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Supply chain and logistics optimization management for international trading enterprises using IoT-based economic logistics model

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Abstract
Under the development trend of economic globalization, the financial difficulties of the supply chain may cause a serious crisis to the enterprises in the whole supply chain. It is necessary to alleviate the transformation pressure faced by international trading enterprises (ITE), to enhance the core competitiveness of ITE. This paper takes the SCLM (Supply Chain and Logistic Management) of ITE as the research object. Based on the analysis of the existing SCLM experience of ITE and the Internet of Things (IoT) technology, this paper puts forward the economic analysis model of the IoT-based SCLM. Specific data of some ITE prove the effectiveness of the proposed model. Further optimization is carried out through process analysis. The results show that the proposed SCLM economic analysis model based on IoT can effectively maximize the interests of enterprises and shorten the supply chain process by adding information groups. The introduced IoT-based method reduces the Average Queue Time (AQT) of vehicles by nearly 7 times and the Average Waiting Time (AWT) by nearly 4 times. After the IoT technology is applied to the SCLM of ITE, this paper significantly improves the cooperation efficiency of various departments, optimizes the relationship between customers and suppliers, and improves the core competitiveness of the enterprise. Therefore, this paper has important reference value for promoting the development of the small and micro machinery industry in China.

Keywords Internet of Things · International trading enterprises · Logistics · Supply chain · Economic optimization

1 Introduction

The current high-level socio-economic development makes a refined and specified labor division possible. As a channel for the exchange of goods, technology, and labor, International Trade (IT) guarantees the social needs of the importing countries and promotes global trade. Therefore, International Trading Enterprises (ITE)-centered research has become a hotspot (Du and Li 2020). The ongoing COVID-19 pandemic has fluctuated the global financial market dramatically, because of which the major consumer markets in Europe and the United States have fallen into a deep recession, the national market demand for bulk commodities has dropped sharply, and developing countries have suffered severely as the main industry and processing markets (Kovtunenko et al. 2020; Shukla and Singh 2020). Worse still, from 2008 to 2016, the raw material cost of industrial products has increased by 20%-50% among different industries. In addition, the China Yuan (CNY) has appreciated by nearly 15%, squeezing the profits of ITE (Belyakov et al. 2020). Therefore, under a turbulent global economy and prominent enterprise issues, a reasonable transformation of the IT industry and the enterprise competitiveness are of great significance for the healthy and Sustainable Development (SD) of ITE.

For ITE, the core of their operations is product quality selection and logistics and warehousing services. Product quality needs to be selected based on experience and operation methods, while logistics and warehousing services can ensure cost reduction and safeguard efficient cargo transportation (Zyz 2020). An ideal Logistics Management System (LMS) can transfer suppliers' goods to demanders at the lowest cost and highest efficiency (Long et al. 2020). With the complication of Logistics Management (LM) services, the existing logistics relationship has been difficult to meet

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the needs of enterprises, while Supply Chain Economic Management (SCEM) can involve all aspects of the supply chain, such as suppliers, manufacturers, exporters, importers, wholesalers, and retailers, thereby improving the overall efficiency and forming a new Supply Chain Management System (SCMS) (Fan et al. 2020). The current SCMS is mostly based on the Internet of Things (IoT), with simple functions, and cannot monitor the entire Supply Chain (SC) process effectively. Thus, the research on IoT-based Supply Chain and Logistics Management (SCLM) needs to be further optimized.

The IoT further expands the internet by connecting things in and between people; it can collect various information without time or spatial constraints. The IoT strengthens the connection in and between people, things, and machines (computer), making the connection more extensive and convenient (Ghasempour 2019). The implementation of IoT relies on advanced technologies and equipment, such as Radio Frequency Identification (RFID) and infrared sensors, to form an intelligent network and strengthen the management of goods (Nauman et al. 2020). During enterprise operation, the SCLM is the core to strengthen the management of each link. SCLM is a completely organic process, covering a wide range and the overall functions from the beginning to the end. The SCLM includes three parts: purchase, production, and marketing, each of which influences and interacts with each other, and the logistics specifically refers to the production. Through SCLM, enterprise management can be improved, and logistics costs can be reduced (Zhou et al. 2021). The IoT can gradually digitalize, intellectualize, and automate the SCLM, thus optimizing the management process. The IoT has a bright development prospect in the intelligent SCLM by accelerating information synchronization and distribution and goods monitoring and tracking in production and transportation. By such actions, commodity information on the SCLM can be feedback to the enterprise in real-time for monitoring and market analysis. Therefore, the application of IoT in the SCLM can minimize errors, reduce information loss, and improve transportation efficiency. Under a market economy, efficient delivery is a must for logistics to reduce loss and improve the throughput of enterprise warehouses (Rejeb et al. 2020).

To sum up, it is of great significance for social development to effectively alleviate the transformation pressure faced by ITE under economic globalization and improve their core competitiveness. The innovation of this paper is summarized: aiming at the problems existing in the IoT-based SCLM, this paper puts forward some optimization strategies, takes ITE as the research object, and through the SCLM optimization, helps relevant enterprises improve efficiency, reduce logistics and transportation costs, and increase enterprise flexibility to ensure the enterprise core competitiveness. Finally, the performance of the proposed SCLM system is analyzed through a case, and the results provide a reference for the development of the IT industry and the stability of the national economy.

The research structure is introduced below: Sect. 2 provides a literature survey on the IoT-based SCLM. Section 3 presents an economic analysis model of the IoT-based SCLM. Section 4 outlines the performance analysis of the SCLM. The final section recapitulates the research conclusions.

2 Research progress of the IoT-based SCLM

Logistics and warehousing service is the core of ITE. Therefore, its intelligent development and optimization are of great practical significance to the survival and development of ITE. This section tries to present a comprehensive understanding of the current situation and intelligent development trend of logistics and transportation management in ITE by reviewing the research of domestic and foreign scholars; then, the existing shortcomings and advantages are summarized, and an optimization scheme is proposed for the problems existing in the IoT-based SCLM of ITE.

