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MOLCHANOV BOHDAN
Kyiv National University of Technologies and Design
https://orcid.org/0000-0002-4633-9654
e-mail: molchanovbohdan@gmail.com

USAGE OF MACHINE LEARNING IN INVENTORY AND WAREHOUSE MANAGEMENT SYSTEMS

The management of inventory and warehouse is a critical component of supply chain operations. This article explores the impact of machine learning on inventory and warehouse management systems. This research is important because machine learning is gaining increasing recognition for its potential to increase operational efficiency and accuracy across industries.

The purpose of this research is to examine the hypothesized potential of implementing machine learning to solve challenging problems in inventory management systems in an attempt to improve their efficiency. In addition, the study aims to evaluate current applications of these capabilities to provide a basis for future research.

The research is grounded in a comprehensive review of existing literature on the use of machine learning in inventory and warehouse management. To explore practical implementations, the study also analyses how leading companies have integrated machine learning into their products.

The result of this study is a review of existing research and practical applications of machine learning in inventory and warehouse management. This paper provides a detailed analysis of how machine learning can be used to improve demand forecasting, inventory levels, warehouse planning, and order fulfillment processes. This material serves as a basis for further study and research in this area.

The scientific novelty of this research is the study of machine learning methods applied to inventory and warehouse management. The study expands the understanding of how machine learning can be used to solve problems in these areas.

The practical implications of the research provide a basis for the implementation of mentioned technologies in enterprises. Firstly, the study highlights the potential for significant cost savings, efficiency gains, and increased customer satisfaction. Secondly, it offers valuable material for further research in supply chain management.

Keywords: machine learning, inventory management, warehouse optimization, demand forecasting, supply chain efficiency.

МОЛЧАНОВ БОГДАН
Київський національний університет технологій та дизайну

ВИКОРИСТАННЯ МАШИННОГО НАВЧАННЯ У СИСТЕМАХ УПРАВЛІННЯ ЗАПАСАМИ І СКЛАДОМ

Управління запасами та складами є критично важливим компонентом операцій ланцюга поставок. У цій статті досліджується вплив машинного навчання на системи управління запасами та складами. Це дослідження є важливим, оскільки машинне навчання набуває все більшого визнання завдяки своєму потенціалу для підвищення операційної ефективності та точності в різних галузях промисловості.

Метою цього дослідження є вивчення теоретичного потенціалу застосування машинного навчання для вирішення складних проблем в системах управління запасами з метою підвищення їхньої ефективності. Крім того, дослідження спрямоване на оцінку поточних застосувань цих можливостей, щоб забезпечити основу для майбутніх досліджень.

Дослідження ґрунтується на всебічному огляді існуючої літератури про використання машинного навчання в управлінні запасами та складами. Для вивчення практичних реалізацій в дослідженні також проаналізовано, як провідні компанії інтегрували машинне навчання у свої продукти.

Результатом цього дослідження є огляд існуючих досліджень і практичних застосувань машинного навчання в управлінні запасами і складами. У цьому документі детально проаналізовано, як машинне навчання може бути використане для оптимізації прогнозування попиту, рівня запасів, планування складів та процесів виконання замовлень. Цей матеріал слугує основою для подальшого вивчення та досліджень у цій галузі.

Наукова новизна цього дослідження полягає у вивченні методів машинного навчання, що застосовуються до управління запасами та складом. Дослідження розширює розуміння того, як машинне навчання може бути використане для вирішення проблем у цих сферах.

Практичне значення дослідження створює основу для впровадження згаданих технологій на підприємствах. По-перше, дослідження підкреслює потенціал для значної економії витрат, підвищення ефективності та підвищення рівня задоволеності клієнтів. По-друге, воно пропонує цінний матеріал для подальших досліджень у сфері управління ланцюгами поставок.

Ключові слова: машинне навчання, управління запасами, оптимізація складу, прогнозування попиту, ефективність ланцюга поставок.

Introduction

A recent study released by the Archives of Computational Methods in Engineering [1] reveals the innovative impact of machine learning (ML) on warehouse and inventory management. The study shows that the implementation of ML algorithms can lead to considerable improvements, such as minimizing of human errors, reduction of labor costs and optimizing cash flow and order fulfilment operations. In this article, we will explore how machine learning is transforming warehouse operations, creating more efficient and cost-effective systems.

