NPS-LM-26-023

ACQUISITION RESEARCH PROGRAM SPONSORED REPORT SERIES

Implementing Commercial Warehouse Automation Processes and Technology in the Navy Exchange Command West Coast Distribution Center

December 2025

LCDR Loc X. Nguyen, USN

LCDR Andrew B. Oxendine, USN

LCDR Brian R. Lasley, USN

Thesis Advisors: Brett Schwartz, Lecturer
Dr. Robert F. Mortlock, Professor

Department of Defense Management

Naval Postgraduate School

The research presented in this report was supported by the Acquisition Research Program of the Department of Defense Management at the Naval Postgraduate School.

To request defense acquisition research, to become a research sponsor, or to print additional copies of reports, please contact the Acquisition Research Program (ARP) via email, arp@nps.edu or at 831-656-37

ABSTRACT

This study examines automated systems available for implementation at the Navy Exchange Service Command (NEXCOM) West Coast Distribution Center (WCDC) in Chino, California. Using data analysis, observations, process mapping, and benchmarking, it identifies opportunities for efficiency gains through automation. It shows that performance metrics such as throughput, labor efficiency, inventory accuracy, order fulfillment time, picking efficiency, and mechanical reliability can be used to set and meet performance targets, leading to the recommendation for an upgraded Motor Driven Roller (MDR) system with zero-pressure accumulation (ZPA) software.

THIS PAGE INTENTIONALLY LEFT BLANK

ABOUT THE AUTHORS

LCDR Loc Nguyen enlisted in the United States Marines Corps in December 2006. Following his enlistment LCDR Nguyen attended San Jose State University and earned his Bachelor’s degree in Finance in 2014. Afloat, LCDR Nguyen served aboard the USS COMSTOCK (LSD-45) as the Assistant Supply Officer, USS JASON DUNHAM (DDG-109) as the Supply Officer. Ashore, he completed his Contracting Internship at Defense Logistics Agency, Columbus, Ohio; served as Installation Financial Officer at Naval Air Facility Misawa, Japan. After graduation, he will report to CTF-68 – US Navy Expeditionary Combat Forces EUR/AF.

LCDR Brian Lasley is a native of Fredericktown, Missouri. He graduated from the University of Missouri in 2015, earning his Bachelor of Science in Physics and his commission through Naval ROTC. His afloat tours include serving as Staff Supply and Materials Officer on Maritime Prepositioning Ships Squadron Three and as Supply Officer on USS GREEN BAY (LPD-20), forward deployed to Guam and Sasebo, Japan, respectively. He has supported exercises Ssang Yong/ Freedom Banner, Noble Tempest, Valiant Shield, Garuda Shield, and Iron Fist, working closely with USMC and foreign national partners. Ashore, Lieutenant Commander Lasley served as the Site Director of Fleet Logistics Center Yokosuka Site Atsugi, where he oversaw fuels, materials, transportation, HAZMAT, postal, and household goods support for Naval Air Facility Atsugi, three resident operational MH-60 squadrons, and units deployed to the Western Pacific. He is currently a resident student at the Navy Postgraduate School in Monterey, CA, pursuing a Master of Science in the Acquisition and Contract Management program. After graduation, Lieutenant Commander Lasley will be stationed onboard USS GEORGE WASHINGTON (CVN-73) as a Principal Assistant to the Supply Officer.

LCDR Andrew Oxendine, from New Bern, North Carolina, graduated from Elizabeth City State University in 2008 with a BS in Industrial Technology. He enlisted in the U.S. Navy in 2009 and was commissioned as an Ensign through Officer Candidate School in 2016. He holds a DAWIA Level II Certification in Life Cycle Logistics and is currently pursuing a master's in Defense Contracting at the Naval Postgraduate School. At sea, he served as Division Officer on the pre-commissioning USS GERALD R. FORD (CVN 78) and as Supply Officer and Department Head on USS MIGUEL KEITH (ESB 5). He is qualified to wear both the Surface Warfare and Naval Aviation Supply Corps Officer pins. Ashore, he served as Integrated Logistics Supply Intern at NAVWAR and as Customer Service Officer at NAVSUP FLC San Diego. He is married to Deshawna Oxendine, and they have three children: Destiny, Drewvon, and Aaliyah. After graduation, LCDR Oxendine will serve as Logistics Supply Officer at COMDESRON 50.

NPS-LM-26-023

ACQUISITION RESEARCH PROGRAM
SPONSORED REPORT SERIES

Implementing Commercial Warehouse Automation Processes and Technology in the Navy Exchange Command West Coast Distribution Center