2.1 Research on IoT-based LM

Nowadays, as the demand for international logistics and transportation costs increases, the competitiveness of most ITE has decreased given traditional inefficient LM, and some of them are on the brink of bankruptcy. Therefore, it is of great significance to control the cost and efficiency of international logistics for enterprises (Ding and Zhao 2021). Ji et al. (2018) constructed an express cabinets-based express logistics system and pointed out that the logistics information system could improve the efficiency of transportation logistics, such as express delivery. Ji et al. demonstrated the role of emerging technologies in logistics information systems through an analysis of the pros and cons of Radio Frequency Identification (RFID) technology (Ji et al. 2018). Dehgani and Navimipour (2019) proposed that logistics information systems were the foundation in SCMS and were characterized by information transparency and security in model construction and quick response (Dehgani and Navimipour 2019). Ivanov and Dolgui (2020) constructed an information platform model based on logistics information system application and inventory management and found that intelligent logistics systems could achieve intelligence transportation and warehousing through algorithm optimization (Ivanov and Dolgui 2020; Yu et al. 2021). Liu et al. (2020) suggested the control method and system under the intelligent logistics system and pointed out the IoT in the closed-loop SC was based on the different characteristics of the SC, and the results proved some theoretical basis for IoT-based Supply Chain Management (SCM) (Liu et al. 2020). Rejeb et al. (2020) implemented an IoT-based collaborative management model for remanufacturing logistics systems, and the design ideas had some constructive significance (Rejeb et al. 2020). Liu et al. (2020) proposed that, in the context of the IoT, the decision analysis and coordination of RFID applications in the SC were based on the IoT technologies and had different requirements for emerging technologies (Pan et al. 2020).

2.2 Research on supply chain and logistic management

The SC mainly involves two aspects: manufacturing and logistics. LM is an important part of SCMS. Haffer (2018) proposed technologies, such as Two-Photon Lithography (TPL) and Logistics Server Provider (LSP) for different SCLM (Haffer 2018). Chu et al. (2019) pointed out that third-party LM meant enterprises concentrated their strength on superior industries and entrusted logistics activities to specific logistics companies by signing contracts. Meanwhile, the enterprise could communicate with logistics companies through information technology and manage the entire logistics process in real-time (Chu et al. 2019). Sodero et al. (2019) combined big data analysis and SCM and emphasized that the deployment of big data analysis might be transformed into SCM practice (Sodero et al. 2019). Yang et al. (2020) evaluated the most advanced big data and business analysis applications through metrology and system analysis in the SCand determined the development trend of SCLM in the era of big data (Yang et al. 2020). Maina and Mwangangi (2020) developed an industry-based definition of SCLM from four dimensions: volume, speed, quality, and authenticity by studying SCM personnel in six countries (Maina and Mwangangi 2020). Benoudina and Redjimi (2021) combined big data analysis to develop a multi-agent-based SCLM system that could perform autonomous corrective control actions (Benoudina and Redjimi 2021). Saurabh and Dey (2021) described the relevance of big data and SCM and proposed a big data center architecture for SCMS using the latest technologies in data management, analysis, and visualization (Wan 2020; Guptaa and Guptab 2019).

2.3 Review of related research issues

According to the above introduction, the application of logistics information systems has not been extended in current literary works. Financial embarrassment can cause serious crises in the enterprise SCM. The current IoT-based SCMS is only integrated with relatively simple functions, such as entry, calculation, and analysis, while compatibility and convenience need much improvement. Besides, the existing SCMS cannot adapt well to different industries and enterprises; specifically, it is imperative to adjust index setting and evaluation methods to induvial enterprises according to their scale and historical conditions. For example, some SCMSs are oriented towards large companies, some are tailor-made for multinational companies, while some are designed for branch companies and procurement channels in many countries and regions around the world. Therefore, a universal logistics management and optimization model for ITE is imminent. The innovation points are pointed out below. (1) The existing IoT-based SCLM for ITE is optimized, improving prediction accuracy and efficiency. (2) Meanwhile, an SCLM with a closed-loop is constructed through the Industrial IoT (IIoT) to achieve the lowest cost.

3 Economic analysis model of the IoT-based SCLM

By analyzing the problems existing in the SCLM of ITE and the research of scholars in related fields, this section analyzes the IoT-based SCLM economic analysis model of ITE. Specifically, the IoT technology is discussed, and the economic analysis model of IoT-based SCLM is proposed to optimize the SCLM of ITE. At the same time, the performance of the proposed model is evaluated by case analysis.

3.1 IoT-based SCLM system

According to the specific situation of ITE and the operation and management modes (Yadav et al. 2020; Luo et al. 2020; Xie et al. 2020; Xu et al. 2021), an intelligent IoT-based SCLM system is proposed to improve the manual logistic system. Figure 1 shows that all links of the SC, such as transportation and warehousing, can be optimized through the intelligent IoT-based SCLM system for ITE. The proposed system monitors the physical environment of the logistics vehicle in real-time through the intelligent analog control module, couples the main enterprise server, and feedback the vehicles' integrated positional and environmental information to the production center in real-time. The proposed system can control the fixed terminal interface, the mobile terminal, and the intelligent sorting and classification system; the proposed system can also identify, classify, and place goods, and recognize sorting personnel, and transmit their information to the main server to organize the inventory data and uploads the identity data. Thus, centralized and intelligent management is realized for logistics and warehousing data (Ka et al. 2021). Then, the identity data and inventory data are uploaded to the enterprise statistics center, and the statistical system can comprehensively analyze the identity data, inventory data, and work data to generate performance