Modern businesses are increasingly relying on technology to enhance their inventory management. Modern software automates important tasks such as order tracking and inventory level monitoring, increasing accuracy and operational effectiveness [2]. The real-time data enables better decision-making, and digital storage improves collaboration and analytics. The integration of inventory management systems with other emerging technologies further simplifies operations and drives success.

However, inventory and warehouse management still faces issues related to varying demand, supply chain disruptions, and user error. Machine learning offers a reliable solution to these problems, ushering in a new era of

adaptability and efficiency in warehouse management. By analyzing huge amounts of data and learning from its patterns, ML improves existing technology tools by providing predictive information, automating decisions, and adapting to changes in real time. This not only increases operational effectiveness, but also supports long-term strategic planning and business expansion.

What Machine Learning Can Do in The Area

Machine learning, an emerging branch of artificial intelligence (AI), offers opportunities that go far beyond basic automation. Unlike conventional programming, which relies on clear guidelines, ML algorithms can handle large amounts of data and learn from patterns on their own [3].

Machine learning works through a structured, multi-step approach. It starts with data acquisition, where relevant information is gathered from a variety of channels, including sales data, stock levels, warehouse scheduling details, and even external variables such as weather conditions and market trends [4].

After the data is collected, it undergoes pre-processing. This important stage includes cleaning the data to eliminate any inconsistencies or errors, handling missing values by converting the data into a format that can be efficiently processed by ML algorithms.

The next step is to prepare the model. At this stage, pre-processed data is fed into a ML algorithm. The algorithm analyzes the data, identifies the main patterns, and adjusts its parameters to optimize performance. This learning process is iterative, meaning that the model continues to improve as it receives more data and feedback.

When the model is trained, it needs to be validated to measure its performance. This requires testing the model against a separate dataset, known as a validation or testing set, which the model had not previously encountered. By comparing the model's predictions with actual results, its accuracy and efficiency can be measured.

When model performance meets the required standards, it is deployed into production. This involves incorporating the model into existing inventory and warehouse management systems, enabling it to process new data in real time. By making predictions and offering actionable insights, the model supports and enhances decision-making.

A diagram of the machine learning implementation process is shown in Figure 1 below.

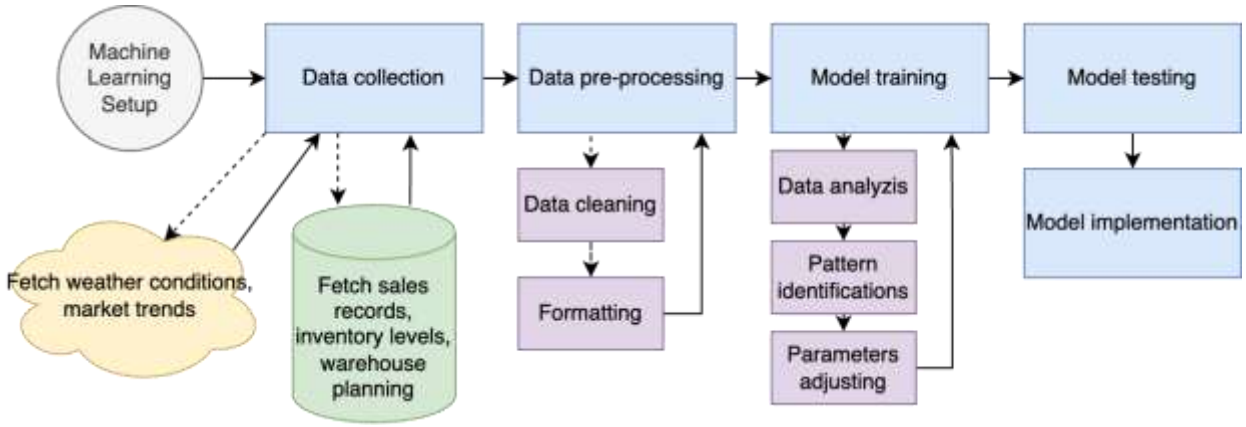

Fig. 1. A diagram of the machine learning implementation process

In the field of inventory and warehouse management, ML may improve and automate numerous aspects. For example:

- Demand forecasting;
- Inventory optimization;
- Anomaly Detection;
- Order Fulfillment Optimization;
- Warehouse Layout Optimization;
- Supply Chain Optimization;
- Predictive Maintenance.

