IoT-based Supply Chain Performance Measurement System: A Conceptual Framework

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Abstract. The normal and effective operation of the supply chain is the key factor to ensure the development of enterprises. With the complexity of the internal and external environment, the harm caused by the non-ideal management of the supply chain also occurs. It is an important task of enterprise management to evaluate the supply chain scientifically and rationally, and then control the direction of the supply chain. Therefore, based on the setup of the supply chain performance measurement system and the technical architecture of the Internet of Things (IoT), this paper proposes a measurement system suitable for the technical environment of the IoT and its corresponding architectural functions, which provides a good reference for the subsequent research on intelligent supply chain computing models.

Keywords: Supply Chain Management (SCM), Internet of Things (IoT), Performance Measurement System, Smart Supply Chain.

1 Introduction

In recent years, with the continuous development of the global economic level, people's consumption level is also constantly improving, which also intensifies the competition between enterprises. Supply chain performance measurement plays an important role in supply chain management and enterprise operation. The performance measurement of a supply chain is a system composed of key performance indicators (KPIs) to measure the effectiveness and efficiency of supply chain management. The selection of the indicators is based on the SMART principle (Specific, Measurable, Achievable, Relevant, Time-bound), which includes decision-making at different levels. However, in the traditional management mode and measurement model, data collection and processing mostly rely on manual forms. Cross-department and cross-business collaboration is not ideal. There is a serious data island, so there are more difficulties and loopholes in the evaluation level.

The full process awareness, secure transmission, efficient collaborative planning and decision optimization of IoT technology help to consider the complexity of the entire supply chain system and directly solve the problem in data acquisition and analysis. This paper integrates IoT technology into the enterprise supply chain performance measurement system, forming a

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flexible supply chain data collection and evaluation system and a typical case of IoT technology in supply chain management.

2 Previous Research

After a long period of development, academia and industry have formed measurement methods based on different perspectives. The BSC model was established in 1992 and evaluated through four dimensions: finance, customers, internal business processes, and learning and growth. Based on the five-dimensional balanced scorecard, a supply chain performance evaluation system based on a neural network was constructed, and an empirical study was carried out on the Iranian food industry[1]. In addition, SCOR model is also a common model for supply chain performance measurement. It is a widely applicable reference model for supply chain operation developed by the Supply Chain Council (SCC) in 1996. Including planning, procurement, production, distribution and returns of five links. SCOR model is beneficial to the development of the whole industry. Yadav, Garg and Sunil[2] develop a framework for supply chain performance measurement for the agriculture supply chain based on IoT and explain the role of IoT in data collection and communication based on SCOR model. In other related studies, the impact of the key drivers of innovation orientation on the long-term performance of manufacturing supply chains is proposed[3]. Sharfuddin and his coworkers[4] adopt a qualitative review methodology to find out if supply chain performance measurement develops with the current emerging technology and proposes a conceptual supply chain performance measurement framework. In addition, the performance ranking of green supply chain is analyzed by fuzzy-VIKOR and grey relational degree, two multi-criteria decision tools[5]. Saleheen and Habib[6] consider BSC and the SCOR model at three decision levels, which incorporates ten supply chain performance measurement attributes and thirty-six performance measurement indexes. The IoT technology is applied in many fields such as e-commerce and information system management, and is one of the most important ways to generate big data. Lee and his coworkers[7] look into the mediating role of supply chain performance in the manufacturing industry. Using the collected data, effective models can be created to optimize the business operation mode of different industries[8]. The use of the IoT in the supply chain is also a research hotspot in recent years, providing many solutions for monitoring, tracing and managing the supply chain[9]. Xia and Liu[10] develops an optimal management and coordination method to improve the performance of cross-border e-commerce supply chain by using IoT tracking technique.