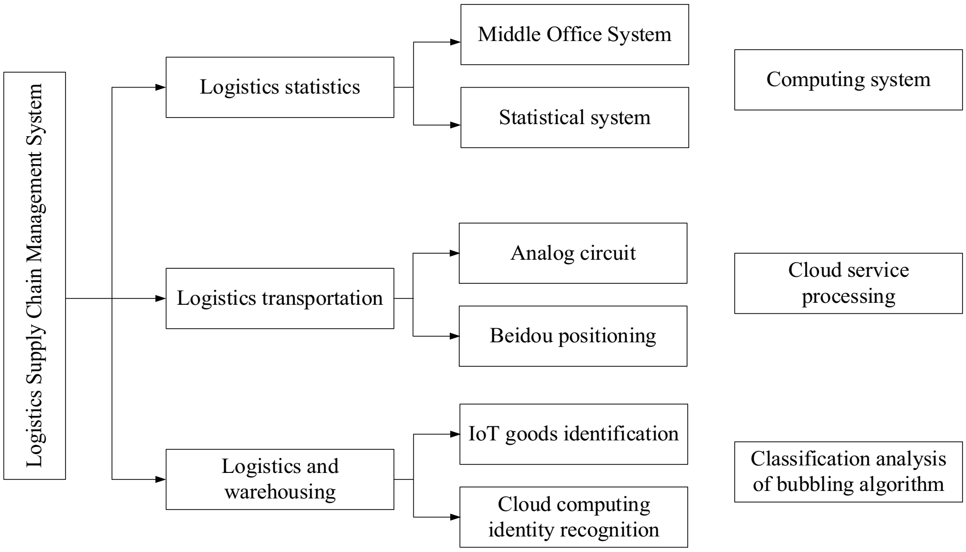


Fig. 1 IoT-based SCLM system

data, thereby realizing intelligent logistics statistics (Gao et al. 2020; Wu et al. 2022; Zhao et al. 2020a, 2021).

According to the current situation of the company, the intelligent IoT-based SCLM system is divided into two parts. The first part is the intelligent logistics transportation system, shown in Fig. 2. The second part is the intelligent logistics and warehousing system, shown in Fig. 3. The main structure of the first part is the application of positioning technology and physical sensors in intelligent logistics vehicles. The technical module is the real-time monitoring system for logistics transportation and the supervision of the information in the main server (Bulatov et al. 2021; Chen and Sivakumar 2021; Xiang et al. 2021; Sahana et al. 2021; Tangonyire and Akuriba 2020).

Figure 3 indicates that the main structure of logistics and warehousing includes: IoT label identification technology; automatic identification, sorting, and placement technology; and sorting personnel identification system. The technical

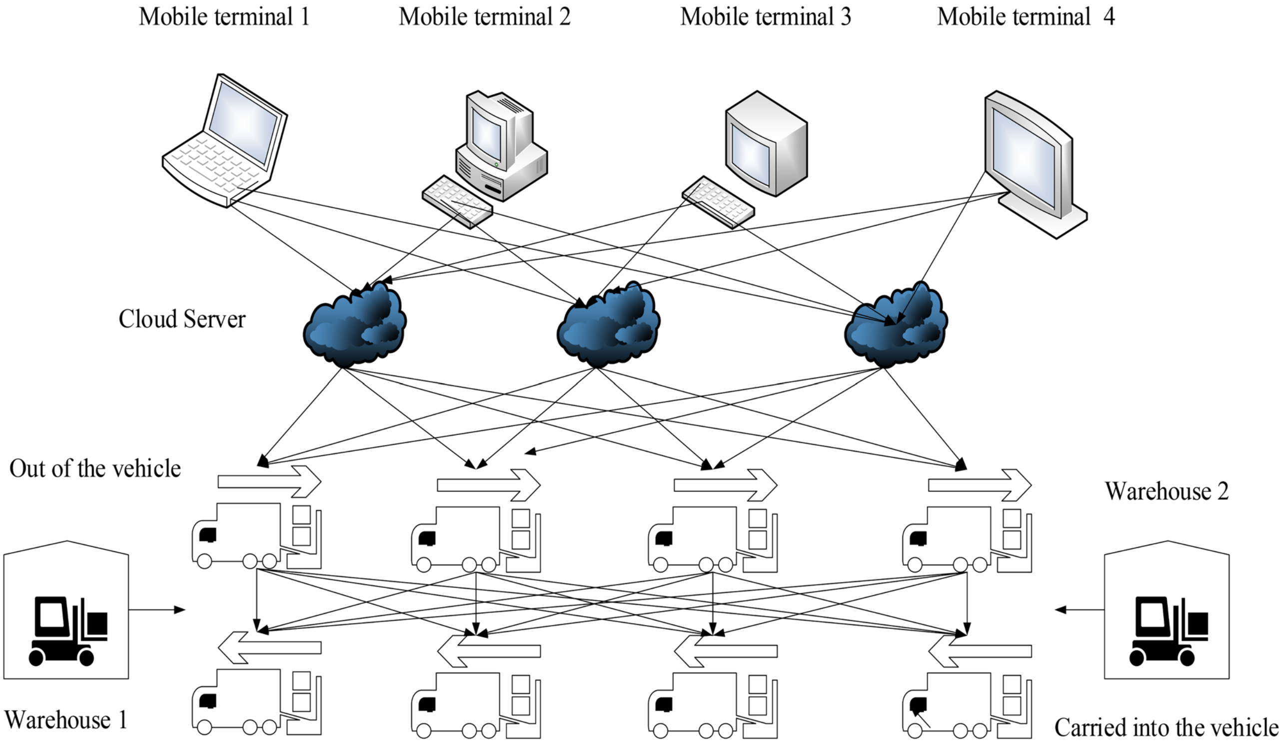
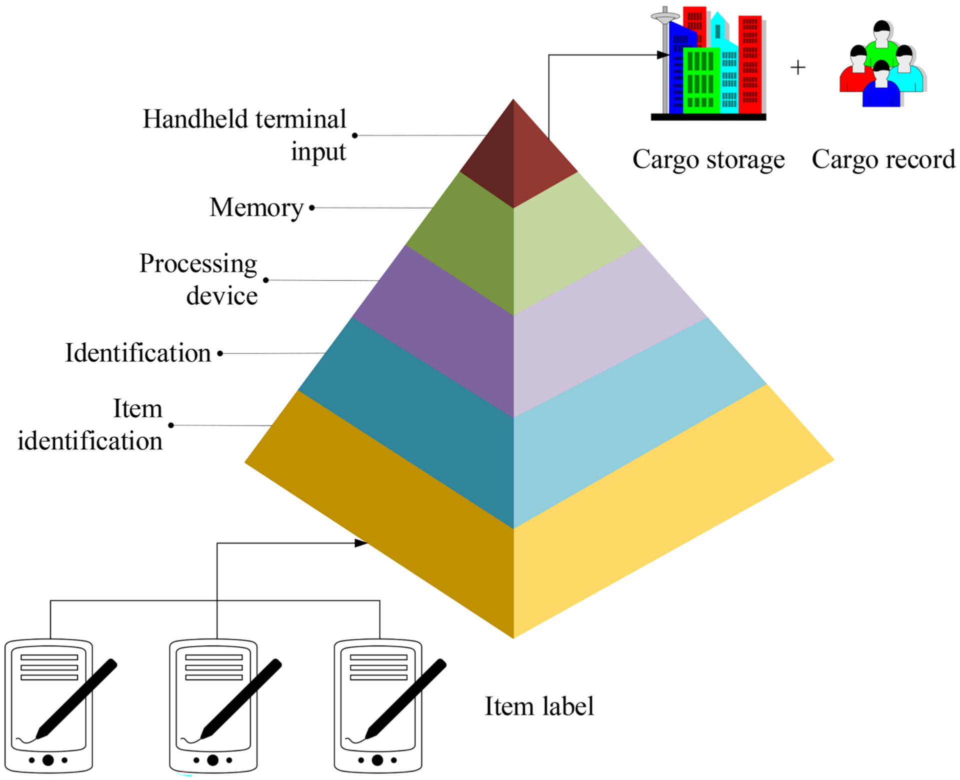