Demand forecasting is the process of predicting what customers' appetite for existing products or services will be, determining what adjustments should be made and what new offers will generate interest [5].

ML in demand forecasting allows businesses to bypass traditional planning challenges such as long delivery times, high shipping costs, excess inventory and inaccurate forecasts that can lead to incorrect decisions [6]. Using sophisticated mathematical algorithms, ML-based demand forecasting automatically detects patterns, captures demand signals, and recognizes complex relationships in large data sets.

This advanced approach contributes to increased customer satisfaction. By more accurate forecasting of future demand levels and material requirements, companies can optimize inventory management, production planning, and supply chain logistics. That leads to improved service levels, reduced inventory shortages, and minimized overstock situations, ultimately improving the overall customer experience.

In today's fast-changing marketplace, where customer expectations and preferences are changing rapidly, a deep understanding of customer demand is paramount to making informed decisions across all business functions [6].

From marketing spend allocation to procurement strategies, from production planning to transportation logistics, accurate demand forecasting is the key to efficient resource allocation and strategic decision-making.

In addition, accurate demand forecasting plays a key role in shaping key business metrics such as turnover, capital expenditures, risk assessment, profitability, cash flow, and production planning. By providing reliable information about future demand trends, ML-based demand forecasting enables companies to make informed predictions about overall sales and revenue, thereby contributing to more reliable financial planning and performance measurement.

Inventory optimization is a strategic management process which ensures that the right products are available in the right quantity and at the right time [7]. It balances supply and demand, reduces inventory holding costs, and increases customer satisfaction [7]. The process involves demand forecasting, advanced inventory management techniques, and data-driven analysis to ensure operational efficiency and greater profitability [7].

Inventory optimization is about finding the right balance between having enough products to meet customer demand and avoiding the headaches associated with excess inventory. It's also managing healthy cash flow when you sell enough products without holding inventory that ties up your working capital.

ML can help optimize various aspects of inventory management. For example, it can determine the optimal amount of each product to keep in stock based on factors such as demand patterns, lead times, and storage costs.

Anomaly detection is a critical task because it helps to identify unusual events and abnormal behavior in the data coming from sensors [8]. It is a process of identifying data points that deviate significantly from the expected norm, which can include identifying unusual fluctuations in inventory levels, unexpected spikes in picking times, or potential security breaches.

Anomalies can indicate malfunctioning system sensors, hardware malfunctions, or potential security threats that need to be addressed immediately [8].

Order fulfillment logistics requires a complex arrangement of warehouse organization, product selection and packaging, and reverse logistics [9]. The complete order lifecycle consists of five main stages, beginning with strategic sourcing and finishing with shipping. Most companies use inventory and supply chain management, order fulfillment, quality assurance, and client support as part of the order fulfillment process.

ML can select the optimal path to fulfill orders quickly and accurately. Shortest path optimization ensures fast order fulfillment, while storage optimization and consistency ensure low return rates.

Moreover, ML can determine the optimal quantity of each product to keep in stock based on factors such as demand patterns, lead times, and transportation costs.

Warehouse layout optimization is the strategic design of a warehouse to maximize space and streamline the movement of goods, ultimately boosting efficiency and reducing costs.

The warehouse layout project is presented in the form of a diagram showing the different areas of the facility and the location of storage systems. This has two clearly defined goals: to maximize the use of available space and to increase operational throughput.

Optimizing warehouse layout reduces labor costs, improves warehouse organization, and increases productivity and efficiency. Since warehouse layouts can vary in size, shape, and functionality, it is best to follow some general optimization steps and practices. These include space assessment, vertical space utilization, selecting the right equipment, reducing labor-intensive applications, using a warehouse management system, optimizing warehouse space, and warehouse automation.

ML can play an important role in warehouse planning optimization by offering valuable business insights to optimize warehouse planning.