3 Measurement Indicators

The establishment of the measurement system helps to make objective, fair and accurate comprehensive evaluation towards the project’s operating benefits and operator performance during a certain period. In the evaluation process, mathematical statistics, operational research principles and specific index systems can be used to make quantitative and qualitative comparative analysis, in accordance with unified standards and certain procedures. The measurement dimension and corresponding content are shown in **Table 1**.

Table 1. Measurement dimensions and content

Measurement Dimensions	Content
Organization Management	SC Department Management SC Staff Management
Product Quality Management	Store Performance Area Effectiveness
Cost Management	Financial Indicator Cost Comparisons Components
Logistics Management	Reliability Reactivity Flexibility Utilization

3.1 Measurement of Organization Management

The measurement of organization management includes SC department management and SC staff management. It refers to a formal employee appraisal system that uses systematic methods and principles to evaluate and measure the work behavior and work achievements of employees in their positions. The results of measurement can directly affect the vital interests of many employees, such as salary adjustment, bonus distribution, and job promotion. Since SC staff plays such a key role in the whole supply management system, the measurement of SC department and staff can directly affect the producing quality. Generally, the measurement process can be divided into three types.

(1) Effect-oriented

The content of this evaluation is based on the results, which puts emphasis on results rather than behavior, based on "what has been done". Since it evaluates work performance rather than work efficiency, standards are easy to formulate and operate. The objective management evaluation method is an example. It has short-term and expressive shortcomings, which makes it more suitable for employees in specific production operations rather than transactional personnel.

(2) Quality-oriented

The content of this evaluation is about assessing the quality of the employee at work, based on "how he does it". It requires qualities such as loyalty, reliability, initiative, innovation and

confidence, so it is difficult to operate specifically, which is suitable for the assessment of employees' work potential, work spirit and communication skills.

(3) Behavior-oriented

The content of this evaluation is mainly to assess the work behavior of employees, based on "how to do" and "what to do", focusing on the work process. The evaluation criteria are easy to determine and highly operable. Thus, it is suitable for the evaluation of management and transactional work.

3.2 Measurement of Product Quality Management

Market analysis experts are usually responsible for the management of chain stores. These market analysis experts interact closely with chain store managers, holding all sales and market trends on their fingertips. They can help designers master development direction. Some data can help to learn deeply about the real situation of store sales. The calculation of store performance is shown in **Formula 1.**

$$\textbf{Store performance} = \text{customer flow*entering rate*transaction rate*customer unit price return rate} . \quad (1)$$

According to store performance, the area-effectiveness of a certain store can be calculated, which can analyze the productivity of the store area, revealing the real situation of store sales. The calculation of area effectiveness is shown in **Formula 2**.

$$\text{Area effectiveness} = \frac{\text{(Day/month/year) turnover}}{\text{area of the store}} \quad (2)$$

3.3 Measurement of Cost Management

It is important to control product costs and thus maximize profits, so an effective assessment of supply chain costs is one of the most important tasks for companies. Our discussion is based on the Total Cost of Ownership (TCO) cost approach, which considers all costs associated with goods and services in the supply chain, including transaction costs related to procurement activities (ordering, transportation, quality, etc.), usage costs, and associated costs due to substandard quality.

The cost can be separated into different components, and the disaggregation indicators and their calculation method, the measurement department are shown in **Table 2**.

Table 2. Cost components

Disaggregation indicators	Calculation method	Measurement department
Plan cost	Forecast costs + Demand management costs	Operation Center Sales Office Production Department Purchasing Department Warehouse
Procurement cost	Procurement management costs + Material procurement costs	Sales Office Purchasing Department R&D
Production cost	Labor costs + Production material costs	Production Department
Transport cost	In-plant transfer costs + Factory-to-sales costs	Warehouse; Carriers

3.4 Measurement of Logistics Management

As an important part of the supply management process, logistics efficiency is also one of retail enterprises' core competencies. From the customer's point of view, the assessment of deliveries is important to ensure the orderly operation of the production and distribution systems, especially in the case of JIT. In this part of the process, we establish indicators to measure the following four areas as **Table 3**.

