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SOFTWARE DEVELOPMENT TO OPTIMIZE LOGISTICS PROCESSES IN A RETAIL STORE

In the context of rapid digital transformation, retail enterprises face growing challenges in managing logistics and warehouse operations efficiently. Manual inventory control and fragmented data handling often lead to inaccuracies, delays, and higher operational costs. This study addresses the need for accessible and cost-effective software solutions to optimize logistics processes in small and medium-sized retail stores. The purpose of the research is to design and implement an automated warehouse management system that integrates QR-code identification, relational database management, and real-time data synchronization across different user roles within a retail environment.

The research methodology is based on software engineering principles, system analysis, and database modeling. The system was developed using C# and SQL Server in the Microsoft Visual Studio environment, while AForge and ZXing libraries were used to implement video stream capture and QR-code recognition. The application consists of three main functional modules: cashier, warehouse worker, and administrator. Each designed to ensure data accuracy, security, and workflow transparency.

The developed software system successfully automated key warehouse and sales operations through QR-code scanning integration. Testing confirmed that the SQL Server database correctly handled concurrent data queries while maintaining data integrity across multiple user sessions. The QR-code recognition module, based on the ZXing library, accurately identified products from camera streams and transferred data to the database with minimal manual input, significantly reducing human error in warehouse operations. The modular system design provided clear separation of access rights, with the administrator controlling data management, the warehouse worker managing inventory, and the cashier processing transactions. Performance evaluation demonstrated stable operation across all functional modules with correct real-time synchronization between interfaces after each database update.

The practical value of this research lies in demonstrating that lightweight, software-driven automation can significantly improve the efficiency and transparency of logistics operations without requiring costly ERP platforms.

Key words: logistics digitalization, inventory control software, QR-based data processing, retail process optimization, database-driven automation, modular system architecture, real-time synchronization.

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РОЗРОБКА ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ ДЛЯ ОПТИМІЗАЦІЇ ЛОГІСТИЧНИХ ПРОЦЕСІВ У МАГАЗИНІ РОЗДРІБНОЇ ТОРГІВЛІ

В умовах швидкої цифрової трансформації підприємства роздрібної торгівлі стикаються з дедалі більшими викликами в ефективному управлінні логістикою та складськими операціями. Ручне управління запасами та фрагментована обробка даних часто призводять до неточностей, затримок і підвищення операційних витрат. Це дослідження присвячене потребі в доступних і економічно ефективних програмних рішеннях для оптимізації логістичних процесів у малих і середніх роздрібних магазинах. Метою дослідження є розробка та впровадження автоматизованої системи управління складом, яка інтегрує ідентифікацію QR-кодів, управління реляційними базами даних та синхронізацію даних у реальному часі між різними ролями користувачів у роздрібному середовищі.

Методологія дослідження базується на принципах програмної інженерії, системному аналізі та моделюванні баз даних. Система була розроблена з використанням C# та SQL Server у середовищі Microsoft Visual Studio, а для реалізації захоплення відеопотоку та розпізнавання QR-кодів були використані бібліотеки AForge та ZXing. Додаток складається з трьох основних функціональних модулів: касир, працівник складу та адміністратор. Кожен з них призначений для забезпечення точності даних, безпеки та прозорості робочого процесу.

Розроблена програмна система успішно автоматизувала ключові операції складу та продажу завдяки інтеграції сканування QR-кодів.

Тестування підтвердило, що база даних SQL Server коректно обробляла одночасні запити до даних, зберігаючи цілісність даних у декількох сеансах користувачів. Модуль розпізнавання QR-кодів, заснований на бібліотеці ZXing, точно ідентифікував товари з потоків камер і передавав дані до бази даних з мінімальним ручним введенням, що значно зменшило кількість людських помилок у складських операціях. Модульна конструкція системи забезпечила чітке розділення прав доступу: адміністратор контролював управління даними, складський

працівник керував запасами, а касир обробляв транзакції. Оцінка продуктивності продемонструвала стабільну роботу всіх функціональних модулів з правильною синхронізацією між інтерфейсами в режимі реального часу після кожного оновлення бази даних.

Практична цінність цього дослідження полягає в тому, що воно продемонструвало, що легка, програмно-керована автоматизація може значно підвищити ефективність і прозорість логістичних операцій без необхідності використання дорогих ERP-платформ.