December 2025

LCDR Loc X. Nguyen, USN

LCDR Andrew B. Oxendine, USN

LCDR Brian R. Lasley, USN

Thesis Advisors: Brett Schwartz, Lecturer
Dr. Robert F. Mortlock, Professor

Department of Defense Management

Naval Postgraduate School

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

AAFES	Army and Air Force Exchange Services
AGV	automated guided vehicle
AS/RS	automated storage and retrieval system
ASME	American Society of Mechanical Engineers
AWS	Amazon Web Services
CORS	Conveyance Order Routing System
CPK	container pick
DC	distribution center
DoD	Department of Defense
ERP	enterprise resource planning
G2P	goods-to-person
HR	human resources
IT	information technology
LTC	less-than-case
MCC	motor control center
MDR	motor driven roller
MWR	morale, welfare, and recreation
NAF	non-appropriated funds
NEX	Navy Exchange
NEXCOM	Navy Exchange Service Command
OEE	overall equipment effectiveness
OSHA	Occupational Safety and Health Administration
PH	product handling
PLC	programmable logic controller
PM	preventative maintenance
PPH	pieces per hour
QA	quality assurance
RAM	reliability, availability, maintainability
RDM	Retek Distribution Module
ROI	return on investment

RPK	replenishment pick
SAT	site acceptance test
SD-15	Guide to Performance Specifications
SLA	service level agreement
SOP	standard operating procedure
UPH	units per labor hour
WCDC	West Coast Distribution Center
WES	warehouse execution system
WMS	warehouse management system
ZPA	zero pressure accumulation

I. INTRODUCTION

This chapter outlines the purpose of the study, explains the problem, presents the research questions and hypotheses, and discusses the significance of the study.

A. PURPOSE

The Navy Exchange Service Command (NEXCOM) at its West Coast Distribution Center (WCDC) in Chino, California, has invested heavily in automation to improve efficiency and accuracy while reducing workload and costs in its supply chain operations (Weisgerber et al., 2024). These efforts support the Department of Defense's (DoD) goals to modernize logistics and improve mission readiness. However, since the implementation phase began in 2021 and is expected to continue until 2024, a problem has emerged: performance measures have not been clearly identified, nor have technology investments delivered operational and financial benefits (Weisgerber et al., 2024). While research has examined the potential benefits of warehouse automation, the implementation and performance measures have not been clearly defined or understood. Without metrics to determine what drives efficient operations, decision-makers have only a limited understanding of how automation can improve processes. With well-defined performance metrics, defining requirements becomes more straightforward and targeted. Companies specializing in warehouse automation have mature, widely available technologies that can yield new solutions tailored to these requirements, directly providing greater value to taxpayers.

The private sector has tried to address this issue. Companies like Amazon are leading the way in using automation to improve warehouse operations, boost order accuracy, and cut costs (Labers et al., 2020). For example, Amazon recognized packaging speed as a performance metric that could be enhanced through automation (Labers et al., 2020). In 2019, it partnered with CMC S.R.L. to develop the automated packaging machine, CMC "CartonWrap," which packs 600–700 boxes per hour, roughly four to five times faster than human workers (Labers et al., 2020). This example shows the process from measuring a metric to setting a requirement to making an acquisition, with data guiding investment choices.

Military retail logistics, however, faces numerous challenges, including strict regulations, outdated IT systems, labor unions, and complex procurement processes. These challenges make it difficult for NEXCOM to demonstrate the return on investment and manage operations funded by non-appropriated funds (NAF) (Weisgerber et al., 2024). While the private sector is responsible for increasing shareholder value, NEXCOM has the primary responsibility of supporting the warfighter while maximizing value for taxpayers and other key stakeholders. Driving toward the most efficient processes, particularly through the implementation of new technologies, has not been a primary focus.

Despite this, NEXCOM identified where automation could greatly improve warehouse operations. Early estimates for WCDC's automation plan predicted a 20–30% faster order processing time, a reduced need for permanent staff due to training, and improved inventory accuracy thanks to automated picking and sorting (Weisgerber et al., 2024). However, without a clear assessment following implementation, it remains unclear whether these goals were met or if problems persist. This uncertainty highlights the importance of evaluating the impact of automation on specific metrics. Automation should also support DoD goals, such as strengthening supply chains, achieving cost savings, and enhancing readiness (Weisgerber et al., 2024). Expanding the automation footprint in warehouse operations will enable achieving these goals, but only with quantitative performance improvements. While automation promises significant improvements, its implementation at WCDC has revealed several challenges that must be addressed to realize these benefits. This leads to the organization's central problem.

B. PROBLEM STATEMENT

Although the WCDC automation project showed promising potential on paper, there is limited data to confirm the actual achievements. Key performance metrics, such as labor productivity, order accuracy, and cost savings, are not well-documented. This lack of clear, measurable data makes it difficult for NEXCOM to evaluate whether automation investments are delivering real operational benefits or cost reductions (Weisgerber et al., 2024).

Without well-defined performance requirements and metrics, decision-makers struggle to select and manage automation technologies effectively. This gap increases the risk of investing in solutions that do not meet operational needs or fail to generate expected savings. It also limits the ability to identify and address issues early, such as underused technology or workforce adaptation problems.

Commercial warehouse operators avoid these risks by establishing clear, measurable goals before adopting automation. They utilize performance data to inform technology choices and continually enhance processes. For NEXCOM, adopting a similar approach—defining requirements based on proven commercial technologies and tracking relevant metrics—will be critical to realizing meaningful improvements in efficiency and cost-effectiveness.

This lack of clear standards also complicates workforce planning and training efforts. Without data on how automation affects labor productivity and error rates, it is challenging to design effective training programs or adjust staffing levels. Regular performance feedback is crucial to ensure that automation effectively supports workers and enhances overall operational efficiency.

