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REVIEW ARTICLE

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Operations management of smart logistics: A literature review and future research

Abstract The global collaboration and integration of online and offline channels have brought new challenges to the logistics industry. Thus, smart logistics has become a promising solution for handling the increasing complexity and volume of logistics operations. Technologies, such as the Internet of Things, information communication technology, and artificial intelligence, enable more efficient functions into logistics operations. However, they also change the narrative of logistics management. Scholars in the areas of engineering, logistics, transportation, and management are attracted by this revolution. Operations management research on smart logistics mainly concerns the application of underlying technologies, business logic, operation framework, related management system, and optimization problems under specific scenarios. To explore these studies, the related literature has been systematically reviewed in this work. On the basis of the research gaps and the needs of industrial practices, future research directions in this field are also proposed.

Keywords smart logistics, operations management, optimization, Internet of Things

1 Introduction

Logistics is becoming increasingly important in the supply chain due to the rapid development of the commodity economy. In 2019, the total value of global logistics reached 6.6 trillion USD with a growth rate of 9.1%. In particular, the Asia-Pacific region holds the largest logistics market share, which is mainly driven by the burgeoning demand in China. However, the booming of retail and E-commerce has also brought challenges to the global logistics industry. For example, in March 2020, the number of global logistics packages reached 43.6 million, with an increase of 8.7% over the same period of last year. Among them, 60.75% were sent by China. With the stress of the increasing logistics volume, Chinese logistics cost accounted for 14.1 trillion yuan in 2019, 6% higher than that of 2018. Meanwhile, the high expenditure was accompanied with the problem of low resource utilization. As reported, the Chinese logistics industry had a 12.6% logistics vacancy rate, a 15% warehouse idle rate, and a 20% logistics labor gap.

With a similar situation worldwide, the era of “smart logistics” facilitates the capacity and efficiency of the logistics service. The logistics industry has exerted its effort by applying the emerging intelligent information technology, such as radio frequency identification devices (RFID) tags, blockchain, big data analysis, artificial intelligence (AI), and drones, to realize the automation, visualization, traceability, and intelligent decision-making of the logistics process (Barreto et al., 2017; Liu et al., 2018). For instance, the leading logistics company UPS has invested one billion USD per year recently in developing their logistics technology, especially focusing on the area of unmanned aerial vehicle delivery. Amazon, one of the biggest E-commerce platforms, has bought the robot manufacturer Kiva Systems for 7750 million USD to build their own smart logistics system. In the Chinese market, developing smart logistics systems has become the paramount strategy of major Chinese logistics companies, such as Alibaba, Shunfeng, and JD.

Smart logistics is also fully supported by governments with related policies and programs, as presented in Table 1. Developed countries, such as the US, the UK, and France, pay more attention to the infrastructure of smart logistics.

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Table 1 Smart logistics policies

Country/Area	Year	Policies/Programs	Policy focuses
US	1993	Commodity Flow Survey (CFS)	Collect the data of commodity flow for transportation planning and assessing the demand of transportation facilities
	2012	The moving ahead for progress in the 21st century	105 billion USD is invested for developing the surface transportation network and infrastructure
UK	2018	Industrial strategy: Artificial intelligence sector deal	Facilitate the development of artificial intelligence and data-driven economics
France	2015	Logistics Strategic Plan 2025	Focus on the development of logistics innovation and the cooperation between smart logistics and smart manufacturing
	2018	Digital industrial transformation: Measures for mid-caps and SMEs	Smart Internet of Things and smart transportation are proposed as the “future industries” in France
European Union	2019	The Trans-European Transport Network (TEN-T) policy	Facilitate the development of a Europe-wide transportation network with innovative applications, emerging technologies, and digital solutions
Russia	2018	The State of the Union Address 2018	Develop a digital platform for the logistics industry that is compatible with the global information space
Japan	2018	Strategic Innovation Promotion Program (SIP) phase two	Expand the related services with a self-driving system
China	2013	Guidance on advancing logistics informatization	Facilitate the standardization, digitization, automation, and intelligence of logistics information collection
	2016	The implementation of “Internet +” efficient logistics	Address the applications of RFID, integrated sensor, robot, and big data analysis in the logistics industry to realize the intelligence of logistics
	2019	Opinions on promoting high-quality development of logistics industry and facilitating the formation of a strong domestic market	Develop a high-quality network of logistics facilities and a shared logistics information platform to support the logistics industry in serving the real economy

Besides the implementation of multimodal transport (such as the plan of Trans-European Transport Networks in Europe), the construction of information infrastructure and the public information platform also raises concerns for governments. For example, the US Bureau of Transportation Statistics conducted the commodity flow survey and applied the data in planning the urban transport corridor. Alliances have been established with information companies, such as IBM, AT&T, and Cisco, to develop the information platform and realize logistics informatization. The German government has set up logistics associated with leading logistics enterprises, which focuses on developing an information network between logistics parks. In China, the government has issued a series of strategic planning at the industrial level, which covers the aspects of the research and development (R&D) of related technology, special funds, industry standards, and guidance. All the measures have proven the determination to promote smart logistics.

Smart logistics, the inevitable trend of the future logistics revolution, is still in its infancy. The immature technology, high level of implementation cost, unstandardized function modules, and lack of a general operation framework are the main barriers to the development of smart logistics. These problems also attract the attention of the academia. Scholars in the areas of engineering, logistics, transportation, and management mainly focus on the R&D and application of underlying technologies, business logic and operation frameworks, related management systems, and specific optimization problems under smart logistics (Chu et al., 2018; Sarkar et al., 2019; Ma et al., 2020). All the efforts have been made to promote the development of smart logistics and increase the operation efficiency, which further satisfy the needs of commercial and industrial development (Yang et al., 2018; Feng et al., 2019). In the following, this study reviews the related literature on smart logistics and explores future research on this topic combined with modern logistics practices.

2 The development of smart logistics

2.1 Smart logistics

Smart logistics, also known as “intelligent logistics” or “logistics 4.0”, comes from the concept of the “intelligent logistics system” proposed by IBM. The concept has no unified definition, and it is generally recognized as a more intelligent and efficient way to plan, manage, and control logistic activities with intelligent technologies (Zhang, 2015; Barreto et al., 2017; He, 2017). As shown in Fig. 1, technologies, such as the Internet of Things (IoT), big data analytics, and AI, applied in smart logistics differentiate from that used in traditional logistics with four characteristics:

(1) Intelligence: Intelligent technologies, such as AI,

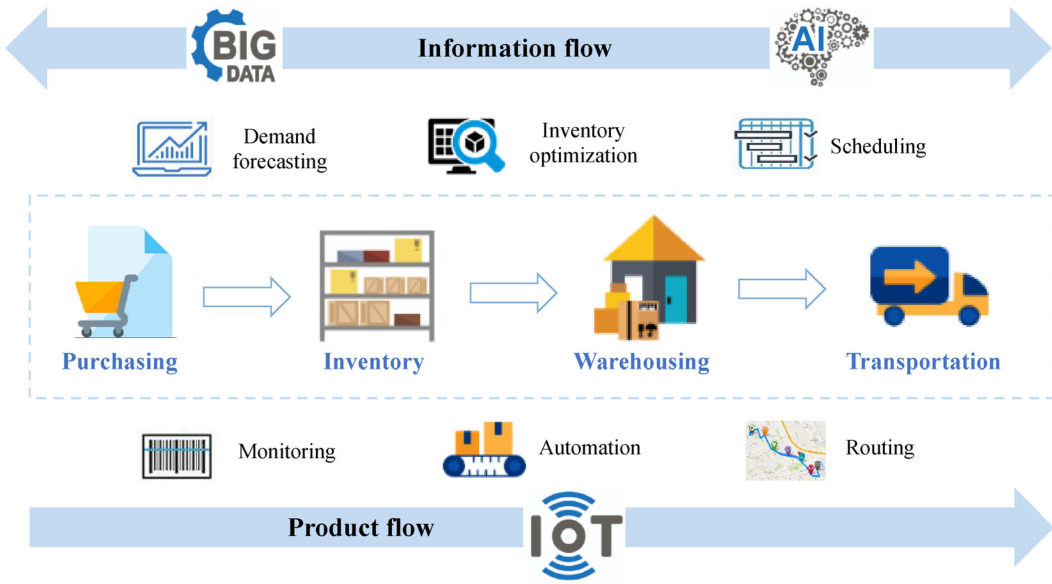

Fig. 1 Smart logistics.

automation technology, and information and communications technology (ICT), are applied in the whole logistics process to improve the automation level of logistics operations and realize intelligent decision-making on common logistics management problems.

(2) Flexibility: Smart logistics has a higher degree of flexibility due to its more accurate demand forecasting, better optimization of inventory, and more efficient transportation routing. The increasing ability to tackle unexpected issues of smart logistics enhances customer satisfaction.

(3) Integration of logistics: With technologies like IoT and ICT, information sharing among agents in the logistics process is realized, and related business processes can be centrally managed, thus strengthening the coordination of different logistics processes.

(4) Self-organization: Real-time monitoring and intelligent decision-making enable the logistics system to function without significant human intervention, which brings higher efficiency to logistics operations.

2.2 Stages of smart logistics

Smart logistics is a new mode realizing the real-time monitoring, omnidirectional control, intelligent optimization, and whole process automation of all logistics activities with IoT and intelligent information technologies to achieve the integration and extension of the logistics value chain. According to different levels of related technology maturity and the operation modes of logistics, the development of smart logistics can be divided into four stages.

The first stage of smart logistics focuses on the intelligence of each logistics function. Transportation routing optimization, warehouse location, intelligent algorithm-based facility planning, and real-time data-driven forecasting are common processes in this stage. The Retail AI Fresh system developed by Walmart and Codelong Technologies is one of the typical cases. In this project, the real-time data of goods in all Chinese Walmart stores are collected by shelf-scanning robots and RFID technologies. This system, which has weak supervision, is capable of identifying various goods, even within grocery bags. With this smart system, functions, such as replenishment, sorting, and inventory monitoring become increasingly intelligent and autonomous.

The second stage of smart logistics is concerned with the intelligence of the whole logistics operation process. Cross-functional resource allocation is essential for achieving the maximum synergy of every logistics function. Therefore, real-time monitoring of each logistics process and innovative management framework coordinated with the integrated intelligent system are required in this stage. Geek+, a global enterprise of autonomous mobile robots (AMR), developed a “Smart Factory” with Shanghai Siemens. In the factory, most of the operations are completed by logistics robots and an AI scheduling system. This project realizes full 24/7 automated operations — from receiving, quality inspection, and warehousing to warehouse handling, outbound collection, and production line feeding. As forecasted, the storage efficiency of this smart factory is increased by 2.5 times. Moreover, the out-of-warehouse efficiency is increased by 2.15 times, and the storage area is reduced by 50%.

The third stage of smart logistics aims to achieve the comprehensive optimization of the logistics process from the supply chain perspective. Intelligent technologies are applied to obtain more effective and efficient collaboration among supply chain participants. The novel business process, management system, and integrated logistics platform adapted for innovative technologies and operations modes play a more important role in this stage. This stage of smart logistics is used in some large multinational manufacturing companies, including Siemens and Haier, which involves most of the supply chain processes. The Interconnected Factory of Haier makes the connections between Haier and the suppliers, distributors, customers, and all the operation functions digitally. In this system, Haier builds a five-tier architecture from the levels of equipment, control, workshop, enterprise, and collaboration, which strengthens the interconnection of supply chain partners and the sharing of information.

The fourth stage of smart logistics attempts to realize the logistics integration of a cross-supply chain with intelligent technologies and innovative collaboration modes. In this stage, resource allocation optimization between parallel homogeneous and heterogeneous supply chains becomes the main task of logistics management. In China, E-commerce giants, including Alibaba and JD, have launched smart logistics projects and invested massively in automated and intelligent technologies while planning to develop urban logistics hubs with collaborative logistics networks, such as the cold chain network, B2B (business to business) network, crowd-sourcing network, and cross-border network.

2.3 Research streams of smart logistics

With the aim of realizing smart logistics, two main research streams are conducted by scholars in the field of management. First, research on enabling technology application corresponds to the first and second stages of smart logistics (shown in Fig. 2). According to the discussion of Porter and Heppelmann (2014), smart logistics has four functions, progressively including monitoring, control, optimization, and automation. This research stream explores methods to apply AI, IoT, and ICT technologies to achieve the intelligence of the above functions and improve the flexibility of the whole logistics process (Lee et al., 2018; Sarkar et al., 2019). Second, to achieve the integration and self-organization of the logistics process, finding ways to improve the optimization with the massive data is another research focus of smart logistics. Intelligent logistics functions provide comprehensive real-time data support, which make traditional optimal models mismatched and less effective. Therefore, scholars have shown solicitude for routing, scheduling, planning, and network optimization problems in the new data environment (Li et al., 2019b; Wang et al., 2020).

3 Operations management research of smart logistics

The development and application of AI, IoT, and ICT technologies endow the logistics industry with new attributes and functions, such as real-time tracking, intelligent optimization, and automated operations. All these new features fundamentally overturn logistics operation modes and management frameworks, which attract increasing attention from the academia and the industry. This section focuses on the advanced research of new operations management problems in smart logistics to reveal the avenues for future research and provide theoretical guidance for industrial development.