Fig. 2 Main structure of the logistics transportation system

Fig. 3 The main structure of the logistics and warehousing system



module uploads the logistics and warehousing information in real-time and statistically analyzes the information in the main server (Wang et al. 2019; Sun et al. 2021; Yi 2021; Lv and Song 2022).

The intelligent SCLM system is constructed based on the IoT through the application of different technologies, such as analog control, algorithm architectures, and RFID. The intelligent SCLM system has diversified functions and can replace manual logistics systems for ITE. The intelligent logistics system is constructed for ITE under the background of purchasing inventory.

3.2 Optimization of SCLM for ITE

The current SCLM system cannot manage transportation accurately or grasp the transportation environment in real-time. In the intelligent IoT-based SCLM system, transportation depends on two major modules: analog circuit and data transmission modules based on positioning technology (Dr 2012; Zhang 2019; Zhang et al. 2021; Zhao et al. 2020b). Here, the intelligent IoT-based SCLM system is optimized from the dimension of transportation, involving intelligent logistics vehicles, data transmission devices, cloud servers, cloud storage, and display terminals. The data transmitting device is respectively connected with the positioning means and the temperature alarm device to transmit positioning data and control signals; the cloud service processor and the data collector are connected through the network to receive positioning data and control signals; the cloud storage is connected with any one or more cloud service processors or data collectors to store positioning data and control signal transmission; the display terminal can receive positioning data, control signals, and display them. The smart logistics vehicle can be positioned in real-time through the display terminal set in the monitoring center. The specific structure is shown in Fig. 4. Through the logistics vehicle system, the real-time data are uploaded to the main data center, and the main data center feeds all the monitoring signals and monitoring data back to the central production design office (Fig. 5). Afterward, the production design office guides and adjusts logistics vehicles to ensure the integrity of the entire SC (Choi et al. 2020; Li et al. 2021; Wu et al. 2020; Zheng et al. 2021).

In the construction of the intelligent IoT-based SCLM system model, the IT goods label is set on any storage device, and the IT goods label is any one of the Quick Response (QS) code, barcode, Near Field Communication (NFC) tag, and RFID identification tag, or their multiple combinations. The label can be tagged on the IT goods, and the identification code contains unique IT goods information, which is any one or more of the QS code information, barcode information, information of NFC tag information, and RFID identification tag information. When any goods are damaged or lost, the manager can check back through the binding data to find out who is responsible for warehousing the damaged or lost goods, which facilitates accountability