Addressing these gaps will enable NEXCOM to make data-driven decisions, optimize automation investments, and better serve military families while maximizing value to taxpayers. Establishing clear performance metrics tied to commercially available technology is key to unlocking the full potential of warehouse automation across the NEXCOM network. To systematically address these challenges, this study is guided by the following research questions.

C. RESEARCH QUESTIONS

This study addresses these challenges by answering the following key research questions:

- **Primary Research Question:** Do commercially available warehouse automation technologies exist that would create measurable increases in efficiency at WCDC?

- **Secondary Research Question:** What performance metrics should be used to evaluate the efficiency of current processes versus automated processes at WCDC?
- **Tertiary Research Question:** What requirements based on performance metrics should be integrated into future automation acquisitions at WCDC?

The methodology addresses these goals by combining quantitative analysis of performance data with qualitative input from on-site observations and stakeholder recommendations. This method provides a comprehensive understanding of the challenges and opportunities of automation at WCDC, along with actionable recommendations for future initiatives (Weisgerber et al., 2024). Answering these questions is crucial not only for improving WCDC's operations but also for informing broader efforts to modernize military logistics. The significance of this study is outlined below.

D. SIGNIFICANCE OF STUDY

This study is essential for several reasons. First, it provides NEXCOM leaders with fact-based insights into how automation impacts operations, the workforce, and finances at WCDC. By using process mapping, performance data, and benchmarking rather than relying on employee interviews, the study provides quantitative data to develop automation requirements. Precise requirements translate the user's needs into contracting officers' actions, resulting in a more efficient acquisition process. Efficient acquisition in this case saves time and taxpayer dollars by ensuring customer requirements are met the first time, without the need for changes after award.

Second, it helps improve logistics and supply chain management by supporting the adoption of public sector approaches to address challenges, such as adhering to regulations, protecting workers, and effectively integrating technology (Weisgerber et al., 2024). This research contributes to the knowledge base on automation in government operations, which faces unique challenges, including non-appropriated funding, union involvement, and stringent procurement rules. By comparing best practices from the private sector, the study bridges the gaps between commercial success and military retail realities.

The results also help NEXCOM justify budgets, improve accountability, and make better decisions for supply chain modernization (Weisgerber et al., 2024). Overall, this capstone research project closes the gap in understanding the effects and growth potential of automation in NEXCOM by analyzing real data and engaging stakeholders. It offers insights for decision-makers and supports military logistics modernization by highlighting best practices. The findings benefit military groups working to update supply chains within DoD limits (Weisgerber et al., 2024). The study supports both immediate improvements at NEXCOM and long-term logistics modernization across the defense sector. With the context and objectives established, the following chapters will review relevant literature and detail the methodology used to investigate these issues.

E. SUMMARY

This chapter discussed the current state of automation at WCDC and how performance should inform the development of new requirements for future acquisitions. The research questions aim to systematically explore the performance measures that can be used to determine these requirements, while also examining the current state of automation in the market. Quantitative data will not only lead to more articulate requirements but also provide key decision-makers with the relevant, actionable information needed to make informed capital investments. In the following chapters, we will discuss the current background and literature regarding warehouse automation in both the private and public sectors, as well as the formalized methodology used in our analysis. Finally, this study will recommend requirements and an acquisition strategy for WCDC.

THIS PAGE INTENTIONALLY LEFT BLANK

II. BACKGROUND AND LITERATURE REVIEW

NEXCOM supports Sailors and their families by providing goods and services through a large retail and logistics network (Navy Exchange Service Command, 2025). NEXCOM runs several distribution centers in the U.S., including the WCDC in Chino, California. To meet the changing needs of its mission and customer expectations, NEXCOM must invest in automation and robotics to modernize its warehouse operations (Epps, 2024). While manual processes may have been prudent in the past, the advent of online shopping has changed what customers demand of their retailers.

The demand for efficiency, agility, and speed has driven the development of new automation technologies, which can help NEXCOM stay relevant in an ever-changing retail environment. The WCDC automation project, running from 2021 to 2024, aimed to improve efficiency, increase inventory accuracy, and lower labor costs by adopting new technologies, including automated guided vehicles (AGVs), robotic sorters, and conveyor systems (Weisgerber et al., 2024). These investments support DoD's goals to boost logistics readiness, cut costs, and build resilient supply chains across military support groups (Weisgerber et al., 2024).

Private companies have shown how automation can transform warehouses by increasing speed, accuracy, and scalability (Halim et al., 2024). However, implementing similar technology in the public sector, especially at NEXCOM, faces unique challenges. These include dependence on NAF, complex purchasing rules, outdated IT systems, and labor unions. Unlike private companies, NEXCOM must demonstrate return on investment under strict oversight (Weisgerber et al., 2024). This can be difficult without enough performance metrics to measure process improvements.

While early plans predicted enormous benefits from WCDC automation, such as 20%–30% faster throughput, better inventory control, and more efficient labor through retraining, the actual results remain unclear (Weisgerber et al., 2024). Without a thorough evaluation, NEXCOM risks making decisions to expand automation without understanding the real benefits, ongoing problems, or effects on workers (Weisgerber et al., 2024). This study addresses that gap by combining process mapping, data review, and benchmarking to provide a comprehensive evaluation.