Table 3. Indicators of Logistics Management

Performance Characteristics	Measurement Indicators	Disaggregation Indicators	Assessment Department
Reliability	Perfect order fulfillment rate	On-time delivery rate	Purchasing department Production department, Warehouse
		Transport salvage rate	Purchasing department Carriers
Reactivity	Lead time for order completion	Lead time for procurement of finished goods	Sales offices
		Lead time for procurement of raw materials	Purchasing department
		Lead time for production and transportation	Production department
Flexibility	Upward	Average order fulfillment time	Production department Suppliers Carriers
	Upward/Downward	Production flexibility	Production department Suppliers Carriers
Utilization	Days of inventory	Days of inventory of raw materials	Purchasing department
		Days of inventory of finished goods	Sales offices

4 Conceptual Framework of the IoT System

4.1 Overall Architecture

According to the structural characteristics of the IoT technology, this paper adopts four layers: perception layer, network layer, platform layer and application layer. As shown in **Figure 1**, in the sensing layer, devices such as RFID and sensors can monitor and trace the whole process of the supply chain and collect relevant information and data at any time. The network layer is responsible for the transmission of data, uploading the corresponding index data to the platform layer for data mining and processing; On the platform layer, the database of different business modules is established, and the effective information of the data is extracted by means of econometric statistics and machine learning. In the application layer, enterprises can adjust the management plan of enterprises and people according to the generated information.

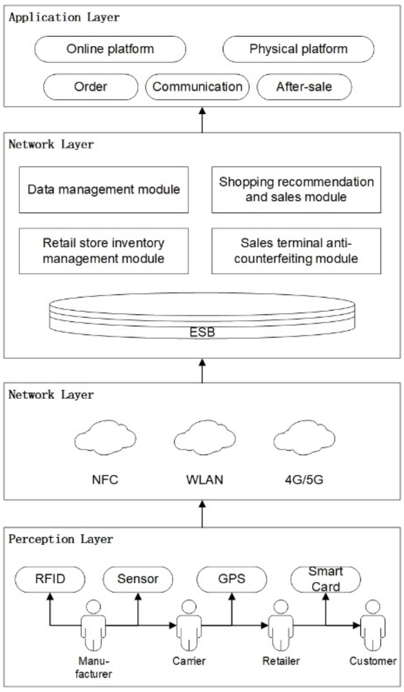

Fig. 1. 4-layer architecture of IoT

1. Perception Layer

The perception layer is mainly responsible for identifying and collecting commodity data. Many types of devices can be connected to goods, such as RFID, sensors, GPS, etc. Combined with the operation process, the data mainly includes location, product and customer information. First, the perception layer contains physical devices with information gathering capabilities. For the circulation of goods in the supply chain, the electronic product Code (EPC), which contains information such as fabric, color, style, etc., is installed into the electronic tag. RFID readers are set up in various links of the supply chain, such as production lines, warehouse import and export, store shelves and other locations. GPS is an important tool for collecting commodity movement data, which is often installed in transport vehicles and can accurately locate the location of goods. Smart cards play an important role in customer identification and platform information sharing.

2. Network Layer

In this architecture, the network layer is responsible for connecting the perception layer and the platform layer, and is the channel for data transmission and data sharing at the upper and lower levels. This level includes near field communication (NFC), wireless local Area network (WLAN), and mobile communication technology. Among them, NFC belongs to the personal area Network (PAN), mainly through the smart phone that supports the NFC function for data transmission, through the mobile phone to scan the electronic label on the goods, so as to learn more about the goods and understand the purchase. WLAN is often used in store management and includes WIFI routers and device access points.

