 - LoRA/ Sigfox Beacon	10–20 km	1–5 years	€20–100 each	Active sensor - Location data a few times a day
T4 - 4G GPS tracker	Global	1–6 months	€100–300 each	Active sensor - Location data a few times a day

performance and value.

2.2. Tracking and tracing

The digitalisation of logistics - Logistics 4.0 – is empowered by real-time data collection and processing for computerised decision-making. Tracking and tracing are an example of generic logistics applications empowered by information technology. This means software applications built on top of the logistics transaction data when each step completed in the supply chain is recorded for the product or shipment into a centralised or non-centralised database (van Dorp 2002). According to Stefansson and Tilanus (2000), the technical implementations of tracking and tracing systems are often simple but can enable advanced logistics decision-making.

Tracking refers to the application of following a shipment in real time for decision-making purposes. Real-time or close to real-time monitoring often comprises timestamps of events, such as loading, shipping, unloading, status changes in the process – waiting for approval, sent, received – or actual location of the event. Tracking systems answer the question of where the package is at a particular moment or where it has been seen last.

Meanwhile, tracing looks at the same kind of event log of a shipment retrospectively. The question is from where and when this package has come. These kinds of questions of origin are important for many applications, including food safety (Fritz and Schiefer, 2009), and environmentally, socially, and economically in sustainable sourcing (Evtodieva et al., 2019).

Advances in the IoT have created new possibilities in terms of building next-level tracking and tracing applications which are based on shipment-level tracking tags. Smart tags can provide location data not only for event-based transactions from the distribution centres and warehouses, but also periodically updated. Such implementations have been proposed by Shamsuzzoha et al. (2013) in industrial project logistics, in the use of big data analytics (Hopkins and Hawking 2018), and in synchronization of production processes (Qu et al., 2016; Zhang et al., 2018).

IoT applications in the food retail context have been studied by Njomane and Telukdarie (2022), who described the experience in South Africa during the Covid-19 pandemic and outlined possible long-term implications. In addition to smart tags, blockchain technology has been proposed to provide actual verification of the events in the form of electronic signatures, which are stored in immutable distributed ledgers (Rožman et al., 2019).

2.3. IoT technology in logistics

In order to implement IoT for logistics, architectural decisions for data processing need to be made. Sensors are the low-level hardware basis for data collection and the backbone of data processing. IoT sensors for logistics applications are either small active or passive tags attached directly to material handling units, such as packages, crates, pallets, or containers; alternatively, they are slightly more expensive edge devices mounted on trucks, trailers, forklifts, or other mobile machinery. These edge devices are typically capable of long-range communication and GPS-type precise location services. Base stations may connect to local assets and transfer the information to the cloud on permanent installations such as distribution centres, production facilities, or warehouses.

Various sensor tag technologies are available based on needs. Table 1 describes the key technologies and their differences in terms of communication range, battery life, tag price, and introduces four levels of trackers. The price data has been collected from retailers' prices by searching on Alibaba to illustrate the differences between those technologies.

The most inexpensive solutions are based on reading passive tags visually such as bar codes, QR codes (Level T1) or by using radio-frequency identification tags, which do not require any direct visual contact (Level T2). According to Raza, 2022, the applications of RFIDs in logistics and supply chain management are widespread and based on standardised tags and readers. The data content on cheaper tags, such as bar codes and QR codes, often has only a reference number and the actual up-to-date data payload is stored in centralised cloud services. This may be enhanced with additional verification technologies such as blockchains, which provide an immutable ledger for ensuring approvals and authentications of transactions. This kind of approach has been employed, for example, in medicine where counterfeit products present a global problem (Kumar and Tripathi 2019).

The next level of tags is low energy active tags (Level T3), which have typically low energy Bluetooth communication, or LoRA type of long-distance communication up to several kilometres. These kinds of active sensors can provide indoor location or other ambient environment information, such as temperature. Low-energy consumption beacons implementing Bluetooth technology are reasonably low cost, as the technology is widespread on mobile phone accessories. Additionally, this can be combined with solar power and connected with standard mobile phones for application creation (Kano et al., 2022). Smarter active devices can provide localisation services for indoor operations, which is a typical need for warehouses and distribution centres (Wu et al., 2022). Long-range communication technology has its roots in smart meters, which transfer small amounts of information on a daily basis. Examples of the use of possible LoRa beacon capabilities in food retail logistics have been presented in the study by Arnaud et al. (2021), but there are currently very few applications available for supply chains.

T4 Level tracing devices are built on positioning devices using satellite navigation services and combine this with an onboard computer communicating to the internet by using mobile phones or satellite phone networks. These devices are typically heavier and have significantly shorter battery life. The devices are mounted on more expensive carriers such as sea containers, trucks, trailers, or other mobile machinery operating logistics chains. GPS trackers are typically connected to cloud-based data collection and transport management systems (Helo and Shamsuzzoha, 2020).

The expected impact of industrial internet technologies and trackers, in general, is often related to improved supply chain transparency (Zelbst et al., 2020). This means more precise information about the transactions, location, and time combined into a level close to that required by the operational control of logistics.

Building an IoT-based Logistics 4.0 solution for an organisation requires a backend solution for data collection and processing. This typically takes place in the cloud-computing environment. The purpose of