By comparing WCDC's results with original plans and industry benchmarks, the study offers key insights into whether automation delivers as promised, how to improve it through process changes and training, and what is needed to expand automation across NEXCOM. These insights are vital to ensure NEXCOM's automation investments boost resilience, cut costs, and support DoD logistics modernization (Weisgerber et al., 2024).

NEXCOM manages the Navy Exchange (NEX), a retail and service organization that offers discounted goods and services to authorized customers. These customers include active-duty service members, reservists, retirees, their families, and NEXCOM staff. NEX operates primarily near Navy fleet hubs worldwide, offering retail services specifically tailored to the naval community. NEX operates like a large commercial retailer, offering a wide range of products and services, from household items to personal care, as well as barbershops and laundry services. However, it differs in some ways: it is tax-exempt, sells military-specific items such as uniforms, and reinvests profits into programs that enhance the quality of life for military personnel, particularly Morale, Welfare, and Recreation (MWR) services.

Unlike private retailers, NEX is tied to the federal government, employs a civilian federal workforce, and depends on Navy base locations and personnel numbers. Congressional funding and military recruitment trends also affect its growth and operations. NEXCOM is funded by NAF, which covers daily expenses, wages, and reserves. Profits go back to support the Navy community. While NEX primarily serves Navy areas, it operates alongside other military retailers, such as the Army & Air Force Exchange Service (AAFES). Both are open to eligible DoD customers and form the core retail services for the military population.

A. ADVANCEMENTS IN AUTOMATION

Warehouse automation is quickly expanding in the logistics and supply chain industries. This growth is driven by labor shortages, rising wages, and the need to improve productivity and throughput. Automation helps reduce operating costs, boost capacity, optimize space use, improve accuracy, and create more sustainable warehouses. Industry forecasts estimate that over 50,000 warehouses worldwide will feature robotics within the next 6 years, a 12-fold increase from the 4,000 automated warehouses reported earlier (Verified Market Research, 2025). The global Warehouse Automation Market is expected to reach $54.05 billion by 2031, with an annual growth rate of approximately 14.45% (Verified Market Research, 2025). This growth is fueled by the increase in e-commerce and omnichannel logistics, which require faster order fulfillment and better inventory management (Verified Market Research, 2025). Technologies such as artificial intelligence (AI), the Internet of Things (IoT), and robotics are driving the next stage of warehouse automation (Verified Market Research, 2025).

Leading private companies such as Amazon, Walmart, and DHL have pioneered the use of automation to boost warehouse efficiency, improve order accuracy, and reduce costs. They leverage real-time data analytics, streamline process redesign, and foster collaboration between humans and machines to improve performance. Amazon, in particular, leads in deploying robotics and automation at scale. It operates more than 750,000 robots worldwide for sorting, lifting, and carrying packages (Greenwaldt, 2024). Amazon uses eight different types of robots for specific tasks, such as:

- **Sequoia:** Utilizes AI, robotics, and computer vision to manage and consolidate inventory, as well as expedite order processing. It also improves ergonomics by delivering items to workers in their "power zone."
- **Hercules and Titan:** Mobile units that carry pods of items to workers for picking. Titan can lift twice as much as Hercules for larger items. They navigate using computer vision and floor markers.
- **Sparrow:** A robotic arm using AI and computer vision to pick and move items into totes.
- **Packaging Automation:** Machines that create made-to-fit paper bags for sustainability.
- **Robin:** An early robotic arm that sorts packages from conveyors onto robotic units.
- **Cardinal:** A robotic arm with advanced AI and computer vision to select, lift, read labels, and place packages up to 50 pounds into carts.
- **Proteus:** Amazon's first fully autonomous mobile robot that works with Cardinal to move carts (Greenwaldt, 2024).

Amazon's fulfillment centers feature extensive conveyor systems, with one facility boasting approximately 17.5 miles of conveyor belts (Greenwaldt, 2024). These systems are monitored using Amazon Web Services (AWS), which enables devices to process data locally (Greenwaldt, 2024). Events from machines trigger automated maintenance tasks. AWS machine learning models predict equipment failures to fix problems before they happen (Greenwaldt, 2024). The operations are coordinated by cloud-based software, described as an AI-driven air traffic control network that optimizes robot routes, speeds, and movements (Greenwaldt, 2024). By 2019, Amazon had deployed 100,000 Kiva robots; now, it has more than 200,000 (Greenwaldt, 2024). Newer robots, such as Pegasus, are more compact, use fewer components, can lift 600 kilograms, and can be customized with conveyor belts (Greenwaldt, 2024). Pegasus has reportedly halved the number of delivery errors in its sortation centers (Laber, 2020). Amazon has also introduced robots, such as Xanthus and Vulcan, the latter of which features a sense of touch (Greenawalt, 2024).

Despite these benefits, automation has challenges. The high initial cost for infrastructure, software, and equipment can limit adoption, especially for small and medium businesses. Successful automation requires careful planning, thorough data analysis, and effective coordination with internal teams, including sales, IT, warehouse operations, and facilities. Engaging suppliers and evaluating their solutions, which may involve sharing sensitive data and visiting other sites, is also essential. Evaluating supplier bids independently helps avoid bias. Building a detailed model to understand future capacity needs over a long period helps assess automation options.