3.1 Research on the impact of intelligent technologies on smart logistics

This section reviews the research on the impact of

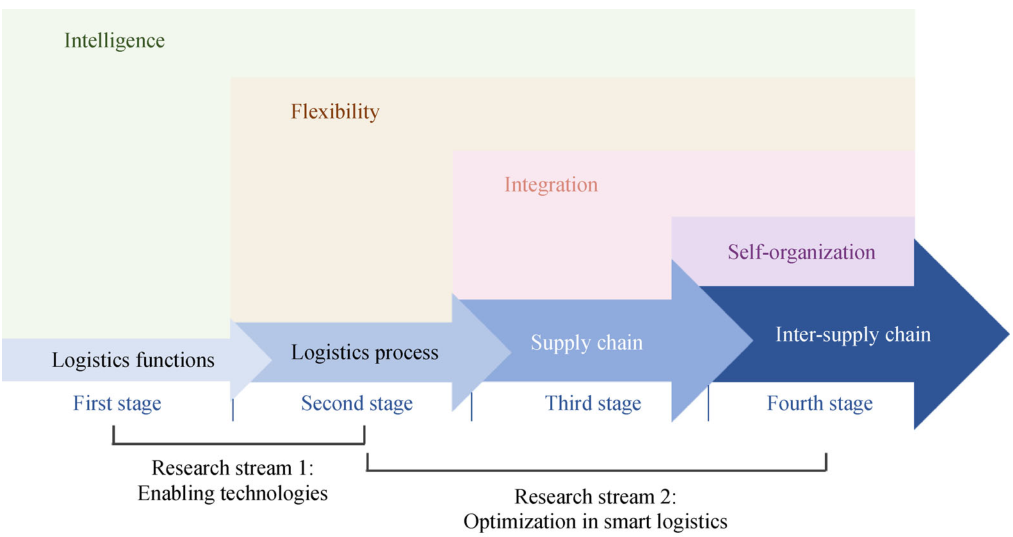

Fig. 2 Research streams of smart logistics.

technologies on smart logistics, mainly focusing on approaches to realize the intelligence of logistics functions. The realization of intelligent monitoring and control is the foundation of logistics optimization and automation, and it depends heavily on the application of intelligent technologies. The main technologies mentioned in previous literature can be classified into IoT, ICT, and AI. The applications and new specific functions of these technologies are shown in Table 2.

When the intelligence of monitoring and control becomes accessible, exerting the effort of the data to perform logistics optimization and automation in an integrated system is the next major concern. Thus, the architectural framework design of the cyber-physical system (CPS), which turns perceptible real logistics issues into a digital virtual system, is another focal point of smart logistics literature (Trab et al., 2017). CPS is an IoT-based smart logistics system and focuses on different logistics operation processes depending on the application scenarios. A CPS framework targeting the logistic process management of production, warehouse, cross-docking transport routing, dispatching, and cold chain carbon trading has been proposed (shown in Table 3). One of the typical examples of a CPS is digital twin (DT). DT provides the mirror-reflection of a physical system by modeling and simulating the lifecycle state of a product with the physical information captured by IoT (e.g., sensors and RFID) (Weyer et al., 2016; Tao et al., 2019). With high-fidelity virtual models on top of various computational intelligence techniques, such as Dijkstra’s algorithm, ant colony algorithm, and cloud computing, more accurate prediction and better optimization can be achieved in DT (Alam and El Saddik, 2017; Schluse et al., 2018).

The realization of logistics process monitoring, control, and optimization has provided the required data and decision support for logistics automation. Therefore, context recognition and collaboration between heterogeneous devices and systems have become the limelight of logistics automation research (Breivold and Sandström, 2015). As the research of smart logistics is driven by the practical demand, most of the designed system frameworks are based on realistic cases and have gone into service (Levina et al., 2017; Trappey et al., 2017; Lee et al., 2018). For instance, Trappey et al. (2017) proposed a patent roadmap and analyzed the cases of UPS and IBM. In the roadmap, related technologies are classified into perception (sensor, GPS, and RFID) and network (cloud computing) layers, which improves the intelligent level of physical logistics services, related value-added services, and sales services (Trappey et al., 2017).

However, a higher efficiency of smart logistics is accompanied by the problem of system security, which can be classified into hardware and information security problems. In terms of hardware, IoT devices, hacking, and system gateways security are considered in the system design, while information security mainly refers to the security of data storage, transmission, and access (Kim et al., 2018; Fu and Zhu, 2019). In this research stream, the design of the authentication mechanism between different interfacing devices and data sharing becomes an emerging research topic for logistics operations management.

3.2 Research on the optimization problem in smart logistics

This research stream in smart logistics is derived from the massive real-time data and the complex instantaneous interactions among different logistics units, which are taken from the enabling technologies mentioned in Section 3.1. To take advantage of the data support and adapt to the new logistics mechanisms, scholars are concerned with traditional logistics optimization problems under the emerging scenarios of smart logistics.

Table 2 Research on the application of intelligent technologies in smart logistics

Logistics functions	Related technologies	Specific applications	Literature
Monitoring	RFID Global Position System (GPS) Geographic Information System (GIS) Wireless networks Bluetooth Cloud storage	**Application areas**: Monitoring the real-time operation situation of ports, warehouse, distribution center, delivery service, and cold chain logistics	Siror et al. (2011); Liu et al. (2014); Lei (2015); Luo et al. (2016b); Zhang (2016); Cho and Kim (2017)
		Functions: Automatic identification, authentication, fleet tracking, and localization of logistics objects and greenhouse gas emission tracking	Lo et al. (2004); Caballero-Gil et al. (2013); Hilpert et al. (2013); Kirch et al. (2017); Jagwani and Kumar (2018); Anandhi et al. (2019)
Control	Cloud computing Fuzzy logic Case-based reasoning Big data analytics Intelligent algorithms	**Application areas**: Context and situation-aware control in the fields of agri-food storage, environmentally sensitive products storage, cloud laundry logistics, cross-docking, delivery services of E-commerce, and transportation in emergency evacuation	Jiao (2014); Luo et al. (2016a); Tsang et al. (2017); Verdouw et al. (2018); Sarkar et al. (2019); Liu et al. (2020); Zhang et al. (2020)
		Functions: Storage conditions control, risk alerts, operation suggestions, continuing feedback control, inventory control, traffic control, flow control of products and services, and material requirement planning control	Blümel (2013); Jiao (2014); Kong et al. (2015); Fukui (2016); Lee et al. (2016); Jabeur et al. (2017); Hopkins and Hawking (2018); Tu et al. (2018); Verdouw et al. (2018)

