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The Optimization of the Pay-per-use Model for the Healthcare Supply Chain

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Abstract: ***Implementing the pay-per-use method can reduce hospital reagent inventory expenses, resulting in significant cost savings. However, this purchasing method, which lacks the capability to determine the order quantity, increases cost risks for reagent suppliers due to extended payment cycles between hospitals and suppliers. This paper aims to optimize the medical supply chain management under the pay-per-use model through process reengineering of the settlement mechanism and demand forecasting. It proposed the Supply, Processing, and Distribution (SPD) model for the healthcare supply chain and conducted an analysis of issues within the hospital settlement model. The paper then used the BP neural network to forecast hospital demand under the pay-per-use model, which was validated using data from Hospital A. The model fit was 0.97 for the training set and 0.87 for the test set, demonstrating the feasibility of reengineering the pay-per-use model and the effectiveness of the demand forecasting model. This study investigates how to optimize the pay-per-use model in the healthcare supply chain with the goal of reducing supplier inventory costs. It focusses on cash flow issues caused by suppliers' inability to accurately forecast the demand for hospital reagents. It provides practical as well as theoretical insight on how to improve the efficiency of healthcare supply chains.***

Keywords: The pay-per-use method; The healthcare supply chain; The Supply, the Processing, and Distribution (SPD) model**.**

1. Introduction

The healthcare supply chain plays a vital role in ensuring the availability of medical supplies and pharmaceuticals, which is the second largest cost for hospitals after staffing expenses [1]. With rising global healthcare expenses, optimizing healthcare supply chain management is critical to enhancing operational efficiency and cost control. However, research indicates that the development of healthcare supply chains still lags behind that of commercial supply chains [2]. Traditional procurement and inventory management methods often result in either excess inventory or stockouts, both of which negatively impact the provision of healthcare services.

With the introduction of the pay-per-use model in the healthcare supply chain, hospitals have effectively reduced the cost of reagents. However, this model involves long payment cycles between hospitals and suppliers. If the accounts receivable cannot be recovered in time, it will further aggravate the cash flow tension of the enterprise, thus affecting the normal operation and development of the enterprise. Delayed receivables can exacerbate cash flow issues, affecting normal business operations and growth. The financial strain not only increases operational risks, but it may also force companies to rely on external financing to sustain cash flow, increasing financial costs and risk. Therefore, effectively managing and collecting receivables has become a critical challenge in financial management for businesses.

This paper optimizes the management of the pay-per-use model in healthcare supply chains by integrating demand forecasting. It specifically addresses the shortcomings of post-settlement processes by redesigning settlement workflows and using demand forecasting to help suppliers reduce inventory costs. The paper verifies the feasibility of incorporating demand forecasting into the pay-per-use model by analyzing data from Hospital A. The study illustrates the practical application of demand forecasting for increasing supply chain efficiency, reducing costs, and improving overall healthcare service. It also offers healthcare providers and supply chain managers practical management insights.

2. Analysis of Healthcare Supply Chain Settlement Models

2.1 The Supply, Processing, and Distribution Model for Healthcare Supply Chain

Test reagents are classified into various categories, including biochemical, immunological, glycemic, blood gas, antibodies, microbiological, drug sensitivity, blood cell analysis, and others, with thousands of items. Different categories have distinct storage and transportation requirements. Approximately half of these reagents have a shelf life of less than a year, which reduces further if reagents are imported from overseas or transferred through distribution networks before reaching hospitals. The requirements for hospital reagent management are high due to factors such as routine maintenance of testing equipment, demand, calibration requirements, and the ISO15189 certification for reagent lot expiration, which results in a change in the shelf life of reagents once opened. The reduction of hospital costs and the enhancement of efficacy continue to be difficult to achieve, despite the efforts to implement effective inventory management. Kazemzadeh et al. focused on the distribution of pharmaceuticals from wholesalers to clinics, providing a detailed analysis of the healthcare supply chain in developing countries. Their research indicates that optimizing inventory management and logistics processes can significantly reduce costs and improve supply chain efficiency [3]. However, this is insufficient, and the healthcare supply chain has been revitalized with the advancement of information technology. The Supply, Processing, and Distribution (SPD) model introduces information systems and smart devices, integrating suppliers with hospitals and clinical needs with specialized operations to create a lean management system.