Workforce impact is another key issue. While automation can replace some jobs, much of the technology aims to increase worker productivity (Gravier, 2024). Many companies fail to invest sufficiently in training their workers for new technology, which leads to resentment and hinders adoption. Being honest about job impacts and providing thorough training, along with follow-up support, helps workers adapt. The inability to utilize new technology effectively is a significant source of dissatisfaction. The future of work in automated warehouses will combine human and robotic skills, requiring retraining and a focus on teamwork (Gravier, 2024).

These challenges are particularly extreme in sectors such as military retail logistics, as exemplified by NEXCOM. NEXCOM has invested heavily in automation at WCDC, aligning with DoD goals for logistics modernization. However, a key issue is the lack of precise data on whether these investments deliver expected benefits. Military retail logistics faces unique challenges, including strict rules, outdated IT systems, labor unions, complex purchasing processes, and the need to demonstrate returns on NAF operations. Evaluating effects on productivity, errors, worker morale, and efficiency is essential but often lacks complete data.

According to Halim et al., who conducted research on automation in e-commerce warehouses in Jakarta using quantitative methods, it was found that warehouse management systems (WMS) significantly improve intelligent warehousing and operational efficiency; however, work process automation itself did not show a strong effect (Halim et al., 2024). Additionally, the influence of experts on intelligent warehousing and efficiency was insignificant. This suggests that successful automation depends on users' understanding, readiness, and clear implementation strategies (Halim et al., 2024). Using technology without sufficient knowledge and readiness may not yield benefits and could result in losses. (Halim et al., 2024). A robust WMS is considered the backbone of warehouse operations and can significantly enhance productivity (Halim et al., 2024).

In summary, automation is transforming warehousing, offering significant benefits but also presenting challenges in investment, integration, workforce adaptation, and performance measurement. Private companies are rapidly adopting advanced robotics and technology. However, public sector groups, such as NEXCOM, face unique rules that require careful study to ensure investments pay off and can be effectively expanded. The success of automation, particularly in processes, and the role of human expertise may vary depending on the quality of technology implementation and the organization's and its workers' preparedness.

B. INDUSTRY STANDARDS

Warehouse and logistics operations are increasingly shaped by automation and data-driven systems. Leading companies, such as Amazon, Walmart, and DHL, set standards by utilizing robotics, AI, IoT, and advanced WMS to enhance operations, improve inventory accuracy, and reduce labor costs (Chinthala, 2021). Technologies like Automated Storage and Retrieval Systems (AS/RS), conveyor and sorting systems, and predictive maintenance tools are now essential in competitive distribution centers (Chinthala, 2021). Human augmentation tools, such as exoskeletons and wearable devices, are also emerging to help workers be more efficient and reduce the risk of injuries. The industry is focusing more on sustainability and scalability, with trends such as AI-powered robotics and smaller, flexible automation systems gaining momentum. Reports show companies like Amazon have workplace injury rates nearly double the industry average, highlighting the challenge of balancing innovation with worker safety. As automation continues to grow rapidly, these trends represent the new standard for modern warehouses.

C. DRIVERS BEHIND AUTOMATION

Warehouse automation is growing due to various economic, technological, and operational pressures that are transforming logistics. The main factors are ongoing labor shortages and rising labor costs, which make it challenging to maintain high throughput solely through manual work (Chinthala, 2021). Automation decreases reliance on manual labor and lowers the risks associated with hiring and retention (Gravier, 2024).

The rapid growth of e-commerce and omnichannel logistics has heightened the need for fast and accurate order fulfillment. Customers expect quicker deliveries and real-time inventory updates, pushing warehouses to adopt technology that meets these demands while controlling costs (Chinthala, 2021). As delivery times get tighter, traditional methods struggle to keep up, making automation a must-have (Halim et al., 2024).

There is also a strong demand for better efficiency and productivity. Automation improves accuracy, reduces errors, and enables warehouses to handle a higher volume without increasing labor hours (Chinthala, 2021). This reduces costs and eliminates many repetitive, tiring tasks that can cause worker fatigue and injuries (Laber, 2020). Advances in robotics, AI, IoT, and predictive analytics have significantly expanded automation’s capabilities. Modern systems are flexible, adaptable, and scalable, offering real-time inventory tracking, autonomous vehicle navigation, predictive maintenance, and smart human-machine teamwork (Greenwaldt, 2024). These features are becoming more affordable and accessible, lowering barriers for large and mid-sized warehouses (Chinthala, 2021).

Space limitations in many facilities prompt operators to utilize vertical storage and AS/RS to maximize capacity, particularly in costly or urban locations (Chinthala, 2021). Supply chain disruptions, such as those during the COVID-19 pandemic, exposed weaknesses in overly manual and lean systems (Weisgerber et al., 2024). Many companies now turn to automation to build stronger, more responsive distribution networks (Chinthala, 2021). Finally, competition forces companies to modernize. Those who invest in automation often gain clear advantages in efficiency, accuracy, and scalability, making them more cost-effective (Greenwaldt, 2024).