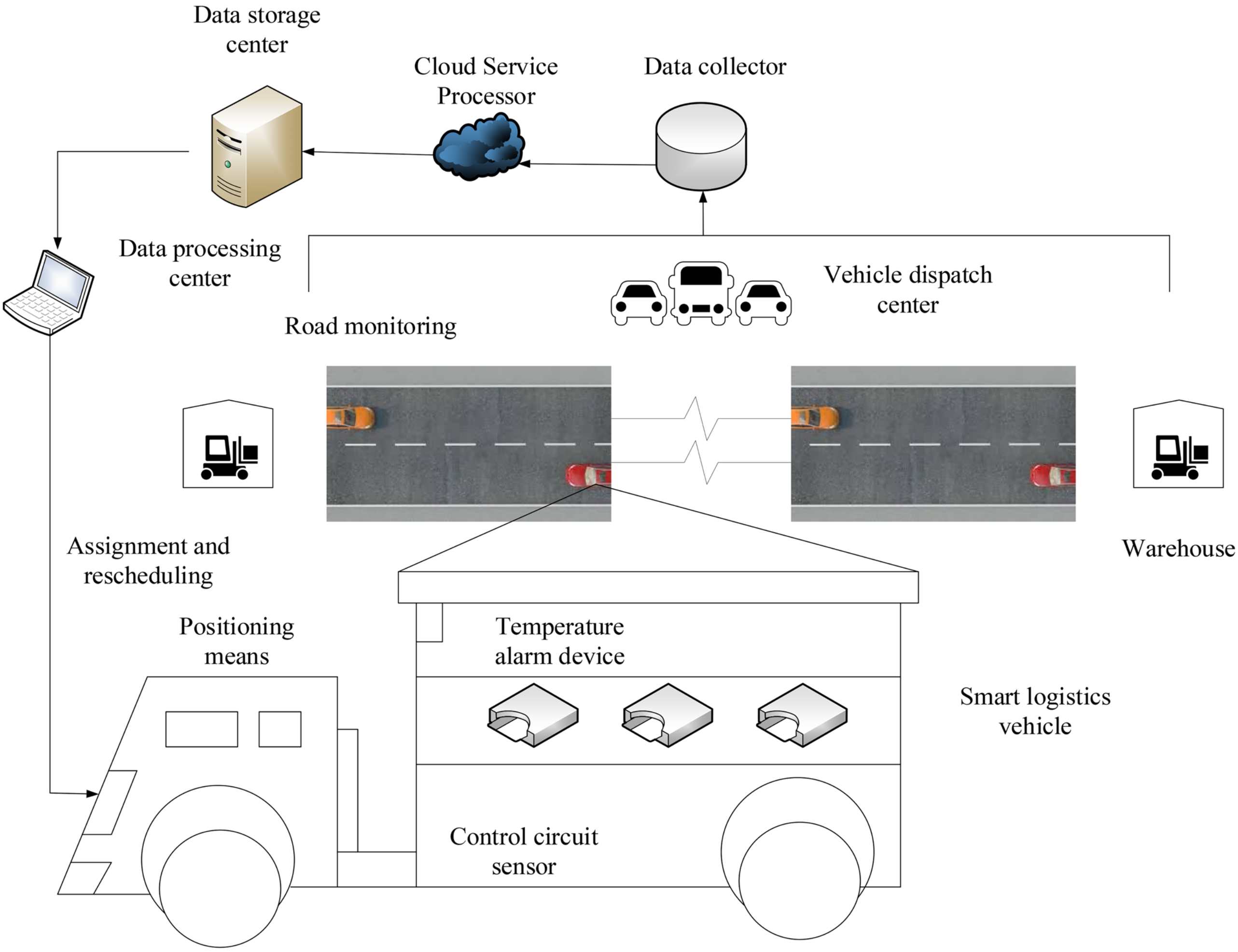


Fig. 4 Optimization of logistics transportation supply for ITE

and management review (Zhou and Polytechnic 2019; Han et al. 2021; Yang et al. 2021).

3.3 Equipment parameters and performance analysis

1. Equipment parameters: The positioning device is installed in the cab of the logistics vehicle to obtain its positional information. The positioning device can be a GPS + Beidou dual positioning module; the model is ATK1218-BD ATK-S1216. The logistics park of a large ITE is chosen for analysis. The loading and unloading area of the park is equipped with 2 loading and unloading lines, 4 rail gantry cranes, and a total of 7 lines in the main box area, of which the sending box area is 1 to 4 lines, the arrival box area is 5 to7 lines, and the maximum number of stacks in the main box area is 2 layers. The container loading and unloading area parameters are shown in Table 1.

The operating parameters of the rail gantry crane required in the case analysis are obtained through consultation on relevant literature and data. However, due to reasons such as technological progress, the selected parameters may deviate from the actual situation. Therefore, the parameters selected are only used for the case analysis here. The operating parameters of the rail gantry crane are shown in Table 2.

2. Empirical analysis: According to the actual requirements, the loading and unloading operations of 132 containers are designed with a completion period of 3 h. At zero time, a train loaded with 60 containers enters the container loading and unloading line for unloading, while an empty container train capable of loading 60 containers enters the container loading and unloading line for loading operations. Within the planned time, 16