This SPD model builds on the traditional centralized procurement approach of effective supply chain management to reduce operational costs and improve service quality [4]. It enables traceability throughout the entire distribution process for disposables, smart services within hospitals, and refined consumption settlement management. This significantly improves healthcare supply management's informational level and overall operational efficiency [5].

Yang et al. evaluated the hospital logistics management model based on the SPD approach. They investigated the impact of this model on hospital supply chain efficiency and operating costs, and discovered that under the SPD model, inventory management becomes more efficient, reducing inventory costs and improving supply chain management efficiency [6]. Furthermore, the SPD model can reduce inventory levels and minimize stockouts by optimizing inventory policies and employing vendor managed inventory (VMI) [7].

2.2 Hospital Settlement Methods under the SPD Model

In the traditional centralized procurement model, hospitals incur significant inventory costs. To determine the actual usage and estimate the next month's requirements, they must count IVD reagent inventories on a weekly or monthly basis. The laboratory initiates purchase requests on a weekly or monthly basis. After receiving the reagents, the laboratory conducts acceptance checks, stores them in refrigerators, scans and documents them, and confirms consumption. The purchasing department then receives invoices from suppliers, and the finance department finally processes them for payment.

Gap: This process is complex and time-consuming, resulting in high inventory costs and operational challenges [8]. According to Gao et al., this model for medical consumables frequently experiences inaccurate inventory forecasting, which leads to an excess or shortage of stock. This entails risks and uncertainties for the timely delivery of medical services [9]. Acharyulu and Shekbar proposed the application of value chain strategies in healthcare supply chain management. The research highlights that value chain strategies can significantly enhance supply chain efficiency and service quality while reducing operational costs. The pay-per-use model effectively addresses these issues [10]. This model allows hospitals to settle payments based on actual consumption, significantly reducing upfront financial pressure and inventory risks. Suppliers are responsible for regular replenishment and management of reagents, ensuring a continuous and stable supply to hospitals. Hospitals can use scanning or other digital means to monitor reagent consumption in real time and settle accounts on a monthly, quarterly, or longer basis [11]. This model has many advantages, including reducing the need for large inventory holdings, freeing up funds for more critical areas, reducing the risks of overstocking or stockouts caused by inaccurate forecasting, simplifying supply chain management processes, lowering management costs and operational complexity, and promoting refined and data-driven reagent management through real-time monitoring, which aids in cost control and decision-making [12]. In addition, the pay-per-use model is widely used in other industries. In manufacturing, it employs IoT technology and machine learning to improve usage measurement, allowing for more accurate depreciation assessments and enhancing the precision of pricing models [13].

Gap: The pay-per-use model not only significantly lowers inventory costs and enhances financial liquidity for hospitals, but it also places new financial and logistical management requirements on medical suppliers. Suppliers must effectively manage inventory costs and space utilization while maintaining service quality and response time. For supply chain management research, exploring how to optimize suppliers' inventory and logistics strategies while meeting hospital demands is crucial for achieving efficient operation of the supply chain under the pay-per-use model [14].

3. Modeling and Optimization of the Pay-per-use Model in Healthcare Supply Chain

Hospitals can adopt a two-step approach to move to a pay-per-use model. First, transition from the traditional supply model to the SPD model. More precisely, this involves collaboration between hospitals and healthcare suppliers to set up a reagent material management system.

Establishing Hardware Facilities

The hospital sets up an in-house service center that includes cold storage, ambient storage, and office areas, along with necessary hardware. Suppliers manage daily receipt, dispatch, barcode printing, labelling, and scanning of reagents in these facilities to ensure proper storage and management. They should establish a network infrastructure with dedicated lines and coordinate front-end systems to ensure stable system operation and smooth data transmission. Moreover, suppliers need to either allocate a new area or upgrade existing storage facilities to accommodate smart devices, as the subsequent phase involves the use of smart refrigerators or cold storage technology. To facilitate restocking and simple access for staffs, detailed space measurements and operational considerations must be conducted prior to the installation of smart refrigerators. After the area is planned, suppliers are responsible for warehouse renovations, which include the design of standard procedures and daily operations for the in-house service center, as well as security cameras, anti-theft measures, signage, and temperature monitoring.

Establish a Supporting Database

Data grooming includes preparing master data for coding and importing, as well as confirming and maintaining the inventory strategy to ensure data accuracy and system functionality. Suppliers assist the hospital in implementing a reagent information management system. This includes deploying the system, as well as creating order and invoicing interfaces with the hospital's material management system.