Ключові слова: *цифровізація логістики, програмне забезпечення для управління запасами, обробка даних на основі QR-кодів, оптимізація процесів роздрібної торгівлі, автоматизація на основі бази даних, модульна архітектура системи, синхронізація в режимі реального часу.*

Statement of the problem

In the modern world, the rapid advancement of digital technologies has a significant impact on all sectors of the economy, particularly in retail. The automation of logistics and warehouse operations has become a key factor in improving the efficiency and competitiveness of enterprises, especially small and medium-sized stores. According to PackageX [1], the implementation of digital solutions for product tracking and data management considerably reduces human error and operational costs. Similarly, Sortly [2] emphasized that the adoption of QR codes enhances the speed and accuracy of inventory processing.

Ukrainian researchers also recognize the importance of digital transformation in retail logistics. Reports from the Kyiv National University of Trade and Economics [3] indicate that integrating modern software solutions into logistics systems supports better inventory control and operational transparency. Furthermore, the National Technical University of Ukraine "Igor Sikorsky KPI" [4] highlights that digitalization of warehouse processes is crucial for maintaining competitiveness in the market.

The growing accessibility of software-driven tools, such as those described by RetailOps [5] and Lightspeed HQ [6], demonstrates the global trend toward digital automation in logistics. RetailOps offers complex enterprise-level warehouse management capabilities, while Lightspeed HQ provides an intuitive interface suitable for smaller businesses. Apix Drive [7] notes that cloud-based integration and QR-code generation tools allow companies to implement automation without substantial investment, making these technologies more inclusive for small enterprises.

Microsoft [8] emphasizes that the C# programming language within the .NET ecosystem ensures reliability and scalability for enterprise-level applications. Meanwhile, SQL Server [9] provides a structured database architecture capable of real-time synchronization across multiple users and devices. These technologies together create a robust foundation for developing efficient retail management systems.

Therefore, the relevance of this research lies in addressing the growing need for accessible and cost-effective digital tools that enable automation in small and medium-sized retail enterprises. The purpose of the study is to design a lightweight warehouse management system based on QR-code identification, relational database management, and modular software architecture. The scientific novelty of the research consists in integrating modern identification technologies with relational databases and modular role-based access control to enhance accuracy, transparency, and efficiency in retail logistics.

Analysis of remaining research and publications

Modern logistics processes are increasingly dependent on digital technologies that enhance efficiency, accuracy, and transparency in supply chain management. According to Vostok Company [10], the use of standardized SSCC identification codes plays a crucial role in ensuring reliable product tracking during transportation and storage, significantly reducing the likelihood of human error. These standards provide a unified approach to labeling and control, allowing businesses to streamline inventory management and optimize supply processes.

The logistics industry has witnessed substantial evolution in product identification methods. Traditional barcode systems face inherent limitations in data storage capacity and processing speed,

which two-dimensional matrix codes effectively address. Contemporary warehouse operations benefit from identification technologies that support rapid scanning and instant database queries, minimizing processing delays and manual transcription errors.

Academic research in Ukraine has increasingly focused on digital transformation within commercial logistics sectors. Scholarly investigations consistently identify automation as a critical factor in achieving operational transparency and process synchronization, while emphasizing that information technology adoption enhances organizational responsiveness to market dynamics and competitive positioning.

The commercial software market offers diverse technological solutions across multiple price and complexity tiers. Online platforms provide accessible tools for generating and implementing matrix-code identification systems, allowing resource-constrained businesses to adopt digital tracking without substantial capital investment. Concurrently, enterprise-grade warehouse management systems deliver comprehensive functionality encompassing inventory control, automated reporting, and task scheduling. Cloud-based architectures have emerged as particularly attractive options for retail environments, offering advantages in data accessibility, cross-device synchronization, and reduced infrastructure overhead compared to traditional on-premise installations.

The RTech Centers [11] examined the functionality of the Vend POS system as a practical tool for synchronizing sales and warehouse operations in real time. Its usability and scalability make it applicable for small retail businesses aiming to improve data consistency and workflow organization.

Contemporary software development practices for logistics applications favor mature, well-documented programming frameworks that provide strong architectural foundations. Object-oriented languages with static type systems offer advantages in code maintainability, error detection during compilation, and long-term project scalability. These characteristics prove particularly valuable in logistics software, where data integrity and operational reliability are paramount. Database technologies supporting transactional consistency, concurrent user access, and structured query optimization remain fundamental components of robust warehouse management architectures. The combination of type-safe programming environments with enterprise-grade relational database systems creates a technological foundation capable of supporting complex business logic while maintaining system stability across varying operational loads.