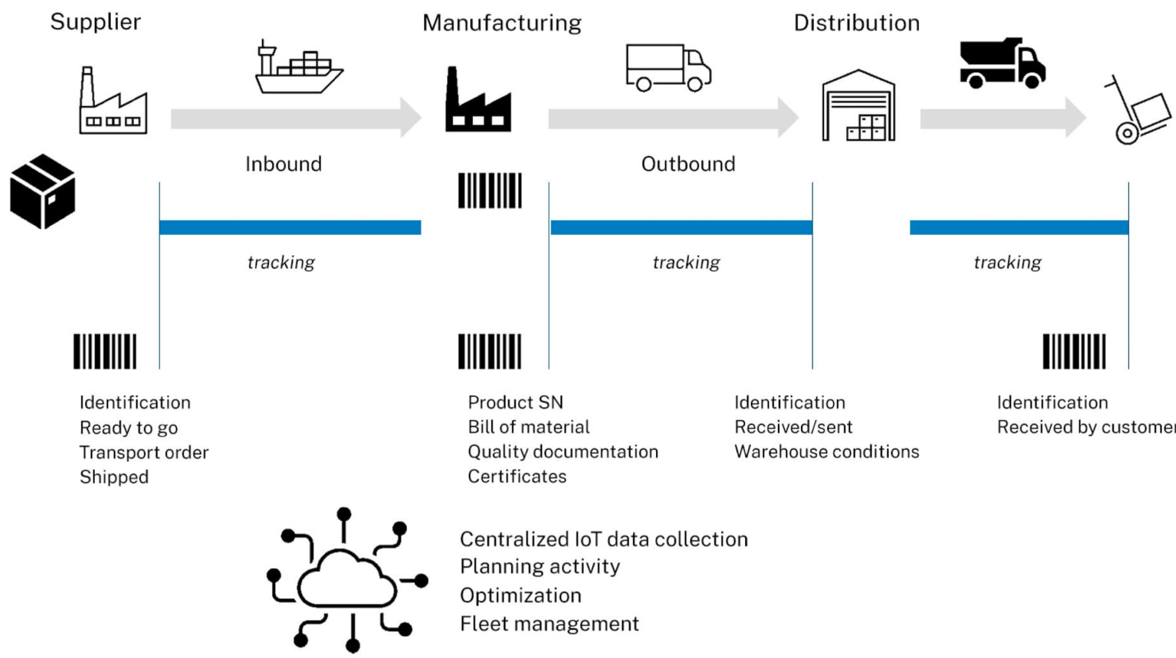


Fig. 1. IoT system connecting data from different stages of the supply chain by using events and sensor data.

the cloud application is to combine sensor events into meaningful information for supply chain management. For example, the backbone systems linked to Industry 4.0 and logistics mentioned by Barreto et al. (2017) include enterprise resource planning, warehouse management systems, transportation management systems, and intelligent transportation systems, as well as information security as a wide concept.

Fig. 1 illustrates a generic architecture of how data is collected from various parts of the supply chain as reading events and during transportation as real-time tracking information. The cloud-based services may include sensor data collection, planning functionality, optimization functionality, and fleet management applications.

3. Methodology

In order to study the value creation mechanisms of tracking and tracing related Logistics 4.0 implementations, an exploratory case study approach was adopted. From a methodological point of view, this kind of case research approach aims to elaborate theory (Ketokivi and Choi 2014), and participative design science aims to enlighten practice in the light of theory (Holmström et al., 2009).

We contacted a systems integration company providing services for the designing of logistics tracking systems and got access to three actual implementation projects where the data was collected. The criteria for selecting the cases to be studied were that all projects should be active in the planning and implementation phases and permission from the end-customer should be granted. Based on this screening, three projects with different technological implications and business areas were selected for illustration. The process for all projects had been similar in that at first a smaller pilot project was executed to verify the technical and business assumptions of the studies. According to the project plans, the expansion to full volume typically takes one to three years. The projects analysed include: (1) container tracking for bulk products, (2) roll cage tracking for the food industry, and (3) plastic crate container tracking. The logistics development projects were analysed in the planning and execution phases between the years 2019–2022.

The total number of possible cases, which could have been selected remains unknown as the selection was done jointly with a service-providing company. This approach is a potential limitation in that selected cases are somehow biased. However, as the purpose of the study was to detect value-creation possibilities, bias in selecting only successful projects should not be a problem.

The actual data collection was conducted by open interviews with the project stakeholders, project managers of the system integration company and the customer managers in two of the cases, as well as through access to business planning documentation of the implementation projects. A demonstration of the actual software in the current stage was also presented. Each project manager had more than five years of experience running IT projects. All customer managers had more than three years of experience managing logistics operations. Appendix 1 shows the collected data from each case.

The collection of data was developed based on discussions with the project managers and letting them explain how the problem has been perceived. The interview protocol for the data collection included sections: (1) interview questions about the project background and

Table 2
Case summary of three logistics tracking/tracing projects.

	Case 1	Case 2	Case 3
Industry	By-product collection and processing	Food wholesale and distribution	Packaged food product distribution
Tracked asset	Truck containers and trucks	Roll cage	Plastic crate
Mode of transportation	Truck	Truck	Truck
Need	Container location and status for production planning and control	Asset management, lost cages, orders shipped to the wrong places	Asset management
Volume of logistics	20 trucks, 500 containers	10 000 roll cages	200 customers, 50 000 crates
Stakeholders	Production companies, transport companies, by-product processor	Wholesales, transport companies, customers	Production sites, transport companies, customers

Table 3
Case 1 - Technology business case evaluation.

Case description	Real-time monitoring of by-product collection process from food factories to processing plants
Business targets	- Tracking - Improved operational performance thank to better traffic planning; - Tracing – Food safety
Key performance indicators	- Cost per ton kilometre transported - Product quality - Lead time on the collection process
Cloud technology	Centralised TMS solution integrated with truck tracking IoT solution and container asset management
IoT asset tracking technology	T4 - GPS-based tracking devices on trucks; Containers linked to trucks by manual entry by the driver; mobile phone-based
Changes in the process enabled by the technology	Integrated by-product processing and transportation management; centralised traffic planning

objectives, (2) technical documentation for selecting the tracking technologies, (3) planning cost-benefit sheets for the projects, (4) interview questions about the expected process changes and value creation. The open interview questions were combined with the business planning documentation and observations from the software demonstrations. In Cases #1 and #3, the end customer managers were also interviewed to confirm the objectives set for the project and the performance indicator setting the targets. Case #2 was still in the early stage of implementation and thus the customer manager interview was not conducted.

4. Results

The exploratory case studies used in the analysis were selected based on the availability of data and the active progress of their logistics development project. The interviews, documents and the software demonstration were key data sources to develop a case description for each. The main focus of the process was to outline how value creation in Logistics 4.0 technologies was planned to be achieved in terms of costs and benefits. For each case study, there is a certain variability in terms of need, the business case, and the actual technological implementation. Table 2 below summarises the background of each of the cases.

4.1. *Case 1 – by-product collection and processing with containers*

The case of by-product collection concerns a company serving the meat-processing industry by collecting by-products from factories and processing these in rendering plants for products to be used as the components of fertilizers, biofuel, and animal feed. The collection process is based on containers located at customers' meat-processing plants, which are monitored, and once filled to the full capacity are transported to the processing factory. The transportation truck takes three containers, and the freshness of the product is a quality parameter in processing the by-product.