D. SUMMARY

Investment in technologies such as AGVs, robotic sorters, and conveyor systems aims to improve efficiency, enhance inventory accuracy, and reduce labor costs (Laber, 2020). These efforts align with DoD goals for logistics readiness and supply chain resilience (Weisgerber et al., 2024). Despite initially optimistic projections, there is a lack of clear evidence of realized benefits, highlighting the need for robust performance requirements (Weisgerber et al., 2024).

Automation offers both major opportunities and challenges for NEXCOM and the broader public sector. The success of investments must be verified through clear performance metrics and aligned with organizational readiness and workforce involvement. Lessons from the private sector and industry standards offer helpful guidance for future modernization efforts at WCDC and beyond. After establishing the context and reviewing existing research on warehouse automation, the following section outlines the methodology used to assess WCDC's current processes and identify potential improvements.

THIS PAGE INTENTIONALLY LEFT BLANK

III. METHODOLOGY

This study uses a mixed-methods approach, including four primary research methods: on-site observations, process mapping and analysis, document and data review, and comparative benchmarking. The research framework is our method for requirements generation, standardized by the Defense Standardization Program Office. It combines both qualitative and quantitative data to evaluate how automation affects operations, the workforce, and finances. The data informs market research strategies and performance metrics, with the ultimate aim of refining requirements for future acquisitions.

Research alone, though vital for understanding current operations and the capability gaps between the public and private sectors in warehousing, must be converted into actionable requirements. The DoD typically relies on the SD-15 Guide to Performance Specifications, published by the Defense Standardization Program Office, to accomplish this for acquisitions. A challenge observed by the team during on-site observations and market research was the growing capability gap between manual and automated operations. Despite recognizing opportunities and wanting to reduce labor hours and boost productivity through automation, NEXCOM still faces difficulties in planning and adopting new technologies (Weisberger et al., 2024).

To address these concerns, this study uses a performance-based specification rather than a detailed specification methodology. In acquisitions, performance specifications for conveying requirements are generally preferred because they allow greater contractor flexibility, reduce design risk to the government, and promote greater competition among potential vendors (Defense Standardization Program Office, 2009). Detailed specifications, excluding specific circumstances, essentially limit the innovative new technologies and require customers to write complex requirements, often in specialized fields where they are not experts (Defense Standardization Program Office, 2009). In the case of WCDC, performance specifications such as throughput can be more simply articulated rather than creating organic designs that may or may not achieve the desired end state.

The SD-15 outlines three essential steps for defining performance specifications:

1. Identifying and Defining User Needs: Gaps in capabilities, as identified by users and data reports, should be used to pinpoint specific areas for improvement (Defense Standardization Program Office, 2009). This study achieves this by utilizing on-site observations, process mapping and analysis, and document and data reviews to understand the operation and user needs.
2. Market Research and Analysis: Once user needs are identified, market research and analysis should be used to determine the state of the industry, vendor capabilities, and standard contract practices for the product (Defense Standardization Program Office, 2009). This study employs comparative benchmarking as a tool to not only understand the automation industry but also to examine how the private sector has addressed challenges similar to those faced by WCDC.
3. Developing Performance Requirements: Using the data collected above, thresholds should be used to create output-oriented performance specifications for requirements (Defense Standardization Program Office, 2009). By specifying the desired outputs, this study recommends specific actions for future acquisitions.

This study on automation aims to close the gap between current and future capabilities. Its goals are to determine the operational, workforce, and financial impacts of automation compared to initial plans, find ways to optimize automation through process changes, retraining, and metrics, and identify barriers and supports for scaling automation across NEXCOM. The study hypothesizes that automation will improve efficiency (H1), performance metrics will require fewer resources to achieve the same or better results (H2), and scaling will depend on overcoming regulatory, technical, and organizational barriers (H3). The study's importance lies in providing data-driven advice to improve investments, efficiency, and operational strength for NEXCOM leaders, contributing to public sector automation research, and serving as a model for other government agencies.

A. HYPOTHESES

Initial research led to the following hypotheses, which will be explored using the above framework:

- **H1:** If automation performance metrics are utilized to establish acquisition requirements for NEXCOM WCDC, commercially available products will satisfy those requirements.
- **H2:** Performance metrics at NEXCOM WCDC will show the same or increased output with fewer resources, such as manpower or time required.

- **H3:** Bureaucratic and regulatory practices within the DoD inhibit NEXCOM WCDC in its pursuit of greater automation.

B. ON-SITE OBSERVATIONS

This method involved firsthand observation of the WCDC operations. The research team organized a site visit to the Chino facility, with management consent, to observe the processes in real operating conditions. During the visit, the researchers explored the warehouse area, watching essential processes from receiving and storage to picking and dispatching. This involved observing the process of receiving and inducting inbound merchandise, utilizing automated conveyor and sortation systems, and the procedures for picking, packing, and loading orders. Particular emphasis was placed on the connections between automated machinery and manual work, for instance, how employees engage with conveyor-diverted boxes at loading bays.