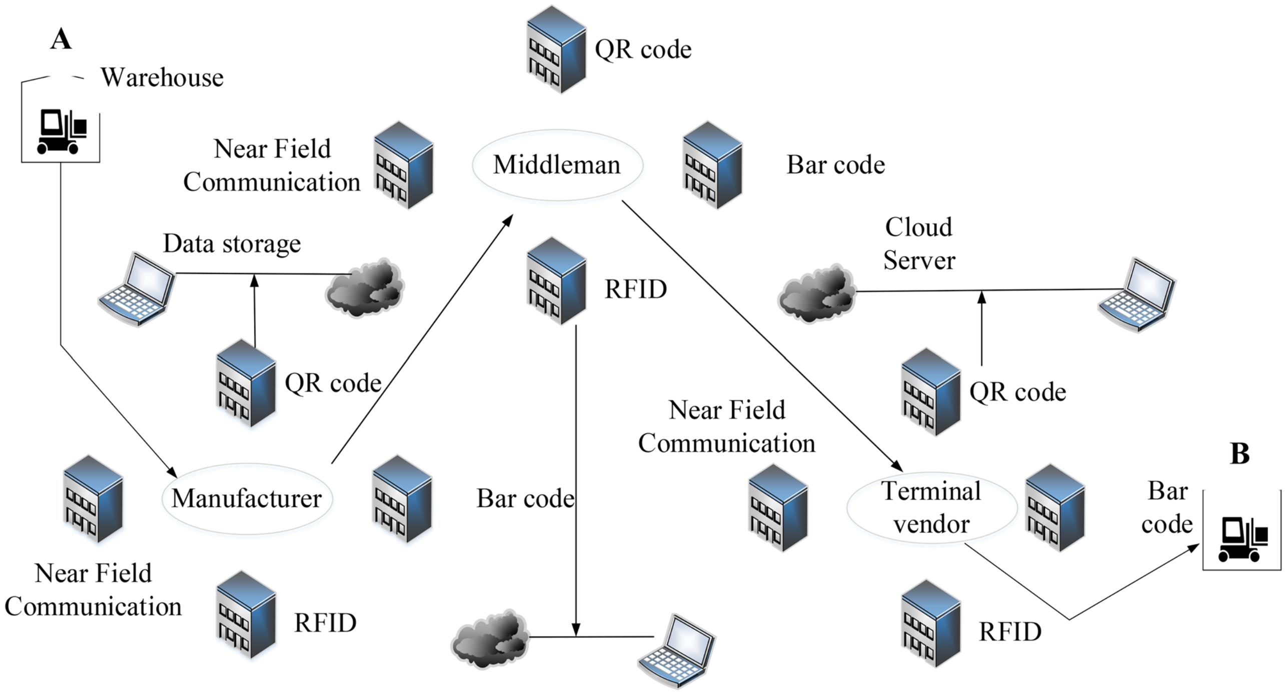


Fig. 5 Optimization of logistics and warehousing supply management for ITE

trucks arrive discretely at the loading and unloading area for operations. Here, the simulation is optimized from two aspects of non-priority and priority. First, without considering priority, the single-queue mode and multi-queue mode are compared and analyzed through the maximum value determined under a specific waiting time, the number of optimal service stations, the corresponding Average Queue Time of vehicles (AQT), Average Queue Length (AQL), and the Average Length of Stay (ALS). After comparative analysis, the superior queue mode is selected for the operational areas with high priority requirements. Secondly, the transportation priority is considered after the optimal queuing model is determined. Then, the influence of the proportion of different priorities is compared and analyzed on the AQT, AQL, and the ALS, and then compared with the change of the AQT of vehicles without considering the transportation priority. Finally, the operation process of the gate area of the logistics park is simulated through the AnyLogic simulation software. The simulation time is set to 30 days. When the simulation is completed, the system automatically outputs the AQL, Average Waiting Time (AWT), and ALS (Liu et al. 2021; Wang 2021).

Table 1 Container loading and unloading area parameters

Functional areas	X coordinate value
Train loading and unloading line	1,2
Sending box area	3,4,5,6
Arrival box area	7,8,9
Truck operation channel	10

4 SCLM performance analysis

This section mainly evaluates and analyzes the performance of the proposed economic analysis model of IoT-based SCLM from four aspects: the performance comparison of the non-priority model, the performance comparison of priority model, the effect of SCLM economic optimization, and the application analysis of SCLM optimization. Then, the performance advantages of the proposed model are highlighted through comparative experiments.

Table 2 Rail gantry crane operation parameters

Related parameter names	Parameter values
The average speed of the cart	90 m/min
The average speed of the car	90 m/min
Average time of up and down of the heavy box	45 s
Average no-load up and downtime	30 s
Alignment locking time	15 s
Alignment release time	10 s
Safe working distance	7 m

4.1 Non-priority model performance comparison

Table 3 shows the optimal service stations, the AQT, AQL, and the ALS of different modes under different time thresholds. The results show that as the waiting time threshold continues to increase, the optimal service stations are declining. When the time threshold of a single model is less than 20 min, the optimal server stations remain at 9, and when the time threshold of the fusion model is higher than 5, the optimal service stations decrease. With the same number of service stations, the AQT of the single model is less than that of the fusion model, but in terms of queue length, the AQL of the fusion model is significantly lower than that of the single model and the ALS is within 25 min. The performance of the single model is much superior to the fusion model. Thus, a single model can effectively reduce the operating and transportation costs in the park.

Table 4 illustrates the impact of vehicle arrival rate, average service rate, and the AWT threshold on the number of service stations in the gate area. When the vehicle arrival rate is large, and the AWT threshold is small, the difference between the two modes is obvious, and when the average service rate and AWT threshold are both small, the difference between the two models is obvious. In most cases, a single model is better than a fusion model, but a single model has a much longer queue length and occupies more space. Therefore, a certain priority must be set for a single model to ensure the efficiency of logistics and transportation in a short time.

4.2 Priority model performance comparison

Table 5 shows the comparative analysis results of different priority jobs in scenes 1–3. The results demonstrate that when the ratio of priority level 1 changes small, the change of each index is not significant, at about 0.1 min, and when the ratio of the priority level 4 changes small, the AQT and the AQL changes significantly, both at about 10 min. With the same ratio change, the higher the priority level is, the smaller the amount of change is for the corresponding indices. Therefore, the company should fully consider the ratio of each priority level on freight when confirming transportation priority.

Table 6 displays the model performance based on the IoT and different IoT priority levels with different service stations. The results suggest that the AWT of the first three priority vehicles based on the IoT is shorter than that of non-IoT-based operations. The higher the priority level, the shorter the AWT is. For example, with 8 service stations, the AWT of vehicles with an IoT-based level 1 priority is reduced by nearly 34 times compared with that of non-IoT-based vehicles. The comparison results of the number of service stations indicate that the fewer the number of service stations is, the longer the AWT is, and the more efficient the prioritized transportation operations are. Therefore, the IoT-based SCLM method can improve the service level of the operation and guarantee the deadline of the goods, thereby improving the punctual delivery rate.

4.3 SC economic optimization results

Table 7 demonstrates the comparison results of the different job optimization methods. The results imply that without IoT structure, the AQT of the fusion model is 2.7 times that of the single model. With the IoT structure, the AQT, AQL, and maximum queue length of the model have decreased significantly. IoT-based operations can shorten the AQT of vehicles with level 1 priority by nearly 7 times. Therefore, the Io-T-based method is superior, and the prioritized intelligent vehicles can effectively shorten the logistics transportation time and improve transportation efficiency.

Table 8 shows the comparison of the iterative convergence graph of the objective function of the different algorithms. The results show that the proposed IoT algorithm can converge faster. Although the calculation results of the two algorithms are similar, here, the algorithm structure is innovatively analyzed from the perspective of the SC, while the previous literature studies from a single logistics structure.