Table 3 Research on the framework design of CPS

Logistics functions	Application scenario	System framework	Literatures
Optimization	Cold chain logistics	Decentralized and centralized carbon trading systems provide a reasonable revenue-and-cost-sharing contract with the trade-off among the market demand, total carbon emission, and supplier's profit	Ma et al. (2020)
	Warehouse management	An IoT-based warehouse management system maximizes warehouse productivity and picking accuracy with computational intelligence techniques	Lee et al. (2018)
	Routing optimization	User-centric logistics service model using ontology: Users' smart devices are applied to collect the location and situation information from the delivery vehicle and user for routing optimization	Sivamani et al. (2014); Shen et al. (2019)
	Dispatching optimization	IoT-based logistics dispatching systems: Dijkstra's algorithm and ant colony algorithm are applied to improve the coordination among demand, order-picking, and cloud technologies	Wang et al. (2020)
	Cross-docking management	An IoT-enabled information infrastructure system provides a closed decision-execution cross-docking loop with frontline real-time data and user feedback	Luo et al. (2016a)
	Emergency medicine logistics	A multi-stage emergency medicine logistics system with ambulance drones shows better performance of survival probability	Wang et al. (2017a)
Automation	Production management	A two-stage inspection process with an automation policy increases the efficiency of discounted sale in the disposal subsection by discarding defective products automatically	Sarkar et al. (2019)
	Storage management	Process-based context-aware storage system: Static and dynamic context data are applied to conduct the staged configuration for resolving process variability at runtime automatically	Murguzur et al. (2014)
	E-commerce logistics distribution	Intelligent E-commerce logistics system: Semantic web and data mining are applied to obtain the probability distribution of random variables for automated decision-making	Wang et al. (2017b)
	Material handling and transport	A smart connected logistics system integrates different IoT technologies with mobile automated platforms, mobile robotic systems, and multi-agent cloud-based control	Gregor et al. (2017)
System security	Data storage and access security	Data storage and access mechanism based on blockchain: Consensus authentication is built by constructing the correlations between the fundamental data and corresponding blockchain	Fu and Zhu (2019)
	System gateways security	Device driver security architecture provides trustworthy gateways between manufacturer and logistics system	Fraile et al. (2018)
	IoT devices security	Blockchain-based security system framework: Multiple-agreement algorithm is applied to enable thin-plate spline performance, which is efficient in solving the vulnerability of IoT multi-platform security	Kim et al. (2018)
	Authentication of object tracking	Fine-grained IoT-enabled object tracking system: Cloud storage, symmetric key cryptosystem, and one-way hash function are applied to perform end-to-end authentication protocol	Anandhi et al. (2019)

3.2.1 Vehicle routing problem in smart logistics

Enabled by intelligent technologies like IoT and ICT, two new directions in the research on the vehicle routing problem (VRP) under the scenario of smart logistics have emerged.

First, multi-objective models and improved intelligent algorithms in dealing with dynamic optimization problems are among the emerging focuses in studies on VRP. In terms of model types, data-driven models and dynamics models with multiple objectives have attracted increased attention from scholars, as these models tackle real-time updating of data and coordination among multiple transportation agents. For example, Katsuma and Yoshida (2018), Wang et al. (2019) and Yao et al. (2019), developed optimization models driven by real-time road traffic and connected vehicle conditions. The connection of vehicles also brings complex coordination issues in solving VRPs. Eitzen et al. (2017) and Anderluh et al. (2021) both developed a multi-objective two-echelon model for VRPs to improve the flexibility of smart city logistics. The two models have objective functions that consider the various needs of stakeholders, such as businesses, residents, and governments; the latter also takes vehicle synchronization into account. Meanwhile, the need for improved optimization algorithms of new models has emerged. To enhance the algorithm efficiency in dealing with massive real-time data and complex logistics mechanisms, heuristic algorithms and intelligent optimization algorithms are commonly introduced (shown in Table 4). For instance, the

Table 4 Research on the algorithms of VRPs in smart logistics

Literature	Algorithm	Targeted model or problem	Details
Tang et al. (2013)	Modified particle swarm algorithm	VRPs with changes of position and speed	The extended algorithm integrates the particle swarm algorithm with the extension clustering method
Chen et al. (2016)	Modified slotted anti-collision algorithm	Multi-object recognition for woodwork logistics	The proposed algorithm integrates the slotted anti-collision algorithm with the simulation results of RFID collisions
Wang and Li (2018)	Hybrid fruit fly optimization algorithm	Multi-component vehicle routing problem	The proposed algorithm provides an entirely new way of solving the routing problem of multi-compartment vehicle (MCV) distribution by virtue of its superiority in improving the total path length and elevating the solution quality
Lin et al. (2019)	Order-aware hybrid generic algorithm	Routing for capacitated vehicles in IoT	The proposed algorithm is composed of an improved initialization strategy and a problem-specific crossover operator
Zhang et al. (2019a)	Hybrid ant colony optimization algorithm	Multi-objective VRP considering flexible time window	The proposed algorithm considers Pareto optimality in multi-objective optimization, which deals with a vehicle fleet serving a set of customers with the required time
Moradi (2020)	Robust strength Pareto evolutionary algorithm	New multi-objective discreet learnable evolution model	The proposed algorithm is embedded in a learnable evolution model to address the VRP with time windows and improve the individual fitness

multi-object recognition algorithm improved by Chen et al. (2016) integrates the slotted anti-collision algorithm with the simulation results of RFID collisions, which deals with the dynamics scanning data of tags. Lin et al. (2019) studied the routing for capacitated vehicles in IoT, which is a widely examined combinatorial optimization problem in smart logistics. They proposed a novel order-aware hybrid generic algorithm composed of an improved initialization strategy and a problem-specific crossover operator.

Second, some scholars have determined that the adoption of big data and technologies of physical and geospatial positioning empowers smart logistics with functions of visualization, prediction, control, and decision-making in VRPs (Su and Fan, 2020). However, the various format or non-format data collected from these intelligent systems also bring new challenges to VRP research. To take full advantage of these data, Borstell et al. (2013) proposed an approach for integrating optical vehicle positioning with logistics VRP, which is motivated by the planar marker detection system. The feasibility of this approach has been demonstrated in three intra-logistic scenarios taking account of user requirements coverage, costs, and accuracy. Klumpp (2018) used geospatial data to advance ex-ante vehicle routing with a conceptual framework and a quantitative test simulation. The proposed conceptual outline was validated to bring distinct advantages economically (reduced transport cost), environmentally (reduced transport emissions), and socially (reduced workload and working hours for drivers).

3.2.2 Cloud-based scheduling in smart logistics

With the popularity of distribution centers and the requirement of quick response, the scheduling of distribution and delivery in logistics is becoming increasingly complex. Meanwhile, the development of smart logistics has also led to higher requests for scheduling algorithms and the capacity of data processing. Related research has mainly improved the logistics scheduling problem in two aspects to adapt to the changes brought by smart logistics. At the logistics mechanism level, enabled by the technologies of IoT, real-time data becomes accessible at any time in the logistics process, and connected devices lead to more complex coordination policies (Zhang et al., 2019b). Therefore, dynamic models with parameters driven by real-time data and hyper-connected logistics mechanism have been considered in recent scheduling research. Kwak et al. (2014) and Hasan and Al-Rizzo (2020) have proposed logistics scheduling models considering the real-time data of resource conditions, context information, and coordination policies of incoming tasks. Chen (2020) further developed a logistics pipeline scheduling system docking with an intelligent interactive database, which synchronizes real-time data of all connected online equipment and environmental and personnel information.