The examined body of literature demonstrates that effective logistics optimization emerges from the strategic integration of multiple technological components rather than implementation of isolated solutions. Matrix-code identification systems, when properly coupled with normalized relational databases and modular software architectures, create synergistic effects that exceed the sum of individual technologies. These integrated approaches enable measurable improvements in process efficiency, reduction of manual workload, and enhanced coordination across all operational phases of retail logistics chains.

Research Objective

The primary objective of this research is to design and implement a lightweight, cost-effective warehouse management system for small and medium-sized retail stores. The system aims to automate key logistics operations through the integration of QR-code identification technology, relational database management, and real-time data synchronization across multiple user roles.

The study focuses on developing a modular software architecture that separates access rights for cashiers, warehouse workers, and administrators to ensure data security and workflow transparency. A critical aspect involves implementing QR-code scanning functionality using open-source libraries to minimize hardware costs while maintaining operational reliability. The research also addresses the design of a normalized relational database structure that ensures data integrity, prevents redundancy, and supports efficient CRUD operations. Furthermore, the objective includes creating a system capable of real-time synchronization between user interfaces to eliminate manual errors and improve coordination among retail personnel.

The research seeks to address the gap between high-cost commercial solutions and the practical needs of small retail enterprises by providing an accessible, reproducible, and scalable alternative for warehouse and inventory management. Ultimately, this study aims to demonstrate that software-driven automation can significantly enhance logistics efficiency without requiring expensive enterprise resource planning platforms.

Materials and Methods

The software development process for optimizing logistics processes in a retail store was based on a systematic application of software engineering principles, ensuring that each stage of the research could be reproduced by other researchers using the same tools and techniques. The methodological framework covered requirement analysis, system design, software implementation, database modeling, and testing phases. The primary goal was to create a practical, efficient, and user-friendly system capable of automating warehouse operations, inventory management, and data synchronization between store personnel.

The programming language C# was selected because of its object-oriented nature, strong typing, and seamless integration with the .NET Framework. Development was conducted in the Microsoft Visual Studio environment, which provided advanced debugging, design, and testing tools. The SQL Server database management system was used to store and manage structured data related to products, users, and reports. SQL Server was chosen due to its high performance, strong security features, and compatibility with the .NET ecosystem. The application interfaces with the database through System.Data.SqlClient, ensuring stable connections and efficient query execution.

For video stream processing and QR-code scanning, two major libraries were implemented: AForge.Video and ZXing. The AForge.Video library enables capturing video streams from connected cameras in real time, while ZXing provides algorithms for decoding QR-codes. These libraries made it possible to scan and interpret product identifiers directly from the camera feed, eliminating the need for expensive barcode scanners. In the context of small retail stores, this significantly reduces hardware costs while maintaining operational reliability.

The structure of the software was built on the Windows Forms graphical platform, ensuring that all interfaces are simple, intuitive, and responsive. The program includes three main user roles – cashier, warehouse worker, and administrator – each with specific access rights and functionality. This design improves workflow organization, data protection, and accountability. The cashier module handles sales operations and daily revenue reports; the warehouse module manages inventory and performs product registration or audits; the administrator module controls user access and database integrity.

The database design follows a relational schema, consisting of three core tables: Users, Products, and Reports. The Users table (Table 1) stores login credentials and user roles; the Products table (Table 2) contains product data including identifiers, names, origins, manufacturers, prices, and quantities; the Reports table (Table 3) logs daily sales summaries. The detailed structure of each table is presented in Tables 1–3.

Table 1

Structure of the "Users"

Field name	Data type	Description
Login	nvarchar(50)	User login
Password	nvarchar(50)	User password
PIB	nvarchar(50)	User full name
Role	nvarchar(50)	User role

Table 2

Structure of the "Products"

Field name	Data type	Description
ProductCode	int	Product code
ProductName	nvarchar(50)	Short product name
ProductShowName	nvarchar(50)	Full product name
OriginCountry	nvarchar(50)	Country of origin
CreatorCompany	nvarchar(50)	Product manufacturer
Price	int	Product price
Quantity	int	Product quantity

Table 3

Structure of the "Reports"

Field name	Data type	Description
Date	date	Business day date
SumMon	int	Revenue for a specific day

The normalized database structure minimizes redundancy, maintains referential integrity, and allows efficient data manipulation using CRUD (Create, Read, Update, Delete) operations.