The relative cost of the collected raw material is low, and for this reason, special attention needs to be paid to logistics costs. As different factories produce by-products at variable speeds and according to varying production schedules, the transport planning task becomes complex. The company thus looks for an IoT solution to track trucks, import the container location and status information from the factories by using mobile phones, and provide this as a map interface for the transportation planners. Table 3 summarises the features of the by-product container technology and business case.

Fig. 2 shows the structure of the logistics process in the case. Transport planning takes place in the cloud-based application, which comprises information provided by the yard management of food processing plants for up-to-date container information. The trucks are equipped with real-time edge devices providing location information. The operations at the rendering factory receiving the goods are planned according to transportation planning operations. Meanwhile, Fig. 3 shows the high-level user interface of a map visualising the location of each container at plant yards or in transportation.

4.2. *Case 2 – food wholesale and distribution*

Case 2 is a wholesale company distributing food products daily to hotels, catering, and restaurant customers by using roll cages and several transportation companies. This is a standard way of operating in the business and follows the same model by other competing companies in

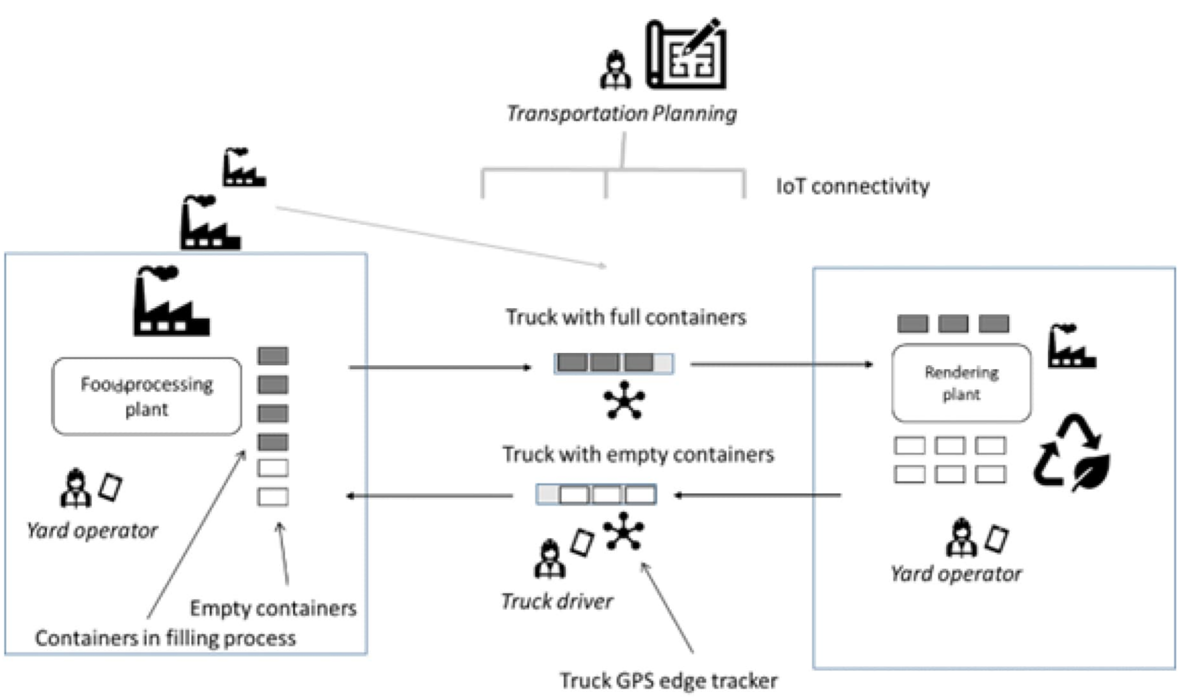


Fig. 2. Case 1 - Logistics process and IoT setup.

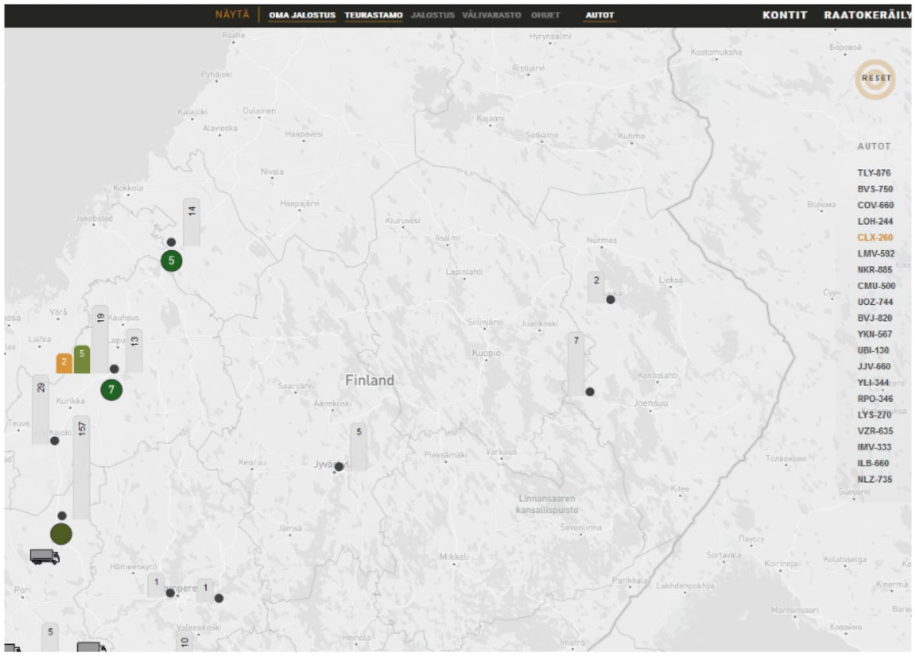


Fig. 3. Case 1 – User interface showing containers at each factory site and truck locations.

Table 4
Case 2 – Technology and business case evaluation.

Case description	Tracking of roll cages in the food distribution for reducing losses of assets and failed deliveries
Business targets	- Tracking – Are roll cages located where they should be, or are they lost in certain locations? - Tracing – What went wrong with the delivery?
Key performance indicators	- Cost of lost roll cages; cost of maintaining roll cages - Number and quality costs of failed deliveries
Cloud technology	Asset tracking portal monitoring the location of roll cages and providing the information for logistics managers Integration possibility with TMS software
IoT asset tracking technology	T3 - BLE (Bluetooth low energy) smart beacons on each roll cage; base stations located at central points and in trucks
Changes in the process from earlier enabled by the technology	Introduction of systematic asset management and maintenance program for the material handling units

the industry. Roll cages often get lost and mixed up with other suppliers' cages. The challenge is to get back the return from the customers. The visibility of the roll cages' location is limited. Another challenge is tracking failed deliveries. From time to time, some roll cages get unloaded in the wrong locations in the distribution round. Returning the goods is challenging, and in many cases, the goods need to be given for free or sold at a high discount to customers in the wrong location. Additionally, a new rush order is needed to ship to the missing customers.