3. Platform Layer

The platform layer is based on SOA, and the data is transmitted into the database through the network layer, which provides interfaces and services for the application layer, including data center, operation module, enterprise service bus (ESB) and other parts. The platform layer is mainly used to store and analyze all information about products and customers to help enterprises better manage and retrieve relevant data. Collect design, production, inventory, logistics and sales information based on the supply chain operation process, establish data management modules, retail store inventory management modules, shopping recommendation and sales modules and sales terminal anti-counterfeiting modules, and obtain and manage them in hardware devices. In SOA, enterprise service Bus, as the core component of system architecture, integrates all kinds of information resources in the supply chain, so as to provide services to consumers more transparently and clearly.

In the platform layer, the data management module is based on information database, system database, electronic resume database, record database, customer shopping behavior database and online and offline inventory database, which is used to store and manage relevant data. The stored data is then further analyzed by intelligent data mining algorithms for use in the sales process. The structure is shown in **Figure 2**.

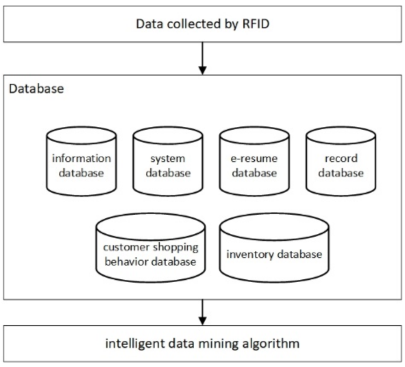

Fig. 2. Structure of data management module

4. Application Layer

As the top layer of the Internet of Things architecture, the application layer is responsible for the final processing and application of the data stored and analyzed at the platform layer, and the real-time perception, analysis and control of these data. It is divided into two application scenarios of online stores and offline stores, and commodity and user data are shared at both ends, so as to realize business functions such as commodity ordering, information exchange and after-sales service, so that consumers can make timely and accurate shopping decisions in the final experience, and increase shopping efficiency and convenience.

4.2 The Function and Measured Content

Each layer of the performance measurement system has a corresponding function. The perceptual layer acquires all quantitative index data in the supply chain by collecting data, such as customer flow, return rate, etc. The network layer transmits all indicator data to the platform layer. The platform layer analyzes and processes the acquired data, so as to obtain macro data of larger scale and effect; The application layer generates decisions based on the analysis results. The specific assessment contents are shown in **Table 4**:

Table 4. The function and measured content

The Layer of System	Function	Measured Content
Perceptual layer	Data collection	Customer flow Entering rate Transaction rate Customer unit price Return rate Cost Components Financial Indicators Perfect order fulfillment rate Lead time for order completion Average order fulfillment time Days of inventory
Network layer	Data transfer	All indicators
Platform layer	Data analysis	Area effectiveness Cost Comparisons Production flexibility
Application layer	Data service	SC Department Management SC Staff Management

5 Implementation Effect

The measurement system proposed in this paper was implemented and verified in a subsidiary of a power group. After long-term observation, enterprises can timely and effectively measure the operation of the existing supply chain through the results provided by the measurement system, and control the overall operation of the enterprise. After three years of continuous tracking of the enterprise, after the implementation of the system, the gross profit rate of the enterprise increased from 15.3% to 17.6%, the operating profit rate showed a substantial increase, and the inventory turnover rate increased from around the industry average to 3 percentage points higher than the industry average, indicating that the implementation of the performance measurement system provides an effective reference for the enterprise's decision-making.

6 Conclusion

As a large-scale digital application technology, the sustainable data acquisition capability and macro data analysis capability of the Internet of Things are suitable tools for dynamic measurement of supply chain performance. This paper sets up a comprehensive and systematic measurement system for enterprise supply chain around organization management, product quality management, cost management and logistics management, covering the whole life cycle of supply chain products. Then, combined with the four-layer architecture of the IoT technology, the overall architecture and implementation plan of the supply chain performance measurement system are sorted out based on the four functions of data collection, data transmission, data analysis and data service, indicating a clear path for the digital transformation of the supply chain and the construction of the measurement system.

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