Throughout these observations, detailed field notes were taken on process stages, task durations, and any operational challenges encountered, including delays or bottlenecks. The team documented instances of both automated and manual loading procedures. For example, it was observed that when the conveyor system autonomously sorts cases directly into a trailer (a floor load), the loading process is completed very quickly, usually within 3–5 minutes after scanning and diverting a case. Conversely, when automation is not used, and employees must manually place cases into a container for a floor load, the process can take significantly longer (about 5–20 minutes). Similar time differences were noted for palletized loads: automated sorting to pallets required an extra sorting phase (roughly 5–15 minutes) to organize and stack cases according to store destination, while a non-automated pallet load involved workers manually moving cases to pallet spots, also taking around 5–15 minutes.

The site visit allowed the researchers to identify process bottlenecks and layout constraints. For example, they observed conveyor halts and blockages in the sorting area, as well as the limited number of conveyor-equipped shipping lanes compared to manual lanes, which employees highlighted as concerns. The team focused on how employees adapted to the new systems, noting interactions between personnel and the WMS, as well as the coordination of tasks between human workers and automated systems. These qualitative findings were later confirmed through management interviews, but any comments from individual employees were considered informal and kept anonymous in our records.

The team was shown various on-site departments and documented the process details sequentially. Whenever possible, discussions were held with floor supervisors and experienced associates to clarify the observations. Any information collected from staff was obtained with their consent, and it was ensured that it would be used solely for internal review. There were no audio or video recordings of employees; handwritten notes and timing, recorded with a stopwatch, were used for specific tasks. This approach minimized interference and upheld ethical standards.

C. PROCESS MAPPING AND ANALYSIS

Another important technique was process mapping, which involved creating detailed diagrams and flow descriptions of the warehouse processes at WCDC to identify the operation's value stream (Womack et al., 1996). The research team collected current process flowcharts from the distribution center. We developed flowcharts for the receiving, picking, and shipping processes that visually demonstrate the decision points and actions for managing merchandise throughout the facility.

Womack et al. explain the importance of identifying the value stream within the framework of "Lean" principles. By pinpointing and eliminating wasted movements and actions, the value stream — covering the entire product life cycle — can be optimized, leading to lower labor costs, less effort, and shorter time-to-market (Womack et al., 1996). At WCDC, merchandise follows a value stream from receipt to shipment, involving a series of manual and automated actions to move it through the system.

Utilizing these flowcharts as a foundation, we conducted a process analysis to identify inefficiencies, redundancies, and areas for improvement. Every primary process (receiving, put-away, order picking, and shipping) was divided into individual tasks. We marked the process maps with information, including estimated task durations based on our observations and system timestamps, as well as volumes.

This study primarily used WCDC internal documents for process mapping. These were often Visio diagrams or similar illustrations that depicted the sequence of actions and decision points. We confirmed the correctness of these maps by conducting on-site walkthroughs, essentially following a sample item's route from receipt to shipment and validating each stage on the flowchart. Further process details were gathered through discussions with department managers. This combination of reviewing documents and verifying in the field ensured that our process maps accurately represented real-world practices, rather than merely theoretical SOPs.

By outlining the existing process flows, we can identify where automated components are practical and where manual tasks still dominate. For example, if the map showed that after conveyor sortation, workers still needed to manually scan each pallet into a trailer due to system limitations, that could be a target for additional system integration. These insights directly inform recommendations for process adjustments or additional training to close any gaps.

D. DOCUMENT AND DATA REVIEW

An extensive examination of internal documents, reports, and WCDC data outputs was conducted to provide quantitative support for the research. This review of documents and data included various sources utilized to assess performance, confirm findings, and comprehend the context of the automation initiative. Primary resources include operational performance metrics, quality and accuracy data, labor and staffing documentation, system-generated reports, meeting minutes, and planning documentation.

Operational Performance Metrics: We collected historical and current data on warehouse throughput, productivity, accuracy, and other key performance indicators. For example, the team prepared reports on orders and cases processed during each shift, showing that WCDC handles about 9,000 cases in an 8-hour shift, which is approximately 1,125 cases per hour. This throughput served as a benchmark for evaluating improvements and comparing them to changes made after automation. We also examined metrics such as order cycle time, labor hours per order to assess efficiency, and units per labor hour as a general productivity measure. These data were gathered from internal "DC Metrics" spreadsheets and weekly reports generated by the WMS.

Quality and Accuracy Data: The study examined error rates and inventory accuracy statistics to assess whether automation had influenced quality. Internal quality assurance (QA) reports delivered accuracy rates for picking and packing. An example of the data utilized is a report on “error rates” from the QA department, which tracked errors before and after the implementation of automation. Inventory accuracy and shrinkage data were also gathered, as automation, such as barcode scanning, can enhance inventory management. These originated from system outputs and were validated against any available audit results.

Labor and Staffing Documentation: To evaluate the impact on the workforce, we reviewed staffing records, including departmental headcounts and labor distribution. A spreadsheet showed the division of warehouse personnel by department, highlighting average salary rates and the number of employees in each operational area. This helped determine whether labor had been shifted due to automation. However, a known limitation was the lack of individual productivity tracking. WCDC did not consistently measure each employee’s output in the legacy system. The current warehouse systems can show the total units picked or received, but they do not specify who picked how many. This gap meant that our labor productivity analysis had to rely on aggregate data, such as total units per labor hour or departmental output, rather than specific performance metrics for individual workers.