This company looks at tracking devices that can beacon their location to drivers in order for them to collect and bring back empty cages. The planned solution includes a Bluetooth low-energy type of beacon for each roll cage. The location information is collected at local base stations and/or a mobile phone application located on the driver's phone. By doing so, the system can provide up-to-date information from the entire distribution network and monitor whether any roll cages are in the wrong places. Table 4 lists the key features of the technology and business case (see Table 5).

Table 5
Case 3 - Technology/business case evaluation.

Case description	Tracking the rental plastic crates for food distribution
Business targets	- Tracking – Providing a solution to see the last seen location for the assets - Tracing – Invoicing the customer, ensuring the washing process of crates
Key performance indicators	- A novel service for customers to get a tracking solution based on rental crates - High-quality invoicing of the use of assets - Reduced the number of lost crates
Cloud technology	A customer portal for sending deliveries of rental crates and other value-added services to link food production
IoT asset tracking technology	T1, T2, T3 - Mobile reader stations based on hand-held readers able to use barcodes, QR codes and RFIDs
Changes in the process enabled by the technology	Centralised software is provided by the rental company

Fig. 4 shows the architecture of the setup in the case of food wholesale. Distribution centres are equipped with a local base station which sends real-time information about the roll cages located in the facility. The roll cages beacon their identity, and this can be read by the truck drivers' mobile phone applications and trucks which have a local base station. Meanwhile, Fig. 5 shows the user interface to monitor roll cage locations and key performance indicators of the roll cage flow.

4.3. Case 3 – packaged food distribution with crates

The product scenario of Case 3 is packed food distribution, which is built on plastic crates stacked on a pallet. A crate rental company offers software as a service solution for small food production companies to rent plastic crates used in the distribution and provides a cloud-based information system for shipping the goods. The standardised crates have a unique serial number, which can be used in picking the goods for customer orders and receiving confirmations of delivery. The company

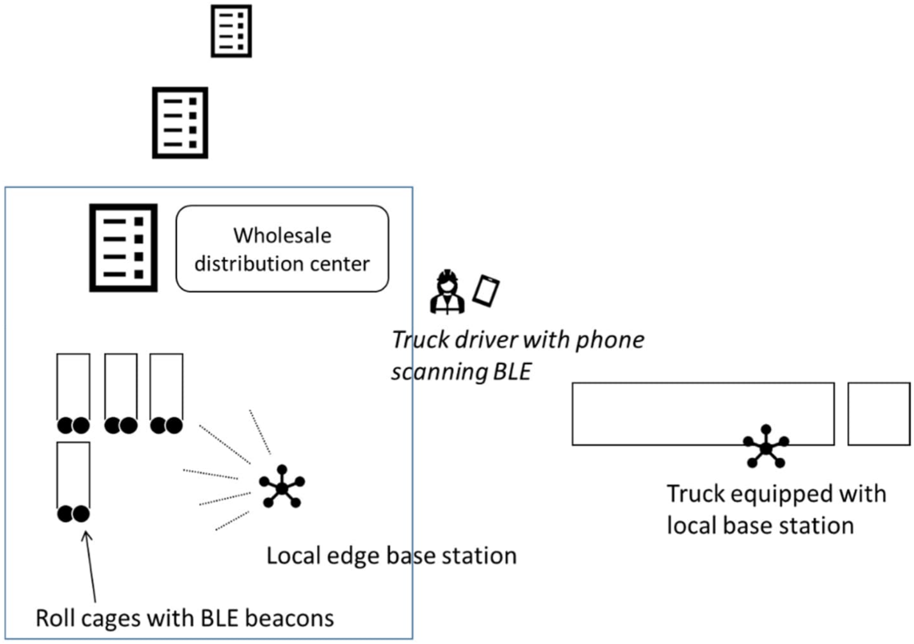


Fig. 4. Architecture setup of the food wholesale with roll cages.