To adapt the models to the heavy workload of the data process, cloud-based approaches have been proposed in logistics scheduling recently. With such approaches, big data task is executed in the cloud and leads to higher computation efficiency and lower cost for logistics enterprises (Rjoub et al., 2019). To implement cloud-based logistics scheduling, scholars have proposed network architectures for integrating cloud-computing infrastructure in the logistics system. For example, Nguyen et al. (2019) designed a three-tiered architecture with connected logistics things, edge, and cloud. Tuli et al. (2020) proposed the stochastic edge-cloud architecture with a residual recurrent neural network. Furthermore, Liu et al. (2015) and Zhu (2018) developed cloud-based scheduling systems for smart port logistics and cooperative logistical delivery and building site logistics, respectively. For specific algorithms targeting cloud-based scheduling models, genetic algorithm, swarm optimization algorithm, and flower pollination algorithm are popular in the related research. For instance, Al-Turjman et al. (2018) and Sun et al. (2019) improved the swarm optimization algorithm for the cloud-based scheduling system for cooperative resources and the logistics distribution path to increase efficiency and fault-tolerance. Meanwhile, Xu et al. (2019) developed a smart logistics scheduling model, along with a double-level hybrid genetic algorithm, which was proven to be superior and effective in problems regarding logistics dynamic scheduling. In addition, Hu (2019) proposed an improved flower pollination algorithm to avert the local optimality defect of traditional optimization in the location of an intelligent logistics distribution center.

3.2.3 Logistics planning in smart logistics

Planning for a smart logistics system has also evoked some interesting model-based studies in recent years. Data collected by IoT technologies have become the spotlight of this research stream. To dig out the usage of the data resource, Andersson and Jonsson (2018) conducted a case study and literature review to explore the application of process-in-use data in demand planning. The data are sorted into five categories corresponding to eight application areas. Furthermore, the research of Kovalský and Mičieta (2017) provided methodological support for solving the planning problem in smart logistics. They identified the necessary logistical capacity factors and analyzed the merits and drawbacks of the static and dynamic approaches for automated logistics planning with tracking data.

Applying the data technically is the next focus for planning in smart logistics. Huang et al. (2019) proposed a real-time data-driven dynamic optimization method for production logistics planning with IoT technology, which facilitates the monitoring of the dynamic manufacturing process and acquisition of real-time information. Li et al. (2019a) formulated a new integrated planning problem for an intelligent food logistics system as a bi-objective mixed-integer linear programming model, which is solved by a novel s-constraint-based two-phase iterative heuristic approach and a fuzzy logic model. The proposed method demonstrates effectiveness and efficiency in minimizing the overall cost and maximizing food quality. Considering the security issues in product placement planning, Trab et al. (2015) proposed a multi-agent model with the monitored environment data. With the input data processed by the given negotiation and decision mechanisms, the placement planning lowers the risk of hazardous accidents in the smart warehouse by reducing the size of floating locations.

3.2.4 Network optimization in smart logistics integration

Achieving cross-supply chain logistics integration is the ultimate aim of smart logistics, which is also the foundation of logistics self-organization (Chen, 2019). Connected by IoT technologies, logistics becomes a more complex system with interactive devices and agents. Researchers have proven that a logistics system, especially a smart one, should be a complex adaptive system (CAS). In the CAS, internal units can realize the evolution of a logistics system from disorder to order by themselves under the control of certain rules (Gallay and Hongler, 2009). To identify these rules, stylized models are applied to explore the internal mechanisms and underlying implications of the system behavior with the most essential system elements (Hongler et al., 2010). With this method, Kim et al. (2017) determined the mechanisms and application contexts of two different supplier contracting strategies on inventory. Hongler et al. (2010) developed a solvable stylized model to explore the coordination patterns of autonomous interacting agents in transportation. In addition, the stylized model can also help design the framework of a logistics network, as shown in the conceptual framework of the physical Internet by Dong and Franklin (2020).

Supported by these system mechanisms and self-organizing patterns, scholars are capable of implementing logistics network optimization. Related optimization research has integrated the extra data or distinct features brought by intelligent technologies and novel operation modes. Liu and Wang (2016a; 2016b) focused on supply network optimization with a multi-level logistics supply network optimization model and a two-phase modeling framework. The former combines customers' potential demand with customers' personalized needs predicted on the basis of customers' webpage score data using clustering. Logistics network optimization based on individualized customer need is verified to be a feasible solution to improve customer satisfaction and the service level of the overall logistics network (Liu and Wang, 2016a). The latter further examines the order allocation of a logistics service supply network, which comprises a "big data prediction stage" and a "model optimization stage". A multi-level logistics service supply model is established on the basis of the best delivery time and customer demand predicted by big data about customer location and click ratios (Liu and Wang, 2016b). Gan et al. (2018) proposed a novel intensive distribution logistic network model considering a sharing economy, where customers' logistic preference is determined by customer shopping behavior analysis with big data technology. Moreover, an improved interval Shapley value method for interest distribution among distribution network participants leads to enhanced stakeholder satisfaction and sustainable alliance development.

4 Future research

Smart logistics is a promising solution for meeting the increasing complexity and volume of logistics operations due to the global collaboration and integration of online and offline channels. Technologies, such as IoT, ICT, and AI, not only bring innovative functions in logistics operations but also change the narrative of logistics management. Methods to apply these technologies effectively and efficiently have become a major concern in logistics research. Most of the previous research has explored the application of these technologies in different logistics processes. These studies present new functions, such as real-time monitoring and situation-aware control, which solve the issue on effectiveness. Some optimization studies on logistics operations management have also aimed to improve the efficiency of smart logistics. However, optimization algorithms and management systems are developed under specific scenarios of different industries. Meanwhile, smart logistics is supposed to be part of the smart supply chain and is compatible with different processes and industries. With the input of this research background, future research can focus on the following aspects (blue items shown in Fig. 3).

(1) General management framework of smart logistics: Smart logistics is supposed to be a disruptive innovation for the logistics industry instead of a simple upgrade. Most of the research has applied related technologies to enhance some logistics functions based on the original management system. However, related technologies can only exert their efforts when they are applied to facilitate the collaboration between different logistics processes and between logistics and other supply chain processes, which is also the core of the industrial revolution. A general management framework tackling this problem is needed as a guide for the logistics industry.

(2) Theoretical research on smart logistics: The lack of general smart logistics management framework is caused by the undiscovered effect mechanism of related technologies on current logistics operations. Future research can focus on the investigations of one specific technology's effect or mechanism from a related theoretical perspective. For example, researchers may analyze how internal logistics information sharing affects logistics performance with information system theories. In addition, researchers may also pay added attention on how the unique attributes of smart logistics and its application affects its executors' profit and the expectation of customers.