Establish the Business Processes

Create an online process for ordering, approving, and receiving reagents. First, clinical department reagent managers submit orders to the system for approval by team leaders. Suppliers then prepare the reagents according to the order and deliver them to the hospital. Finally, the supplier's staff verify and receive the goods upon their arrival, sign the delivery note and invoice, and apply unique codes to the reagents to ensure accurate tracing and management. Furthermore, 2-3 in-house service personnel are assigned to guarantee the timely delivery and management of reagents, thereby attaining an efficient distribution model.

The following step is to gradually transition the settlement model to a pay-per-use system after successfully transitioning to the SPD model and ensuring the stable operation of the procurement information system. This involves initially establishing monthly quotas based on rough estimates of reagent usage provided by hospital doctors.

The hospital upgrades RFID tags in its reagent refrigerators or cold storage units to streamline settlements and monitoring. RFID smart devices automatically record usage and manage settlements, enabling doctors to access reagents as needed.

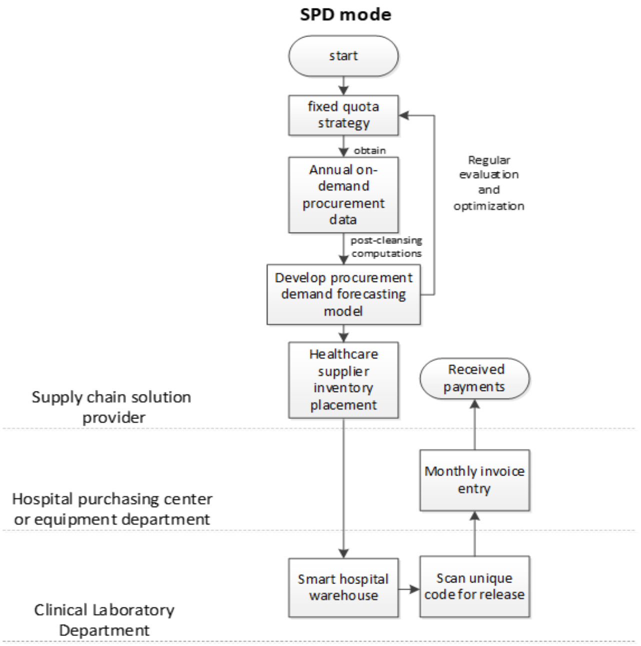

Figure 1: Business process optimization diagram for “pay-per-use model” under the SPD model

The previous strategy relied on subjective judgements by hospital staff, leading to the optimization of the procurement mode process based on the fixed number strategy process in the SPD mode (see Figure 1). By obtaining precise reagent usage data over a year and collaborating with the hospital’s equipment and information departments, a forecasting model can be built using data on resource consumption, reagent service levels, and financial conditions. Considering the periodic fluctuations in hospital demand, an initial analysis of reagent consumption data, inventory data, and related information over the past 12 months are conducted to establish a monthly inventory strategy. Based on the forecast results, a monthly procurement plan and safety stock levels are developed. A trial run is conducted to assess the effectiveness and make necessary adjustments. Regular evaluations and optimizations of the procurement strategy are performed to ensure its flexibility and accuracy. This approach facilitates a demand-driven usage system. The implementation of a data-driven monthly quantity strategy further enhances the efficiency and accuracy of supply chain management by delivering reagents to departments for receipt and settlement.

4. Demand Forecasting Based on the SPD Model

This study applies a BP neural network to forecast the demand for check reagents at Hospital A, providing a preliminary validation of its feasibility. Data from Hospital A covering January 2022 to December 2023 were collected, cleaned, and categorized. A hidden layer with 100 neurons was added to the model to enhance its learning capability. The model was run multiple times to select the optimal results, as illustrated in the Figure 2.