Table 3 Comparative analysis of truck queue indices with different time thresholds and different queue modes

	Number of service stations (sets)		AQT (min)		AQL		ALS (min)	
Waiting time threshold (min)	Single queue	Multi-queue	Single queue	Multi-queue	Single queue	Multi-queue	Single queue	Multi-queue
5	9	10	2.58	4.77	4.89	0.57	7.79	9.97
10	9	9	2.58	6.96	4.89	1.01	7.83	12.16
15	9	9	2.58	6.96	4.89	1.12	7.64	12.28
20	9	9	2.58	6.96	4.89	1.24	7.86	12.38
25	8	9	21.26	6.89	32.96	1.35	26.45	12.47
30	8	9	21.26	6.79	32.96	1.56	26.63	12.15

Table 4 The impact of vehicle arrival rate, average service rate, and AWT threshold on the number of service stations in the gate area (To be continued)

Service rate (vehicles/min)	5-single queue	5-multi-queue	10-single queue	10-multi-queue	15-single queue	15-multi-queue	20-single queue	20-multi-queue	25-single queue	25-multi-queue	30-single queue	30-multi-queue
0.14	12	16	12	12	12	12	12	12	12	12	12	12
0.145	12	16	11	12	11	11	11	11	11	11	11	11
0.15	11	15	11	12	11	11	11	11	11	11	11	11
0.155	11	13	10	11	10	11	11	11	10	10	10	11
0.16	10	13	10	11	10	11	10	11	10	10	10	10
0.165	10	13	10	11	10	11	10	10	10	10	10	10
0.17	10	12	10	10	9	10	10	10	10	10	109	10
0.175	10	11	9	10	9	9	10	9	9	9	9	9
0.18	9	11	9	10	9	9	9	9	9	9	9	9
0.185	9	11	9	9	9	9	9	9	9	9	9	9
0.19	9	10	9	9	9	9	9	9	9	9	8	9
0.195	9	10	8	9	8	9	9	9	8	9	8	8
0.2	9	9	8	9	8	9	9	8	8	9	8	8
0.205	8	9	8	9	8	9	9	8	8	8	8	8
0.21	8	9	8	9	8	8	9	8	8	8	8	8
0.215	8	9	8	8	7	8	8	8	8	8	8	8
0.22	8	8	8	8	7	8	8	8	7	8	8	7
0.225	8	8	8	8	7	8	8	8	7	8	7	7
0.23	8	8	7	7	7	7	8	7	7	7	7	7
0.235	7	7	7	7	7	7	7	7	7	7	7	7
0.24	7	7	7	7	7	7	7	7	7	7	7	7
0.1	2	2	1	1	1	1	1	1	1	1	1	1
0.2	2	2	2	2	2	2	2	2	2	2	2	2
0.3	3	3	2	3	2	2	2	2	2	2	2	2
0.4	3	4	3	3	3	3	3	3	3	3	3	3
0.5	4	4	4	4	3	3	3	3	3	3	3	3
0.6	4	5	4	4	4	4	4	4	4	4	4	4
0.7	5	6	5	5	4	5	4	4	4	4	4	4
0.8	5	6	5	5	5	5	5	5	5	5	5	5
0.9	6	7	6	6	5	6	5	6	5	6	5	6
1	6	7	6	7	6	6	6	6	6	6	6	6
1.1	7	8	7	7	7	7	6	7	6	7	6	7
1.2	7	9	7	7	7	7	7	7	7	7	7	7
1.3	8	9	8	8	8	8	8	8	7	8	7	8
1.4	8	10	8	9	8	8	8	8	8	8	8	8
1.5	9	11	9	9	9	9	9	9	9	9	9	9
1.6	10	11	9	10	9	10	9	9	9	9	9	9
1.7	10	12	10	10	10	10	10	10	10	10	9	10
1.8	11	12	10	12	10	11	10	10	10	10	10	10
1.9	11	13	11	11	11	11	11	11	10	11	10	11
2	12	14	11	12	11	12	11	12	11	11	11	11

Table 5 Comparative analysis of the impact of proportions of different priority on gate area operations

Percentage of different priorities	scene 1			scene 2			scene 3		
	AQT (min)	AQL (vehicle)	ALS (min)	AQT (min)	AQL (vehicle)	ALS (min)	AQT (min)	AQL (vehicle)	ALS (min)
Scenario 1-Level 1	0.681	1.097	5.964	0.647	1.094	5.808	0.698	1.154	5.928
Scenario 1-Level 2	0.953	1.275	6.085	0.972	1.363	6.152	1.165	1.447	6.363
Scenario 1-Level 3	2.386	2.27	7.601	2.705	2.39	7.94	3.178	2.443	8.413
Scenario 1-Level 4	56.684	30.72	61.876	65.923	30.91	71.082	68.868	31.878	74.061

Table 6 Comparison and analysis results of the model performance of different operation modes under different numbers of service stations

Different optimal work methods	Number of service stations = 8			Number of service stations = 9		
	Priority 1	Priority 2	Priority 3	Priority 1	Priority 2	Priority 3
8-No IoT-Level 1	21.265	21.265	21.265	2.586	2.568	2.586
8-IoT-Level 1	0.681	0.647	0.698	0.375	0.381	0.387
8-IoT-Level 2	0.953	0.972	1.165	0.521	0.546	0.614
8-IoT-Level 3	2.386	2.705	3.178	1.107	1.287	1.344
8-IoT-Level 4	56.684	65.923	68.868	5.693	6.778	6.801

Table 7 Comparison and analysis results of different job optimization methods

Percentage of different priorities	AQT (min)	AQL	AQL (vehicle)
No IoT-Single	2.587	4.88	41
No IoT-Multi	6.699	1.03	5
IoT-Level 1	0.371	1.05	4
IoT-Level 2	0.514	1.15	6
IoT-Level 3	0.969	1.44	11
IoT-Level 4	5.366	4.15	37

Thus, the research results can ensure the efficiency of the SCLM of ITE.