(3) Research on smart logistics visualization: Previous literature has mainly focused on the intellectualization of four logistics functions (monitoring, controlling, optimization, and automation). IoT technologies bring massive and various data for decision-makers. Inappropriate data exhibition may cause unrelated data to conceal key information. The reasonable and user-friendly data visualization of logistics information is the last and important step for improving decision accuracy and operation efficiency. Moreover, research exploring the key elements of logistics decisions and data analysis methods are important in providing theoretical and methodological support for visualization design and implementation.

(4) Research on the collaboration of smart logistics and other intelligent modules: Smart logistics, the indispensable component of smart supply chain, smart transportation, and smart city, is supposed to be logically and functionally compatible with different intelligent modules (Chen, 2019). Theoretical research on the collaboration effects, mechanisms, and performances of smart logistics and these intelligent modules for different shareholders is expected. Moreover, optimization research contributing to efficient algorithms and integration models under specific application scenarios is needed for related industries.

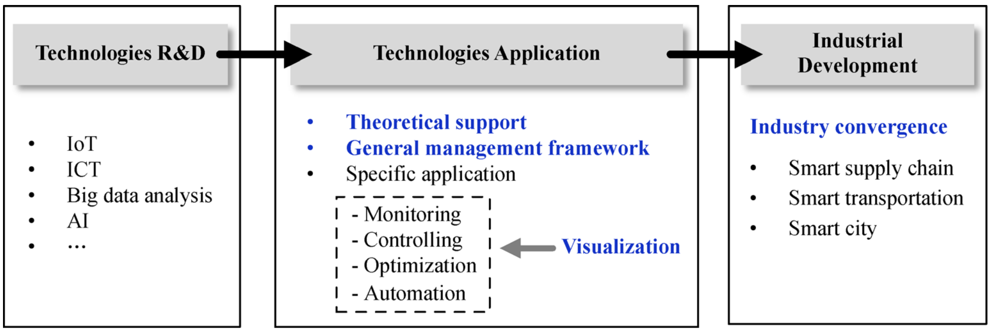

Fig. 3 Future research in smart logistics.

References

Al-Turjman F, Hasan M Z, Al-Rizzo H (2018). Task scheduling in cloud-based survivability applications using swarm optimization in IoT. Transactions on Emerging Telecommunications Technologies, 30(8): e3539

Alam K M, El Saddik A (2017). C2PS: A digital twin architecture reference model for the cloud-based cyber-physical systems. IEEE Access, 5: 2050–2062

Anandhi S, Anitha R, Sureshkumar V (2019). IoT enabled RFID authentication and secure object tracking system for smart logistics. Wireless Personal Communications, 104(2): 543–560

Anderluh A, Nolz P C, Hemmelmayr V C, Crainic T G (2021). Multi-objective optimization of a two-echelon vehicle routing problem with vehicle synchronization and "grey zone" customers arising in urban logistics. European Journal of Operational Research, 289(3): 940–958

Andersson J, Jonsson P (2018). Big data in spare parts supply chains: The potential of using product-in-use data in aftermarket demand planning. International Journal of Physical Distribution & Logistics Management, 48(5): 524–544

Barreto L, Amaral A, Pereira T (2017). Industry 4.0 implications in logistics: An overview. Procedia Manufacturing, 13: 1245–1252

Blümel E (2013). Global challenges and innovative technologies geared toward new markets: Prospects for virtual and augmented reality. Procedia Computer Science, 25: 4–13

Borstell H, Pathan S, Cao L, Richter K, Nykolaychuk M (2013). Vehicle positioning system based on passive planar image markers. In: International Conference on Indoor Positioning and Indoor Navigation. Montbeliard: IEEE, 1–9

Breivold H P, Sandström K (2015). Internet of Things for industrial automation—Challenges and technical solutions. In: International Conference on Data Science and Data Intensive Systems. Sydney: IEEE, 532–539

Caballero-Gil C, Molina-Gil J, Caballero-Gil P, Quesada-Arencibia A (2013). IoT application in the supply chain logistics. In: International Conference on Computer Aided Systems Theory. Berlin: Springer, 55–62

Chen Q Y, Lin Y H, Qiu R Z (2016). Optimization of the multi-object recognition algorithm based on RFID for woodwork logistics. Journal of Fujian Agriculture and Forestry University (Natural Science Edition), 45(4): 476–480 (in Chinese)

Chen X (2019). The development trend and practical innovation of smart cities under the integration of new technologies. Frontiers of Engineering Management, 6(4): 485–502

Chen Y (2020). Novel smart logistics pipeline based on cloud scheduling and intelligent interactive data center. In: International Conference on Inventive Computation Technologies (ICICT). Coimbatore: IEEE, 467–470

Cho S, Kim J (2017). Smart logistics model on Internet of Things environment. Advanced Science Letters, 23(3): 1599–1602

Chu Z, Feng B, Lai F (2018). Logistics service innovation by third party logistics providers in China: Aligning guanxi and organizational structure. Transportation Research Part E: Logistics and Transportation Review, 118: 291–307

Dong C, Franklin R (2020). From the digital Internet to the physical Internet: A conceptual framework with a stylized network model. Journal of Business Logistics, in press, doi: 10.1111/jbl.12253

Eitzen H, Lopez-Pires F, Baran B, Sandoya F, Chicaiza J L (2017). A multi-objective two-echelon vehicle routing problem. An urban goods movement approach for smart city logistics. In: XLIII Latin American Computing Conference. Córdoba: IEEE, 1–10

Feng B, Ye Q W, Collins B J (2019). A dynamic model of electric vehicle adoption: The role of social commerce in new transportation. Information & Management, 56(2): 196–212

Fraile F, Tagawa T, Poler R, Ortiz A (2018). Trustworthy industrial IoT gateways for interoperability platforms and ecosystems. IEEE Internet of Things Journal, 5(6): 4506–4514

Fu Y, Zhu J (2019). Operation mechanisms for intelligent logistics system: A blockchain perspective. IEEE Access, 7: 144202–144213

Fukui T (2016). A systems approach to big data technology applied to supply chain. In: International Conference on Big Data. Washington DC: IEEE, 3732–3736

Gallay O, Hongler M O (2009). Circulation of autonomous agents in production and service networks. International Journal of Production Economics, 120(2): 378–388

Gan M, Yang S, Li D, Wang M, Chen S, Xie R, Liu J (2018). A novel intensive distribution logistics network design and profit allocation problem considering sharing economy. Complexity, 4678358

Gregor T, Krajčovič M, Więcek D (2017). Smart connected logistics. Procedia Engineering, 192: 265–270

Hasan M Z, Al-Rizzo H (2020). Task scheduling in Internet of Things cloud environment using a robust particle swarm optimization. Concurrency and Computation: Practice and Experience, 32(2): e5442

He L (2017). The development trend of China's smart logistics. China Business and Market, 31(6): 3–7 (in Chinese)