For example, a study by Alessandro Tufano, Riccardo Accorsi and Riccardo Manzini delves into the use of ML for predictive warehouse design [10]. They developed classifiers trained to predict various aspects of warehouse systems, including storage technology, material handling systems, warehouse space allocation strategies, and picking policies. In their research, they introduced the concept of a training table that includes benchmarking metrics applicable to any storage system and studied how data availability in warehouse management systems affects prediction accuracy.

ML can also optimize the placement of goods based on factors such as size, weight, and demand to increase the efficiency of warehouse space utilization.

The supply chain in the warehouse and inventory control includes the transportation of goods from vendors to consumers. It includes various stages such as sourcing, production, storage, and distribution [11].

Special sensors can be integrated into ML to monitor inventory levels, shipment locations, and potential supply chain disruptions in real time. By analyzing historical data and external factors, ML can identify potential risks such as delays, shortages, or quality issues. It can also analyze traffic patterns, weather conditions, and fuel efficiency to recommend the most efficient routes for transportation, resulting in shorter delivery times and lower costs.

ML algorithms can be trained on historical data to establish a baseline for typical warehouse operations. These algorithms can then continuously monitor the data in real time and identify any significant deviations from the norm, flagging potential anomalies.

It excels at recognizing complex patterns in data [12]. This allows it to detect minor anomalies that may be missed by manual methods, such as gradual changes in equipment operation or unusual access patterns in a warehouse [12].

By analyzing sensor data from warehouse equipment, ML can predict potential malfunctions before they occur. This allows for preventive maintenance, avoiding costly downtime and ensuring uninterrupted operations.

In addition to anomaly detection, **predictive maintenance** is an approach that uses time-series data and ML techniques to predict when maintenance should be performed on machines or equipment [13]. Using historical data, sensor data, and advanced analytics, predictive maintenance aims to identify potential malfunctions or problems before they occur, allowing you to take proactive maintenance measures and minimize downtime and costly repairs [13].

Predictive maintenance is one of three key maintenance strategies used by businesses, alongside reactive maintenance, which addresses issues as they arise, and preventive maintenance, which follows a set schedule to check for potential faults [13]. Unlike preventive maintenance, predictive maintenance offers a more proactive approach by continuously monitoring the real-time condition of equipment, rather than depending on historical data or expected performance. This allows for more accurate insights into the actual state of machinery, improving reliability and reducing downtime [13].

Analyzing data from sensors embedded in equipment, as well as other sources like historical maintenance records and operational logs, ML algorithms can identify subtle changes that may precede equipment failures. These early warning signs allow for preventive maintenance to be scheduled, avoiding unexpected downtime. Additionally, ML can optimize maintenance schedules by predicting the remaining useful life of equipment, ensuring it's serviced before failure but avoiding unnecessary procedures that reduce equipment lifespan.

Similar to its role in anomaly detection, ML in predictive maintenance leverages the power of AI to analyze vast amounts of data and identify patterns that might go unnoticed by traditional methods.

Ultimately, using AI and ML to monitor asset health, predict failures, and optimize maintenance schedules can significantly enhance the efficiency and effectiveness of predictive maintenance, leading to cost savings, improved customer satisfaction, and increased profitability for businesses.

Usage of Machine Learning in Popular Systems

Machine learning is already implemented to multiple warehouse and inventory management systems.

Amazon has been a leader in incorporating machine learning (ML) and artificial intelligence (AI) into its business processes. A key example is the integration of ML into the Fulfillment by Amazon (FBA) program, where sellers opting for international shipping benefit from Amazon’s ML-driven inventory management system [14]. This system leverages various inputs, including product value, shipping times, and internal Amazon data, to predict customer demand and optimize stock levels. The success of this inventory management approach is evaluated using the Inventory Performance Index (IPI), a metric that tracks the efficiency of FBA's inventory control [14].

One of Amazon’s significant initiatives is the “Hands Off the Wheel” program [15]. This initiative uses AI to automate repetitive jobs, but instead of eliminating jobs, Amazon transfers employees to more creative roles where they can add more value to the company [15]. This approach allows Amazon to be nimbler and find new ways to stay ahead of competitors.