4.4 Supply chain optimization application analysis

Table 9 illustrates the loading and unloading operations in different paths. The results show that the variance of loading and unloading operations on different paths is 0.5, and the variance of the completion time of loading and unloading operations on different paths is 5.8, indicating that the operations under different paths are basically balanced, and the corresponding empty driving ratio only changes significantly under path 4. Thus, the difference between them is not very obvious. This also shows that the proposed model effectively balances operations in different SC and improves the efficiency of loading and unloading operations while ensuring that the overall transportation remains unchanged.

Table 10 displays the priority coefficients under different task paths. The delay time under different task paths. The results suggest that the higher the priority is, the fewer delays in its loading and unloading operations are. Therefore, the optimized IoT-based operations of container loading and unloading can improve the operation efficiency of specific items, increase the punctual delivery rate of goods, and thus, improve the service quality of the enterprise.

Table 11 illustrates the comparison of truck delay time before and after the application of the IoT. The results imply that before and after the application of the IoT, the completion time of ITE operations is almost the same, about 107 min, but the AWT for IoT-based operations has been reduced by nearly 4 times. At the same time, based on the IoT, the containers and equipment can be positioned accurately in real-time, thus improving the efficiency of loading and unloading operations. This shows that container loading and unloading operations based on the IoT can reduce the waiting time of transport vehicles and improve the overall operational efficiency of the park.

Table 8 Iterative convergence graph of the objective function of different algorithms

Number of iterations	Objective function value	Objective function value
7.255301	128.4808	128.6542
12.72578	127.6387	127.9855
18.10702	125.0975	122.9394
28.93196	121.2044	120.9239
49.93932	118.6844	118.5707
52.66117	118.0085	116.5537
54.30321	114.2729	111.8466
64.31606	112.4175	109.494
69.74191	110.7259	104.2795
74.15042	107.1639	98.72921
73.95409	103.4258	94.52787
77.46127	100.2024	93.69095
81.84301	96.13068	89.31912
87.22425	93.58946	85.78549
99.04869	91.22689	82.42454
109.9807	89.37281	78.2213
119.0922	87.85607	74.69113
127.1061	82.93978	71.49877
130.5776	79.03673	67.12821
135.9231	75.81584	63.93805
150.514	73.62694	64.62123
159.5542	70.75087	63.62424
176.8402	67.37631	63.46387
196.8837	64.0055	63.30696
207.9407	64.53023	64.15367
227.2257	64.21664	63.15196
249.2771	64.07671	63.49575
273.1581	63.76937	63.33317
288.7842	63.7906	63.17216
304.4192	63.98176	63.35053
338.3933	63.34833	63.69749

Table 9 Comparative analysis of loading and unloading operations in different paths

Door crane serial number	Total operation time (min)	Total idle time (min)	The proportion of empty driving (%)
1	98.15	4.56	4.44
2	104.93	4.08	3.74
3	101.43	4.4	4.16
4	101.96	5.87	5.44

Table 10 Priority coefficients under different task paths

Task number	Priority	Delay time	Proportion of delays
1	2	0	0
2	4	0.07	1.2
3	2	2.73	45
4	6	0	0
5	2	0	0
6	2	2.01	33.1
7	8	0	0
8	8	0.82	13.6
9	2	0	0
10	2	0	0
11	4	0	0
12	8	0	0
13	6	0	0
14	8	0	0
15	8	0.44	7.2
16	8	0	0

Table 11 Comparison of truck delay time before and after the application of IoT

Collection card arrival time	Expected completion time	The actual completion time
0.632569	18.49686	12.23226
1.381564	23.83789	17.5733
2.190528	29.80674	24.79366
3.208527	34.52641	30.13938
4.34748	44.57483	46.14258
5.516261	54.31051	58.0709
6.772889	56.52833	58.09491
7.673369	69.70523	66.88771
8.779058	66.2804	65.96767
10.7561	79.16507	79.79288
11.77683	94.85086	90.15344
13.27303	98.32663	99.57932
14.53137	107.4374	102.4267
15.72764	107.4609	109.9662

5 Discussion and conclusion

Based on the existing SCLM, an IoT-based SCLM model is proposed in response to the problems in the logistics and transportation of ITE. The proposed model can be divided into three parts: intelligent warehousing, intelligent transportation, and intelligent computing. Corresponding sensors are used in intelligent transportation, and the big data analysis method can construct the central transportation scheduling analysis method. In intelligent warehousing, a single point-to-point identification method is introduced. The effective calculation of each link in the SC ensures the safety of the goods. In intelligent calculation, big data processing algorithms are introduced. By optimizing transportation scheduling and intelligent warehousing, the AWT of transport vehicles is reduced, while the efficiency of container loading and unloading operations and the overall efficiency of the park are improved. The results have important reference value for promoting the transformation of the SCLM of ITE.

However, there are also some deficiencies. Firstly, the IoT-based processing algorithm is the key to improving transportation efficiency. In this paper, some existing algorithms are selected and analyzed, and the optimization of the algorithm is not specific enough. Secondly, in the performance analysis of the model, some newly studied algorithms are selected for comparison. In the follow-up work, in-depth research will be conducted from these two aspects to deepen the optimization of the algorithm. At the same time, more algorithms will be introduced into the optimization system to improve the efficiency of the SCLM of ITE. For example, Machine Learning (ML) can help SCLM to optimize capacity utilization, improve customer experience, reduce risk, and create new business models. Due to the diversity of its learning ability, Deep Learning (DL) has a good application effect in SCLM. Neural Network (NN) or Particle Swarm Optimization (PSO) algorithms in DL can effectively optimize the SCLM system. These algorithms will be deeply studied in the follow-up work.

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Declarations

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors. Informed consent was obtained from all individual participants included in the study.

Conflict of interest All Authors declare that they have no conflict of interest.

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