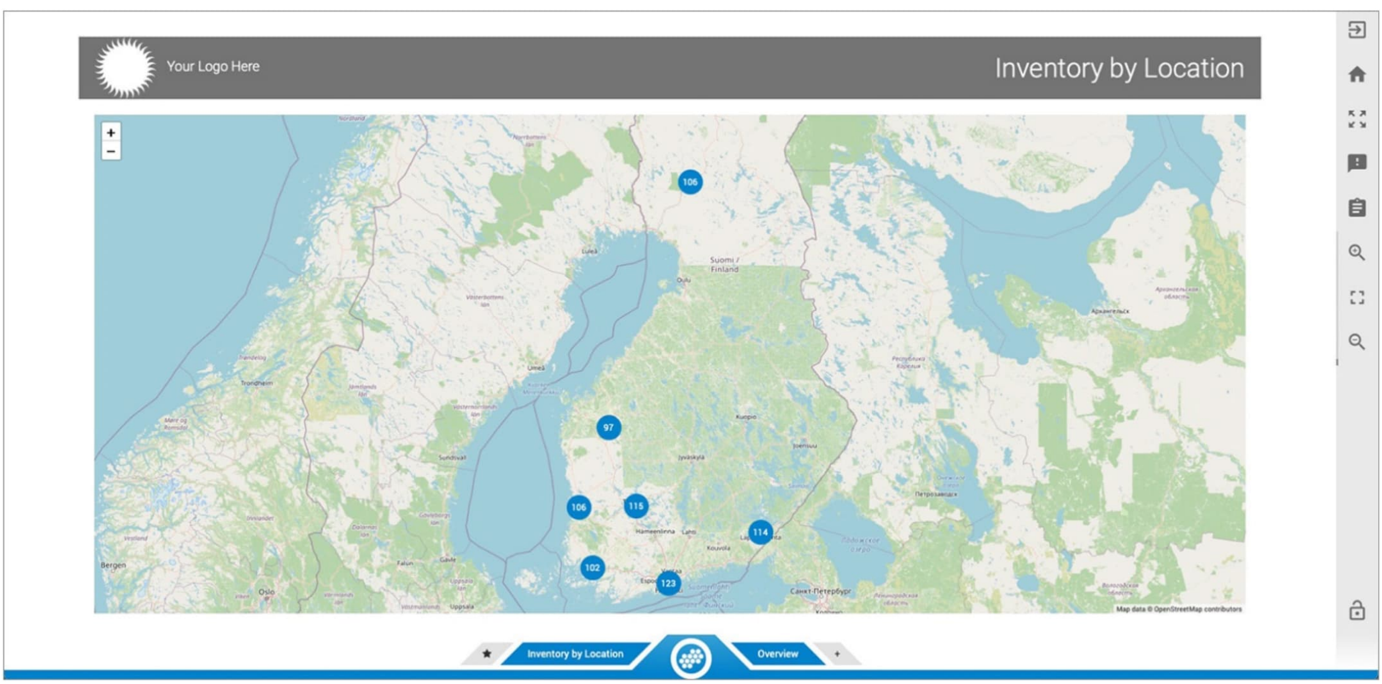


Fig. 5. Examples of user interfaces for monitoring logistics with IoT showing the roll cage locations at each part of the distribution network.

in Case 3 wants to have a mobile reader terminal, which can be rented to customers for processing the shipments and at the same time providing accurate information on the need for rented plastic crates.

The company seeks a novel solution to provide good visibility for customers to see their shipments and at the same time have up-to-date information about the crate locations to ensure the efficient circulation of crates in the logistics process. Table 3 lists the technology applied in the case and the business objectives for implementation.

Fig. 6 illustrates the process and the architecture of the crate-based food distribution. Food producers using the rental crates scan crates in their shipping operation. Inexpensive mobile readers and fixed shipping stations are used to process the correct information. The information is collected into a cloud-based portal which can provide software for shipping notes and managing traceability information. Empty crates are returned to factories. The crate rental company can adjust the pools of crates at each location and charge the users for the services consumed. Meanwhile, Fig. 7 shows the user interface for creating the shipping information.

4.4. *Analysis of findings - use case typology*

The results show that the value-creation mechanisms are based on different types of solutions with various IoT tag technologies. The data-driven digital transformation varies based on use cases and the processes

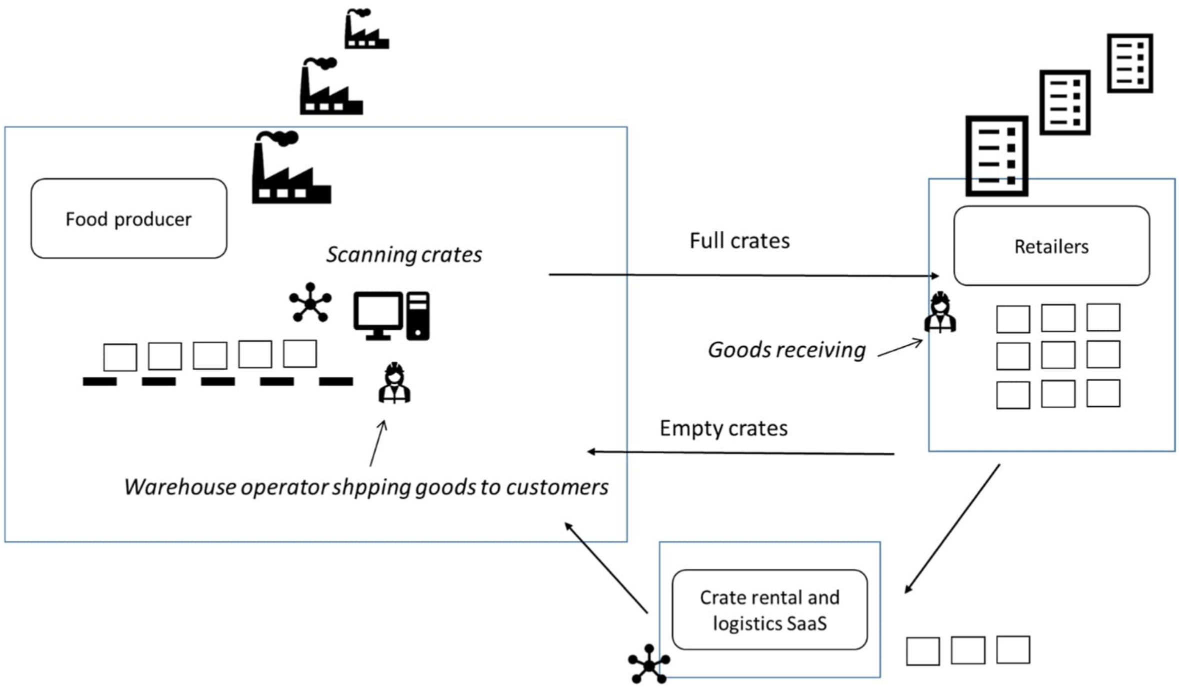


Fig. 6. Process and architecture of crate-based tracking of food distribution.

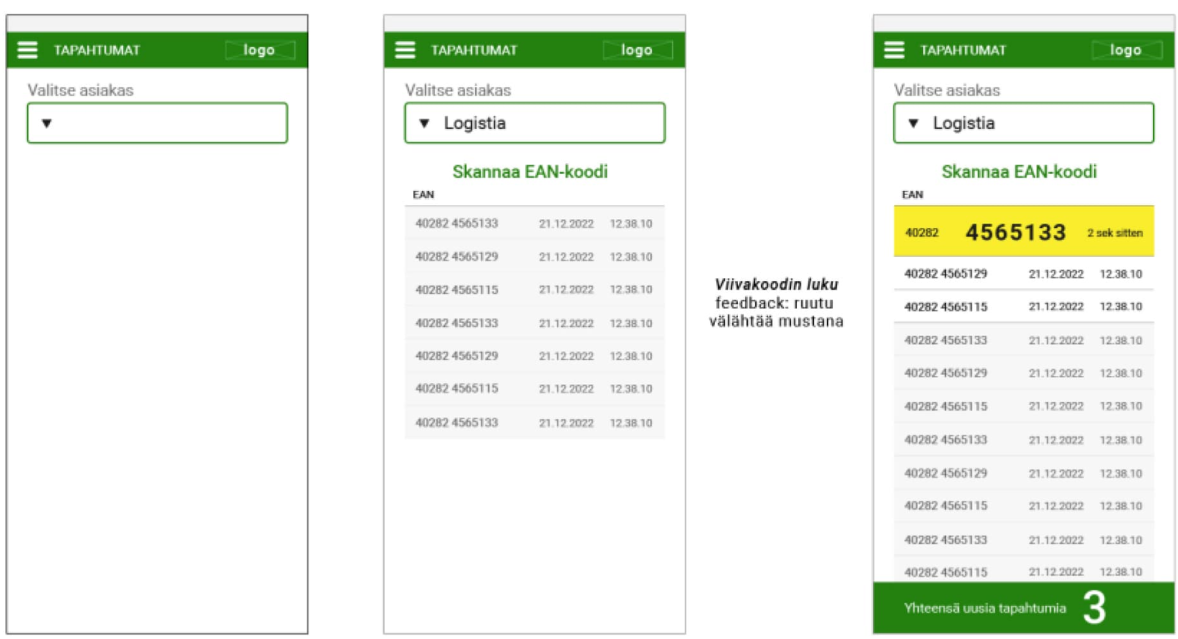
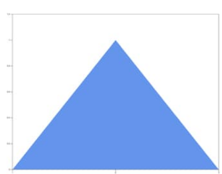