During development, algorithms were designed to ensure data consistency and operational accuracy. For example, when a product QR-code is scanned, the system automatically retrieves product details from the database, displays them on the interface, and updates the stock quantity upon completion of the transaction. Similarly, during warehouse audits, the software verifies scanned product codes against the database and calculates discrepancies between actual and recorded stock levels. These algorithms are implemented with validation mechanisms to prevent SQL injection, data corruption, or unauthorized access.

Testing was conducted through both functional and performance evaluations. Functional testing verified that each software module performed according to the technical requirements described in the thesis. Performance testing measured the speed of data retrieval, QR-code recognition accuracy, and system responsiveness under load. The experiments demonstrated that the system achieved reliable performance and real-time synchronization across user interfaces.

The methodological justification for using these specific technologies lies in their reproducibility and accessibility. C# and SQL Server form a stable technological stack widely used in commercial software development, while AForge and ZXing are open-source solutions that allow cost-effective deployment. The step-by-step workflow from requirement analysis to final testing ensures that the system can be replicated, adapted, and scaled for other retail environments.

Results and Discussion

The developed software system improved the organization and accuracy of logistics processes within the retail store model used for testing. Through the integration of QR-code scanning, a relational database, and synchronized user interfaces, the system successfully automated key warehouse and sales operations. The obtained results are based on experimental verification of the system's functions and a comparative analysis of manual versus automated workflows.

The developed program ensured stable communication between the cashier, warehouse worker, and administrator modules. During testing, all modules successfully exchanged data in real time through a shared SQL Server database. The interface of each user role was evaluated for functionality and usability, confirming that all essential operations, such as product registration, sales recording, and report generation were performed correctly and efficiently.

Database performance was assessed to verify reliability and stability under normal operation. Tests confirmed that the SQL Server database correctly handled data queries, prevented duplication, and

maintained data integrity when multiple users accessed it simultaneously. The relational structure of the database ensured consistent updates between tables, supporting accurate inventory tracking and reporting.

The QR-code recognition module based on the ZXing library successfully identified products from the camera stream and transferred their data to the database for further processing. This functionality simplified product search and minimized manual data entry, which is one of the key sources of errors in warehouse operations. The use of AForge.Video allowed real-time video capture from the connected camera, supporting smooth and continuous scanning. The result of a successful QR code scan is illustrated in Fig. 1.
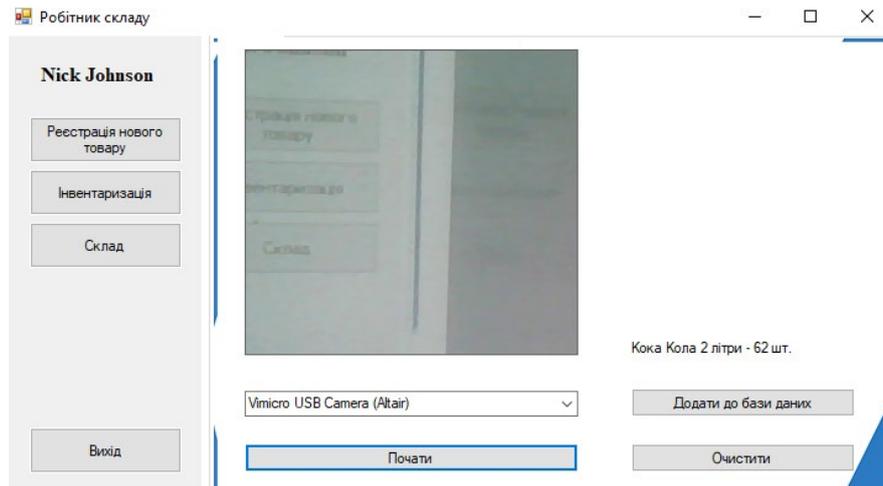