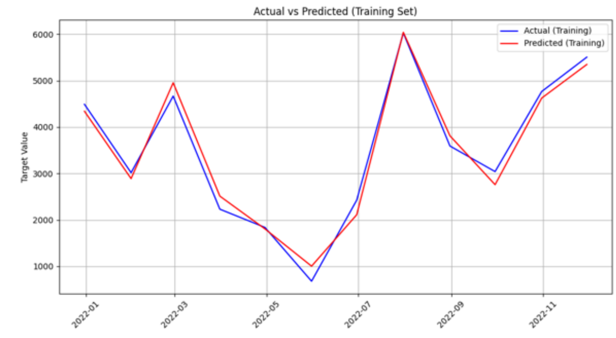

Figure 2(a): BP neural network training set

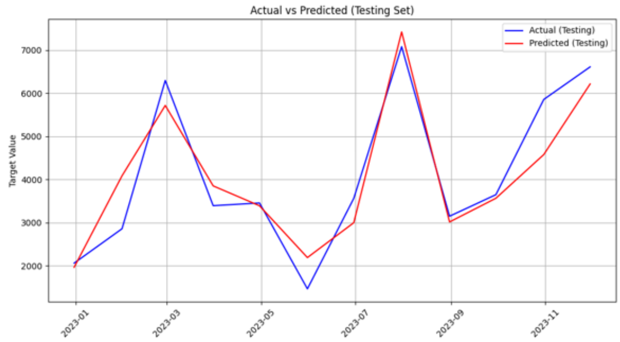

Figure 2(b): BP neural network test set

The actual number of iterations of the code was 165, achieving a training set MAPE (Mean Absolute Percentage Error) of 9.16% and a goodness of fit of 0.97. For the test set, the MAPE was 14.4% with a goodness of fit of 0.87. Given that BP neural networks require extensive data to improve prediction accuracy, the December data currently meet the preliminary demand forecasting objectives.

5. Conclusion

5.1 Contributions

This paper proposes an optimized pay-per-use settlement approach based on the existing settlement model for healthcare supply chains. This model effectively reduces initial financial stress and inventory risk for hospitals. By recording usage in real-time and settling accordingly, this model simplifies the supply chain management process and improve capital efficiency. The introduction of demand forecasting further enhances this model. By analyzing historical data and usage patterns, suppliers can more accurately forecast future demand, optimize inventory levels, and refine replenishment strategies. This minimizes cost wastage due to inventory surpluses or shortages and improves supply chain responsiveness and reliability. Verification with reagent data from Hospital A demonstrates the feasibility and effectiveness of demand forecasting within the pay-per-use model. The results indicate that the optimized approach significantly lowers inventory costs for suppliers, reduces material waste, ensures timely availability of reagents for clinical departments, and improves overall supply chain management efficiency. Both hospitals and suppliers benefit from reduced costs, enhanced operational efficiency, and improved service levels.

5.2 Implication for Policy and Practice

This study identifies that the current hospital procurement model faces issues with inventory costs, often resulting in either excess inventory or shortages. Requiring laboratory staff to determine reagent demand themselves has a significant negative impact on efficiency, creating risks and uncertainties for the timely provision of medical services [14]. Accurate demand forecasting can reduce the high inventory costs associated with over-purchasing by medical suppliers, prevent disruptions in testing services due to supply shortages, and eliminate the high inventory holding costs of traditional supply models, thus improving capital turnover efficiency. Moreover, analyzing historical data can reveal the underlying patterns and influencing factors of reagent demand, providing valuable decision support for hospital management and guiding strategic planning for laboratory development. The practical findings of this research offer valuable references and practical guidance for medical institutions and the broader healthcare sector in forecasting IVD reagent demand, especially within the context of the pay-per-use model, thus advancing the development of smart healthcare.

5.3 Research Directions

The implementation of the pay-per-use model can enhance service levels and reduce inventory costs for suppliers. Following an analysis and optimization of the current healthcare supply chain management model, inventory transfer alone is insufficient to address the issues [15]-[16]. Given the time constraints and experimental conditions, this research has the potential for further development and refinement.

1) Diversification and in-depth comparison of models: Although BP neural network forecasting methods were used in this study for the initial comparative analysis, future research could incorporate more advanced forecasting models, such as deep learning or time series analysis, for broader comparison experiments. Increasing the granularity from monthly to weekly data could enhance prediction accuracy and provide additional perspectives and depth in this field of study.

2) Meticulous correlation between reagents and testing items: This study simplified the relationship between reagents and testing programs. Future research should consider the proportion of primary to secondary reagents and the need for equipment calibration during reagent use. This detailed analysis will improve the accuracy and practical value of demand forecasting.

3) Improvement of data quality and comprehensiveness: Due to data limitations and unavoidable errors, there is still room for improvement in current forecasting efforts. Future research should expand the indicators for demand forecasting, incorporating factors such as seasonal variations and market trends, to build a more accurate and comprehensive forecasting model.

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