They have also built a powerful forecasting model that is entirely cloud-based. This model uses their data to make improved choices, optimize operations, and provide a better customer experience.

Amazon uses ML on AWS to aggregate and analyze data on product purchases and run forecasting models [16]. Moreover, the company uses the browsing and sales information to deliver more personalized product recommendations. ML allows experimenting with data, which enables data analysts to develop a more personalized consumer experience [16].

In besides using ML for software purposes, Amazon has made significant strides in deploying collaborative robots using AI advances over the past decade.

Amazon's latest industrial robots, developed using the latest advances in computer vision and ML, can work safely alongside humans. These include Proteus, Amazon's first autonomous mobile robot, and new robotic material handling systems, including Cardinal and Sparrow [17]. These robots are part of Amazon's efforts to create a safer and more ergonomic workplace by focusing automation efforts on physically demanding and repetitive tasks.

SAS is one of a lead companies in business analytics software and services, has been at the forefront of incorporating ML into their technologies.

SAS offers its machine learning solution, SAS Machine Learning [18], which integrates data preparation, feature engineering, modern statistical methods, and ML techniques into a single, scalable in-memory processing environment. This solution supports the entire ML lifecycle, from model development and testing to deployment. By utilizing algorithms optimized for parallel computing, it delivers fast and accurate results.

SAS has also developed a machine learning-based approach for predictive warehouse design. This method aids in the strategic planning of warehouse systems by training classifiers to predict key components such as storage technology, material handling systems, warehouse space allocation strategies, and picking policies for storage systems [18]. Additionally, SAS’s warehouse management systems track warehousing and picking operations, generating vast amounts of data. However, logistics operators often face significant costs maintaining these systems without leveraging the collected data to monitor business processes, optimize warehouse flows, and support strategic decisions. SAS's ML approach focuses on utilizing this data for more than just basic tracking, exploring its potential to enhance decision-making and efficiency.

Moreover, SAS has developed a digital twin for the supply chain [19]. This virtual model represents processes, products, or services, enabling businesses to analyze data and monitor systems in real time. The digital twin helps solve problems before they occur, prevent downtime, and develop new capabilities, while simulations allow for future planning and profit-optimized decision-making.

Similarly, Oracle NetSuite, a leader in cloud-based business management services, has incorporated ML and AI into its platform to enhance various aspects of its services. One notable application of ML in NetSuite is financial forecasting. Machines can analyze large volumes of data much faster than humans, delivering outputs and insights in hours, compared to the traditional methods that could take weeks or months depending on data complexity [20].

NetSuite also provides a comprehensive set of inventory management features, such as multi-site inventory control, warehouse and order execution management, automated repletion, lot and batch tracing, and cycle accounting. ML analyzes historical sales data to forecast future demand, helping companies keep optimal inventory levels and prevent overstocking or shortages. To automate the warehouse, NetSuite uses autonomous mobile robots trained by machine learning to move heavy packages, while the software tracks inventory in real time, ensuring that records are always up-to-date.

Microsoft Dynamics 365 Supply Chain Management also uses ML in its warehouse and inventory management systems [21]. It allows businesses to intelligently orchestrate and automate fulfillment using real-time multi-channel inventory data, AI, and ML. This system optimizes order processing, ensuring efficient and accurate deliveries, while enhancing overall warehouse operations.

ML is also used in supply chain planning to analyze historical sales data and predict future demand, in warehouse management and fulfillment, in asset management and maintenance to predict when equipment is likely to fail and schedule preventative maintenance.

Conclusions

Machine learning leads to be implemented in every aspect of human being, including warehouse and inventory management. It offers a powerful set of tools to optimize processes, enhance efficiency of performance for value. It may be complicated to implement ML to an existing system because of such challenges as requirement of quality data to be trained on and costs upfront for integrating. However, according to researches, in result such implementation to supply chains could cut costs by 15%, reduce inventory by 35%, and improve efficiency by 65% [22].

There already are a lot of powerful solutions based on ML which use it for demand forecasting, inventory optimization, warehouse layout optimization, order fulfillment optimization, supply chain optimization, anomaly detection, predictive maintenance robotics control etc. and there is no doubt its capabilities will expand with time as nowadays power of AI growth each day.

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