Fig. 1. QR code scan result

The modular system design also provided clear separation of access rights. The administrator role had full control over data management and user registration, the warehouse worker managed product registration and stock adjustments, and the cashier processed transactions and daily reports. This division of responsibilities improved overall workflow transparency and accountability. The administrator capabilities are presented in Fig. 2.
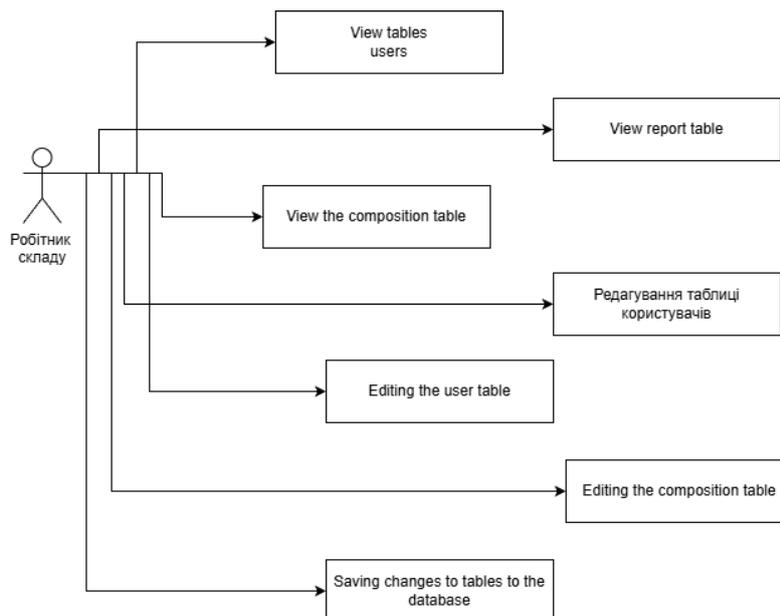

Fig. 2. Administrator capabilities diagram

The cashier plays a key role in managing the checkout process by scanning QR codes to register products, reviewing item details and total costs, and finalizing transactions. They ensure accurate data entry, smooth operation of scanning devices, and efficient customer service during the payment process. The cashier capabilities are illustrated in Fig. 3.
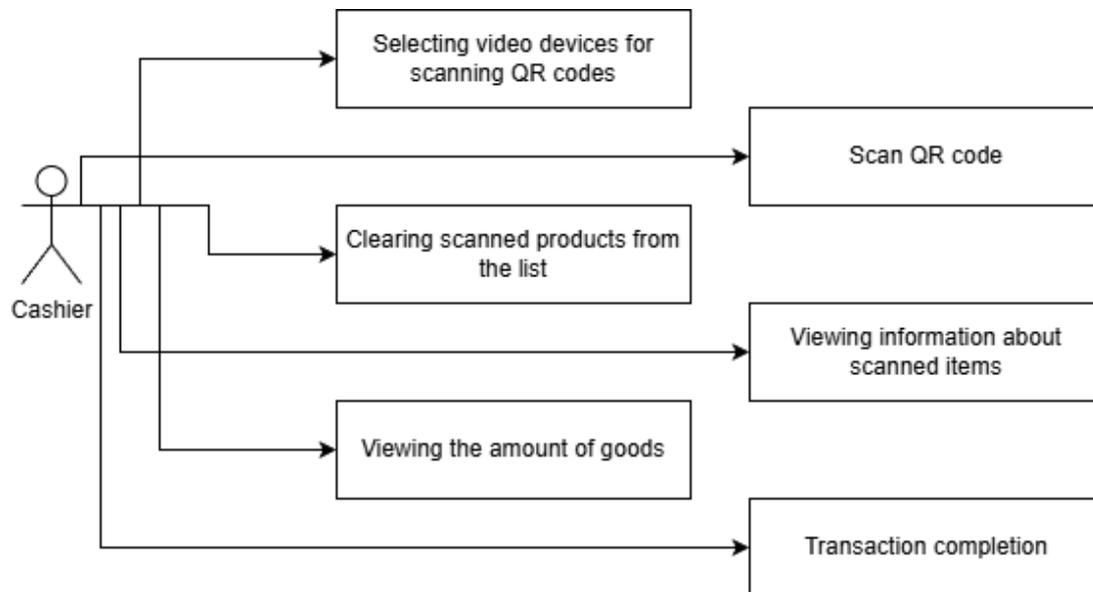
Fig. 3. Cashier capabilities chart