Hilpert H, Kranz J, Schumann M (2013). Leveraging green is in logistics. Business & Information Systems Engineering, 5(5): 315–325

Hongler M O, Gallay O, Hülsmann M, Cordes P, Colmorn R (2010). Centralized versus decentralized control—A solvable stylized model in transportation. Physica A: Statal Mechanics & Its Applications, 389(19): 4162–4171

Hopkins J, Hawking P (2018). Big data analytics and IoT in logistics: A case study. International Journal of Logistics Management, 29(2): 575–591

Hu W (2019). An improved flower pollination algorithm for optimization of intelligent logistics distribution center. Advances in Production Engineering & Management, 14(2): 177–188

Huang S, Guo Y, Zha S, Wang Y (2019). An Internet-of-Things-based production logistics optimisation method for discrete manufacturing. International Journal of Computer Integrated Manufacturing, 32(1): 13–26

Jabeur N, Al-Belushi T, Mbarki M, Gharrad H (2017). Toward leveraging smart logistics collaboration with a multi-agent system based solution. Procedia Computer Science, 109: 672–679

Jagwani P, Kumar M (2018). IoT powered vehicle tracking system (VTS). In: International Conference on Computational Science and Its Applications. Melbourne: Springer, 488–498

Jiao Y B (2014). Based on the electronic commerce environment of intelligent logistics system construction. Advanced Materials Research, 850–851: 1057–1060

Katsuma R, Yoshida S (2018). Dynamic routing for emergency vehicle by collecting real-time road conditions. International Journal of Communications, Network & System Sciences, 11(2): 27–44

Kim S H, Cohen M A, Netessine S (2017). Reliability or inventory? An analysis of performance-based contracts for product support services. In: Ha A, Tang C, eds. Handbook of Information Exchange in Supply Chain Management. Cham: Springer, 65–68

Kim T Y, Dekker R, Heij C (2018). Improving warehouse labour efficiency by intentional forecast bias. International Journal of Physical Distribution & Logistics Management, 48(1): 93–110

Kirch M, Poenicke O, Richter K (2017). RFID in logistics and production—Applications, research and visions for smart logistics zones. Procedia Engineering, 178: 526–533

Klumpp M (2018). Economic and social advances for geospatial data use in vehicle routing. In: International Conference on Dynamics in Logistics. Bremen: Springer, 368–377

Kong X T, Fang J, Luo H, Huang G Q (2015). Cloud-enabled real-time platform for adaptive planning and control in auction logistics center. Computers & Industrial Engineering, 84: 79–90

Kovalský M, Mičieta B (2017). Support planning and optimization of intelligent logistics systems. Procedia Engineering, 192: 451–456

Kwak K H, Bae N J, Cho Y Y (2014). Smart logistics service model based on context information. In: Park J, Zomaya A, Jeong H Y, Obaidat M, eds. Frontier and Innovation in Future Computing and Communications. Lecture Notes in Electrical Engineering, vol. 301. Dordrecht: Springer, 669–676

Lee C K M, Lv Y, Ng K K H, Ho W, Choy K L (2018). Design and application of Internet of Things-based warehouse management system for smart logistics. International Journal of Production Research, 56(8): 2753–2768

Lee S, Kang Y, Prabhu V V (2016). Smart logistics: Distributed control of green crowdsourced parcel services. International Journal of Production Research, 54(23): 6956–6968

Lei L (2015). Research on the key technology of RFID and its application in modern logistics. In: AASRI International Conference on Industrial Electronics and Applications. Paris: Atlantis Press, 328–331

Levina A I, Dubgorn A S, Iliashenko O Y (2017). Internet of Things within the service architecture of intelligent transport systems. In: European Conference on Electrical Engineering and Computer Science (EECS). Bern: IEEE, 351–355

Li S, Sun Q, Wu W (2019a). Benefit distribution method of coastal port intelligent logistics supply chain under cloud computing. Journal of Coastal Research, 93(SI): 1041–1046

Li Y, Chu F, Feng C, Chu C, Zhou M (2019b). Integrated production inventory routing planning for intelligent food logistics systems. IEEE Transactions on Intelligent Transportation Systems, 20(3): 867–878

Lin N, Shi Y, Zhang T, Wang X (2019). An effective order-aware hybrid genetic algorithm for capacitated vehicle routing problems in Internet of Things. IEEE Access, 7: 86102–86114

Liu B W, Liu X F, Li J T (2014). Research on heterogeneous information integration for intelligent logistics information system based on Internet of Things. WIT Transactions on Information and Communication Technologies, 46: 1783–1789

Liu C, Feng Y, Lin D, Wu L, Guo M (2020). IoT based laundry services: An application of big data analytics, intelligent logistics management, and machine learning techniques. International Journal of Production Research, 58(17): 5113–5131

Liu P, Yang L, Gao Z, Huang Y, Li S, Gao Y (2018). Energy-efficient train timetable optimization in the subway system with energy storage devices. IEEE Transactions on Intelligent Transportation Systems, 19(12): 3947–3963

Liu T, Yue Q, Wu X (2015). Design and implementation of cloud-based port logistics public service platform. In: International Conference on Computer & Communications. Chengdu: IEEE, 234–239

Liu Y Q, Wang H (2016a). Optimization for logistics network based on the demand analysis of customer. In: Chinese Control and Decision Conference (CCDC). Yinchuan: IEEE, 4547–4552

Liu Y Q, Wang H (2016b). Optimization for service supply network based on the user's delivery time under the background of big data. In: Chinese Control and Decision Conference (CCDC). Yinchuan: IEEE, 4564–4569

Lo C C, Hsieh W C, Huang L T (2004). The implementation of an intelligent logistics tracking system utilizing RFID. In: The 4th International Conference on Electronic Business. Beijing, 199–204

Luo H, Chen J, Huang G Q (2016a). IoT enabled production-logistic synchronization in make-to-order industry. In: Proceedings of the 22nd International Conference on Industrial Engineering and Engineering Management. Paris: Atlantis Press, 527–538

Luo H, Zhu M, Ye S, Hou H, Chen Y, Bulysheva L (2016b). An intelligent tracking system based on Internet of Things for the cold chain. Internet Research, 26(2): 435–445

Ma X, Wang J, Bai Q, Wang S (2020). Optimization of a three-echelon cold chain considering freshness-keeping efforts under cap-and-trade regulation in Industry 4.0. International Journal of Production Economics, 220: 107457

Moradi B (2020). The new optimization algorithm for the vehicle routing problem with time windows using multi-objective discrete learnable evolution model. Soft Computing, 24(9): 6741–6769

Murguzur A, de Carlos X, Trujillo S, Sagardui G (2014). Context-aware staged configuration of process variants@runtime. In: International Conference on Advanced Information Systems Engineering. Thessaloniki: Springer, 241–255