Fig. 7. User interface of reading station mobile application.

Table 6
Case summary.

	Case 1	Case 2	Case 3
IoT technology	T4 – GPS trackers	T3 – BLE beacon	T1-2 Barcode, QR code, RFID
Asset management	Linking containers to trucks and yard management	Avoiding losing roll cages	Ensuring the washing of crates
Fleet	Location of containers for traffic planning	Fleet of each owner's cages and not mixing with the competitors	Invoicing the rented crates and lost crates
Traffic control	Optimization of supply chain operational performance	N/A	Possible link to TMS systems as a data input
Value creation	Operations performance	The overall cost of asset life cycle	Customer service – offering logistics tools for customers

Table 7
Costs of running tracking/tracing infrastructure (example).

Parameters	Value	Unit	Explanation
Sensor tag			
Hardware cost per unit	30	EUR/pcs	
Life cycle [years]	3	pcs	
Broken tags/year	2	%	Distribution assumption = @RtaTRIANGULAR(1; 2;3) 
Number of tags in the fleet	10000	pcs	
Annual costs	102000	EUR/year	
Edge station parameters			
Hardware cost	600	EUR/pcs	
Life cycle [years]	5	pcs	
Number of edge stations	50	pcs	
Annual costs	6000	EUR/year	
Edge station parameters			
Hardware cost	600	EUR/pcs	
Life cycle [years]	5	pcs	
Number of edge stations	50	pcs	
Annual costs	6000	EUR/year	
Cloud infrastructure parameters			
Data storage and applications	0.75	EUR/ month/tag	Distribution assumption = @RtaTRIANGULAR(0,5; 0,75; 1) 
Annual costs	6000	EUR/year	

of the companies. Table 6 summarises the three cases from the point of view of technology, use case, and value creation. Each case has a different type of tracking device, ranging from the cheapest barcode/ QR/RFID type of passive reader used with large volume plastic crates to active Bluetooth low energy (BLE) beacons used with roll cages containing several end-product packages, and ends up with the most expensive type of GPS trackers which are mounted on trucks and collect the container information.

Logistics management can focus on a single factory or warehouse, but most applications cover broader parts of the supply chain. Case #1 used the most expensive tracking devices and the value creation observed was related to improvement of the daily activities in the field: efficiency and quality of operations. The value creation for Case #2 was related to a larger number of assets and an extension of the asset lifecycle value. Case #3 included the most inexpensive tracking technology and linking the end-customer's value creation process to the operations side.

The three cases show that there is a link between the number of material-handling units (containers, roll cages, crates) and the cost of trackers used. For high volume, cheaper methods such as fixed codes are used. On medium volume, beacons start to make sense, and on the smallest number of items to be tracked the most expensive active (T4 Level) GPS trackers seem to be the most feasible solution.

According to interviews with the project stakeholders, the analysis of each case seems to be based on the cost of running the tracking/tracing infrastructure. The results seemed to converge despite the differences in the cases in terms of logistics processes. This may be due to the interviewing process where the main point was to develop items for the value creation and payback modelling, which may lead to a similar type of thinking with a focus on costs and benefits.

Tables 7 and 8 below illustrate an example of the analysis provided by the systems integration company. These tables show how each of the tracking device-related cases was evaluated by using a simplified cost-benefit analysis, where each parameter was converted to financial metrics. The key items of the calculation template were: (1) the cost of the sensor tag, (2) the cost of possible edge stations for each distribution centre, and (3) cloud software operations and infrastructure.

These cost elements are then evaluated against the benefits that visibility to the supply chain can provide. The parameters with uncertainty used statistical distribution to describe possible variability. For example, the number of broken tags was assumed to follow a triangular distribution, where the most likely value was 2%, a minimum of 1%, and 3% of broken tags per year. Also, other input parameters, including operational expenses for running the cloud infrastructure and the average duration of trips, were modelled in the same way. A log-normal distribution was used to model the variability of these parameters.

By using a Monte Carlo simulation (Argo simulator) and generating a run of 1000 scenarios, the results were generated as illustrated in Fig. 8. The result shows normally distributed benefits measured in financial terms with a skew towards the right side.

The numbers used in Tables 7 and 8 are hypothetic al and illustrative, but they show the logic used in investment analysis for selecting the tracker solution for each case. The use of simulation can show potential outcomes of the implementation when uncertainty of input parameters has been introduced. According to the interviews, the cost of tracking was compared with the expected value that the solution can deliver. The role of the calculation template was to make tangible the value creation of each investment and expected process changes.

4.5. Analysis of results and framework of value creation mechanism

The results of the case studies in this paper suggest that the value creation mechanisms for Logistics 4.0 and tracking/tracing applications can be rooted in increasing the service and revenue, decreasing operational costs, or improving asset utilisation. These objectives are operational and can be linked to business analyses and tangible performance-related objectives.