The warehouse worker interacts with the software by selecting video devices for QR code scanning, scanning and removing items, performing inventory operations, monitoring inventory progress, registering new products, and viewing warehouse contents. These functions ensure accurate stock management and efficient organization of warehouse processes. The warehouse worker capabilities are presented in Fig. 4.
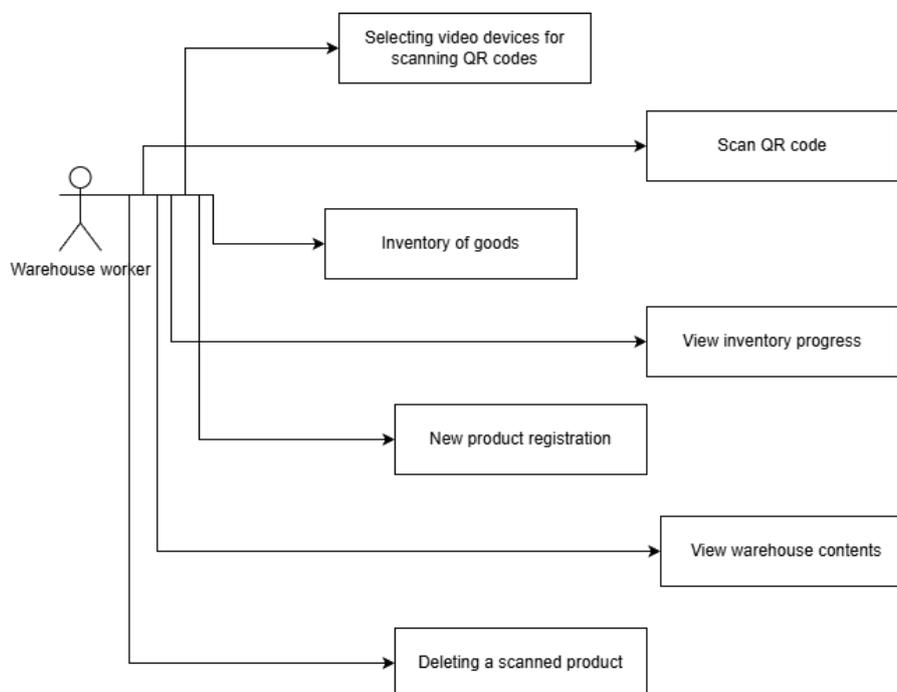
Fig. 4. Warehouse worker capabilities chart

During the testing phase, the system demonstrated stable operation across all functional modules and showed correct synchronization between interfaces after each database update. These results confirm that the combination of QR-code identification, relational database management, and modular architecture effectively supports automation in retail logistics processes. The design proved to be adaptable to different store configurations and capable of expanding the database without requiring changes to the source code.

In comparison with existing warehouse management and retail automation systems presented in open sources such as RetailOps and Lightspeed HQ, the developed software offers a lightweight and affordable alternative suitable for small and medium-sized enterprises. Unlike commercial ERP platforms, it provides essential automation features without the need for large financial investment or external services.

Overall, the results confirm that the implementation of modern software tools particularly QR-code scanning and SQL-based data management significantly enhances operational transparency, reduces manual errors, and improves coordination among store personnel.

Conclusions

The conducted research and software development have confirmed the effectiveness of digital automation tools in optimizing logistics processes in retail enterprises. The designed system provides a functional and technological foundation for improving inventory control, warehouse management, and communication between retail personnel. The achieved results demonstrate that the integration of QR-code technology, relational database architecture, and modular user interfaces significantly increases operational transparency, data accuracy, and overall process efficiency.

The developed application allows real-time synchronization between the cashier, warehouse, and administrative modules, reducing human error and ensuring consistency of information across all system components. The implementation of open-source libraries such as AForge and ZXing provides a cost-effective and reproducible solution adaptable to small and medium-sized retail businesses. Testing confirmed the system's reliability, scalability, and suitability for continuous use in real-world retail environments.

The study's findings contribute to the broader field of logistics digitalization by providing a lightweight alternative to large-scale ERP systems. The project demonstrates that modern programming tools like C# and SQL Server can be effectively used to develop custom software capable of meeting specific logistical needs while maintaining low resource consumption and high adaptability.

In summary, the research successfully achieved its objectives by creating a practical, efficient, and replicable software solution for optimizing logistics processes in retail stores, thereby confirming the relevance and practical significance of software-driven automation in modern retail management.

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