Nguyen J, Wu Y, Zhang J, Yu W, Lu C (2019). Real-time data transport scheduling for edge/cloud-based Internet of Things. In: International Conference on Computing, Networking and Communications (ICNC). Honolulu, HI: IEEE, 642–646

Porter M E, Heppelmann J E (2014). How smart, connected products are transforming competition. Harvard Business Review, 92(11): 64–88

Rjoub G, Bentahar J, Wahab O A, Bataineh A (2019). Deep smart scheduling: A deep learning approach for automated big data scheduling over the cloud. In: 7th International Conference on Future Internet of Things and Cloud. Istanbul: IEEE, 189–196

Sarkar B, Guchhait R, Sarkar M, Cárdenas-Barrón L E (2019). How does an industry manage the optimum cash flow within a smart production system with the carbon footprint and carbon emission under logistics framework? International Journal of Production Economics, 213: 243–257

Schluse M, Priggemeyer M, Atorf L, Rossmann J (2018). Experimentable digital twins—Streamlining simulation-based systems engineering for Industry 4.0. IEEE Transactions on Industrial Informatics, 14(4): 1722–1731

Shen Z M, Feng B, Mao C, Ran L (2019). Optimization models for electric vehicle service operations: A literature review. Transportation Research Part B: Methodological, 128: 462–477

Siror J K, Huanye S, Dong W (2011). RFID based model for an intelligent port. Computers in Industry, 62(8–9): 795–810

Sivamani S, Kwak K, Cho Y (2014). A study on intelligent user-centric logistics service model using ontology. Journal of Applied Mathematics, 162838

Su Y, Fan Q M (2020). The green vehicle routing problem from a smart logistics perspective. IEEE Access, 8: 839–846

Sun R, Liu M, Zhao L (2019). Research on logistics distribution path optimization based on PSO and IoT. International Journal of Wavelets, Multiresolution and Information Processing, 17(6): 1950051

Tang H, Yang X, Xiong S (2013). Modified particle swarm algorithm for vehicle routing optimization of smart logistics. In: Proceedings of the 2nd International Conference on Measurement, Information and Control. Harbin: IEEE, 783–787

Tao F, Zhang H, Liu A, Nee A Y C (2019). Digital twin in industry: State-of-the-art. IEEE Transactions on Industrial Informatics, 15(4): 2405–2415

Trab S, Bajic E, Zouinkhi A, Abdelkrim M N, Chekir H, Ltaief R H (2015). Product allocation planning with safety compatibility constraints in IoT-based warehouse. Procedia Computer Science, 73: 290–297

Trab S, Bajic E, Zouinkhi A, Thomas A, Abdelkrim M N, Chekir H, Ltaief R H (2017). A communicating object's approach for smart logistics and safety issues in warehouses. Concurrent Engineering, 25 (1): 53–67

Trappey A J C, Trappey C V, Fan C Y, Hsu A P T, Li X K, Lee I J Y (2017). IoT patent roadmap for smart logistic service provision in the context of Industry 4.0. Journal of the Chinese Institute of Engineers, 40(7): 593–602

Tsang Y P, Choy K L, Wu C H, Ho G T S, Lam H Y, Koo P S (2017). An IoT-based cargo monitoring system for enhancing operational effectiveness under a cold chain environment. International Journal of Engineering Business Management, 9: 1–13

Tu M, Lim M K, Yang M F (2018). IoT-based production logistics and supply chain system—Part 2. IoT-based cyber-physical system: A framework and evaluation. Industrial Management & Data Systems, 118(1): 96–125

Tuli S, Ilager S, Ramamohanarao K, Buyya R (2020). Dynamic scheduling for stochastic edge-cloud computing environments using A3C learning and residual recurrent neural networks. IEEE Transactions on Mobile Computing, 99: 1–15

Verdouw C N, Robbemond R M, Verwaart T, Wolfert J, Beulens A J (2018). A reference architecture for IoT-based logistic information systems in agri-food supply chains. Enterprise Information Systems, 12(7): 755–779

Wang C L, Li S W (2018). Hybrid fruit fly optimization algorithm for solving multi-compartment vehicle routing problem in intelligent logistics. Advances in Production Engineering & Management, 13 (4): 466–478

Wang D, Zhu J, Wei X, Cheng T C E, Yin Y, Wang Y (2019). Integrated production and multiple trips vehicle routing with time windows and uncertain travel times. Computers & Operations Research, 103: 1–12

Wang J, Lim M K, Zhan Y, Wang X (2020). An intelligent logistics service system for enhancing dispatching operations in an IoT environment. Transportation Research Part E: Logistics and Transportation Review, 135: 101886

Wang K, Liang Y, Zhao L (2017a). Multi-stage emergency medicine logistics system optimization based on survival probability. Frontiers of Engineering Management, 4(2): 221–228

Wang Y, Bai X, Ou H (2017b). Design and development of intelligent logistics system based on semantic web and data mining technology. In: International Conference on Computer Network, Electronic and Automation (ICCNEA). Xi'an: IEEE, 231–235

Weyer S, Meyer T, Ohmer M, Gorecky D, Zühlke D (2016). Future modeling and simulation of CPS-based factories: An example from the automotive industry. IFAC-PapersOnLine, 49(31): 97–102

Xu W, Guo S, Li X, Guo C, Wu R, Peng Z (2019). A dynamic scheduling method for logistics tasks oriented to intelligent manufacturing workshop. Mathematical Problems in Engineering, 7237459

Yang S, Wang J, Shi L, Tan Y, Qiao F (2018). Engineering management for high-end equipment intelligent manufacturing. Frontiers of Engineering Management, 5(4): 420–450

Yao K, Yang B, Zhu X L (2019). Low-carbon vehicle routing problem based on real-time traffic conditions. Computer Engineering and Applications, 55(3): 231–237 (in Chinese)

Zhang G (2015). Large data and intelligent logistics. Journal of Transportation Systems Engineering and Information Technology, 15(1): 2–10, 233 (in Chinese)

Zhang H, Zhang Q, Ma L, Zhang Z, Liu Y (2019a). A hybrid ant colony optimization algorithm for a multi-objective vehicle routing problem with flexible time windows. Information Sciences, 490: 166–190

Zhang J, Liu Y, Zhao Y, Deng T (2020). Emergency evacuation problem for a multi-source and multi-destination transportation network: Mathematical model and case study. Annals of Operations Research, 291(1–2): 1153–1181

Zhang L (2016). Application of IoT in the supply chain of the fresh agricultural products. In: International Conference on Communications, Information Management and Network Security. Shanghai: Atlantis Press, 201–204

Zhang M, Fu Y, Zhao Z, Pratap S, Huang G Q (2019b). Game theoretic analysis of horizontal carrier coordination with revenue sharing in E-commerce logistics. International Journal of Production Research, 57(5): 1524–1551

Zhu D (2018). IoT and big data based cooperative logistical delivery scheduling method and cloud robot system. Future Generation Computer Systems, 86: 709–715