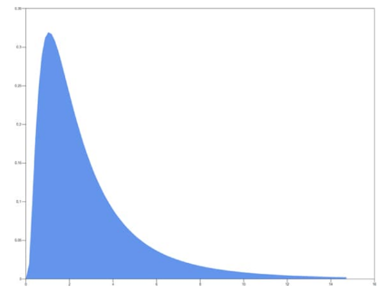
Based on the above, we have outlined a framework of expected benefits, as illustrated in Fig. 9. The three use cases analysed in this study can be grouped under operational efficiency, visibility of real-time actions, transparency of past actions, and safety/security. These are the measurable objectives, which can be linked to key performance indicators. The cases show variability in terms of the target of tracking. In this framework, the tracking and tracing targets can be grouped into material handling units and the tracking/tracing of trucks and other vehicles. In the cases, the variability was from crates and pallets to vehicle tracking.

Subsequently, a set of use cases detected from studied companies were mapped into the intersection of the two dimensions. The use cases were operational logistics control and asset management types of categories. The framework is a proposal based on the three case studies analysed in this paper and is not complete as other types of organisations could have different types of needs. However, in some sense, the dimensions and the groupings in this framework are generic for supply chains.

5. Conclusions

The research problem stated in the beginning was to build an understanding of how tracking and tracing focused Logistics 4.0 technology can provide value for logistics operations. The results from the

Table 8
Benefits of running tracking/tracing infrastructure (example).

Parameters	Value	Unit	Explanation
Average trip duration	2.121	days	Distribution assumption = @RtaLOGNORMAL(3; 3) 
Number of trips	172	trips/tag/year	
Total number of trips in the fleet	1720627	trips/year	
Number of incorrect deliveries	3.3	%	~56229 deliveries
Return cost of incorrect deliveries	80	EUR/delivery	Estimate based on the average return trip and handling cost
Total annual cost reduction potential	4498336	EUR/year	= Number of incorrect deliveries * Return cost for incorrect delivery
Other cost-reduction benefits	50000	EUR/year	User input based on: - Reduced maintenance costs of material handling units (crates, pallets) - Improved work time analytics
Total benefits per year	4806430	EUR/year	Output based on Monte Carlo simulation
per tag	480.6	EUR/year	
per trip	2.793	EUR/trip	

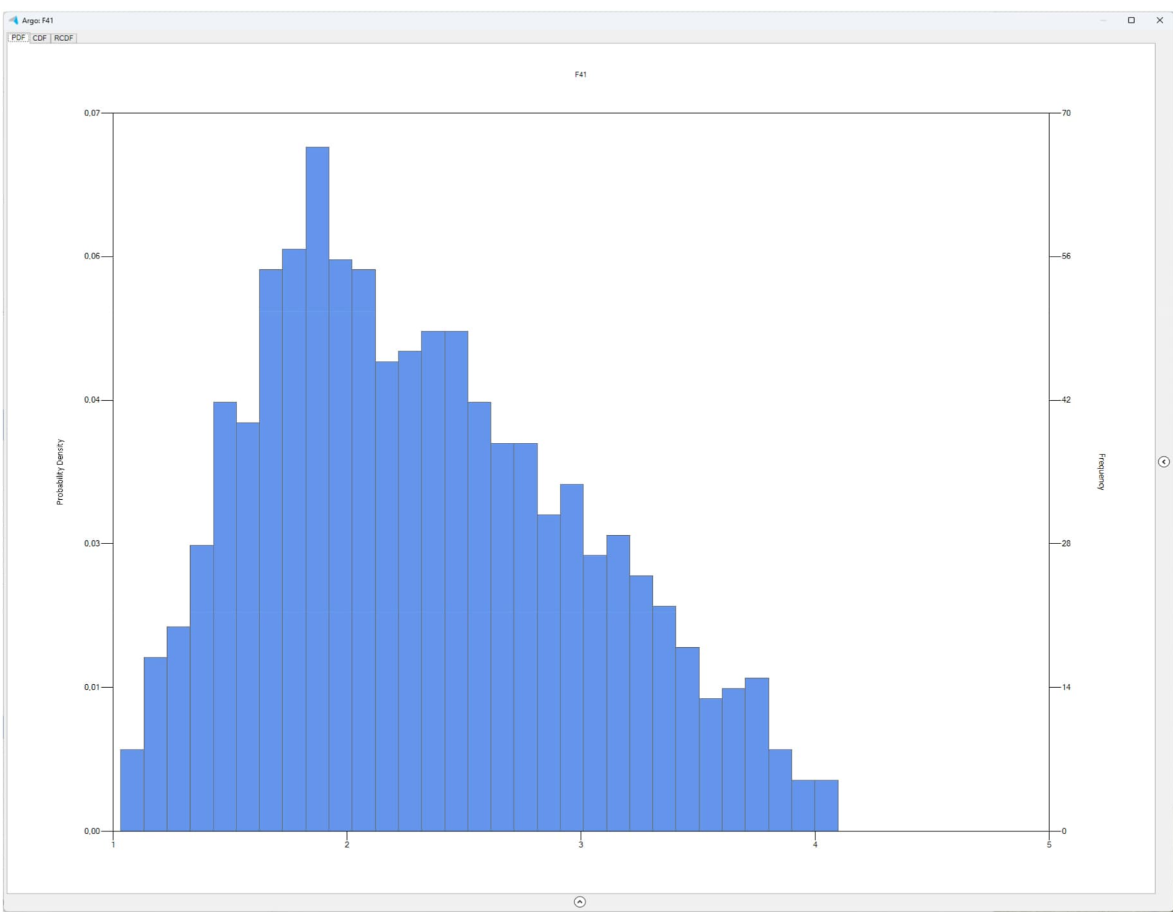


Fig. 8. Simulation results of benefits distribution – expected value delivered in EUR.

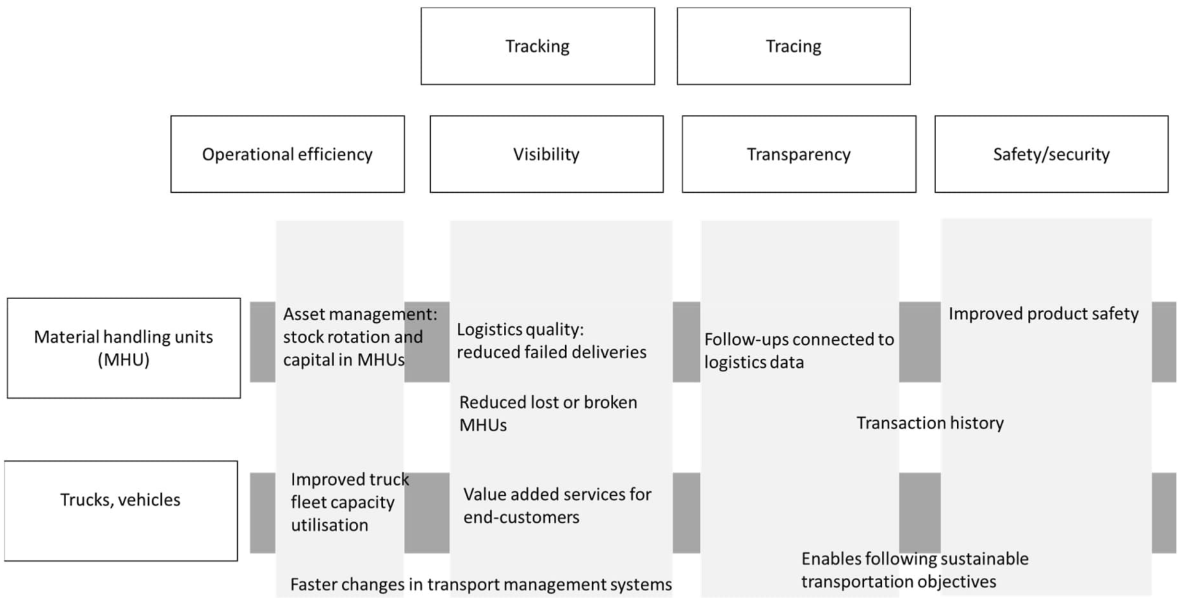


Fig. 9. The framework of expected benefits of Logistics 4.0 tracking/tracing technology.

exploratory case studies showed a set of five different objective types which may take place individually or as a combination of multiple objectives. All these recognised objectives are operational and measurable.

Digital transformation in supply chains can be achieved in different ways. Logistics 4.0 and IoT solutions may present a key competitive factor in many industries. This study has demonstrated some possible value-creation mechanisms from the case studies and how costs and benefits can be evaluated by selecting the right combination of technologies. The analysis of three cases shows that the benefits that companies seek by investing in Logistics 4.0 tracking and tracing solutions built on IoT are related to.

- Operational efficiency of material handling units – efficient stock rotation and tied-up capital: real-time data allows for operation with a smaller buffer.
- Operational efficiency of trucks – better management of capacity utilisation rate: up-to-date knowledge of fleet activity allows for higher utilisation of vehicles and containers.
- Real-time control - improved ability to respond to rapid change is made possible by combining information about changes in demand and supply chain activities into a single design view.
- Lower total cost of ownership: optimised transport routes reduce mileage and the consumption of fuel.
- Improved safety: traceability and trackability are the keys to product safety, especially in food-related operations.

The findings are in line with earlier studies of logistics digitalisation, for example, the case studies conducted by Hopkins and Hawking (2018), as well as Cishosz et al. (2020) and Beaulieu and Bentahar (2021), which focused on other types of applications.

5.1. Discussion

The concept of Logistics 4.0 is still quite novel as concluded by Dallasega et al. (2022). In this connection, this research has contributed to demonstrating some possible mechanisms in which value of logistics digitalisation can be created. The results do not cover all the possible aspects of the concept, but the technologies presented and the implications derived from the case studies in the empirical part of the paper are in line with the international survey conducted by Dallasega et al. (2022). Transparency of real-time data, data security, and identification combined with advanced planning systems and analytics are some important needs in industrial applications. From a theoretical point of view, these are mainly related to interconnection and material flow transparency, as well as organisational capacity factors of the Logistics 4.0 measurement model proposed by Dallasega et al. (2022).

The three case studies analysed in this research show examples of how operational information system investments are linked to these kinds of decisions. Organisations need to have a certain maturity in logistics planning and information systems, which can utilise the data provided by smart tags. The selection of tracking technology is a decision which should be driven by a business case analysis. New technologies will emerge in the future and the costs of tags will be reduced. The suitability of each technology solution from a business perspective may change over time, but an analytical approach to planning is recommended.

The results from this research are in line with earlier studies. For example, Lagorio et al. (2023) showed a large list of inexpensive edge technologies, which are emerging as potential enablers of operational improvements in logistics. The results can be compared with Hrouga and Sbihi (2023), who outlined a practical roadmap for a case organisation in retail for the implementation of Logistics 4.0. Cybersecurity and big data analytics were highlighted as important features. In our study, the analytics and operational control-related items were more on top. The use of data analytics seems to be a common factor for the studies. The results did not show any radical changes in organisation or remarkable attempts to achieve self-organising models (Swierczek 2023). However, these might be something that organisations may achieve in the long run when there is more experience in using systems and building new innovative models on top of proven technologies.

New use cases for tracking/tracing have also emerged. In addition to providing better visibility, various environmental efficiency measurements form a new control parameter. Companies want to provide their customers with reliable information on the environmental impact, such as greenhouse gas emissions or water and energy consumption, as well as certificates of origin.

5.2. Further research

Advanced companies are building their applications on bespoke solutions, which require skills in an organisation to manage such development projects. Further development work is needed to provide solutions that smaller companies can leverage and potentially gain similar benefits to larger ones. In addition to business case and economic-based analysis, other aspects such as organisational changes and impacts on human resources of supply chains should also be studied in the future. Logistics 4.0 technologies also enable new types of innovation and product development for service business models, which are interesting for further research. The proposed framework should also be tested in further companies aiming to utilise the emerging Logistics 4.0 technologies.

Data-driven digital transformation of supply chains is going to impact a great share of supply chains in the near future. For this reason, more academic work is needed to support successful implementations for all sizes of organisations.

CRediT authorship contribution statement

Petri Helo: Writing – original draft, Visualization, Software, Project administration, Methodology, Data curation, Conceptualization. **Vinh V. Thai:** Writing – review & editing, Investigation, Conceptualization.

Data availability

The authors do not have permission to share data.

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Appendix 1. Data collection and analysis from cases

Case	Data sources	Data analysis processing
Case #1	• Logistics manager at the company – interview 60 min • Project manager at integrator company – interview 60 min	• Software demonstration on actual system • Key performance metrics • Outlining costs and benefits for the investment calculation table based on interview
Case #2	• Project manager at integrator company – interview 45 min	• Project requirements documentation • Software demonstration of a pilot version of the system • Outlining costs and benefits for the investment calculation table
Case #3	• Operations manager at the customer company – interview 60 min • Project manager at integrator company – interview 60 min	• Software demonstration of the actual system • Outlining costs and benefits for the investment calculation table based on interview

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