System-Generated Reports: We collected data exports from WCDC’s primary IT systems, specifically the Retek Distribution Module (RDM) and Discoverer Plus. RDM is the core software for the distribution center, managing the movement of goods and resources within the DC. It handles functions such as inventory receipts, put-away, picking, and shipping within the business system. Discoverer Plus is an Oracle-based analytical tool that enables querying the operational database for customized reports and analyses. The team used Discoverer Plus to extract specific historical data, including throughput before automation was introduced and current statistics, as well as to run ad hoc queries on inventory and order data. Additionally, WCDC employs the Conveyance Order Routing System (CORS), which integrates with RDM and Discoverer Plus to monitor shipping transactions. CORS also relays carton scan data to RDM during trailer loading. We reviewed shipping reports and logs from CORS/RDM to evaluate the efficiency of the automated sortation process for trailer loading.

Minutes from Meetings and Planning Documents: The research team also reviewed internal meeting agendas, emails, and planning documents related to the automation project. This included agendas from discussions with WCDC leadership, such as those with the Regional Director of Distribution, which provided qualitative context. Specifically, they highlighted management's view on the main implementation challenges and the progress of any ROI assessments. Notes from the meeting on July 17, 2025, recorded conversations about performance metrics and the need for more detailed data in ongoing operations. These documents helped identify the data points NEXCOM leadership prioritized and highlighted any data issues. They often included follow-up action items, such as requests for specific data extracts, to ensure the research team collected all relevant information. The data and insights gathered through these methods provide the foundation for the following analysis, which examines WCDC's operational performance and identifies opportunities for automation.

E. COMPARATIVE BENCHMARKING

To provide context for WCDC's automation experience and understand the automation market, the research includes comparative benchmarking. This involves examining industry standards and other relevant organizations to evaluate how WCDC's practices and performance compare, and to identify improvements that could be achieved by adopting established methods.

Initially, we used the earlier 2024 thesis by Weisgerber et al. as a starting point. The research, focused on developing an automation planning strategy for WCDC, established baseline benefit expectations and highlighted challenges specific to the NEXCOM (military retail) context. Our study treated those expectations as hypotheses for validation—essentially using the case study as a standard of "what was expected to happen." For example, if the case study anticipated improved space usage or reduced handling time due to robotics, our assessment checked whether those outcomes were achieved.

Next, we gathered information on benchmarks for warehouse automation in the private sector. NEXCOM's management wanted to understand how their operations compared to industry standards, so we analyzed metrics such as order pick rate, hourly warehouse cycle time, accuracy percentages, and cost per unit shipped, based on industry studies or vendor data. We also reviewed the capabilities offered by major automation vendors like Dematic, Honeywell Intelligrated, and Manhattan Associates, along with the performance improvements these systems typically claim. The research team was tasked with investigating commercial automation solutions for market analysis, and we compared WCDC's technologies and results with those of their suppliers in similar warehouse environments. For example, if a retail industry's automated sorting system generally doubles output, we assessed whether WCDC experienced similar gains or encountered shortcomings.

Ultimately, the benchmarking guided market research by identifying gaps and key elements relevant to expanding automation. For example, if our benchmarking showed that private-sector warehouses track productivity with a Labor Management System and achieve higher pick rates, it suggested that NEXCOM might need to invest in more robust tracking tools. This aligns with findings that WCDC currently lacks an integrated labor management system. Using comparative benchmarking to steer market research helps concentrate on practical innovations without being overwhelmed by excessive market data. The data and insights gathered through these methods form the foundation for subsequent analysis that examines WCDC's operational performance and identifies opportunities for automation.

IV. ANALYSIS AND DISCUSSION

This chapter analyzes the data to identify which commercially available products, metrics, and proposed requirements are suitable for automation acquisition. Data sets from WCDC show a semi-automated, manual-intensive operation with consistent performance but ongoing inefficiencies. Processes are linear but rely heavily on manual labor.

The merchandise loading process, for example, comprises multiple individual subprocesses, illustrating the potential for increased efficiency through automation. Significant variation in combinations of load types constrains the managerial capability to track this effectively. The hybrid approach currently used has different time requirements based on whether processes are automated and whether merchandise is loaded to the floor or to a pallet. In this context, automation refers to the ability to load merchandise onto a conveyor belt. Large or bulky items that cannot be loaded onto a conveyor take more time and manual intervention to load. For automated processes where merchandise is unloaded to the floor, once scanned and diverted, it is typically loaded within 3 to 5 minutes. For automated loads to pallets, after scanning and diverting, merchandise must be separated by location and stacked onto pallets, a process that generally takes 5 to 15 minutes. For non-automated processes, floor loads require manually pushing merchandise into a container after scanning and diverting, taking 5–20 minutes. Similarly, non-automated loads to pallets involve manually placing merchandise on designated pallets, typically taking 5–15 minutes.

Figure 1 illustrates the simplified process, including both automated and non-automated steps, for loading onto pallets. In each case, manual labor is used for tasks such as scanning, wrapping, and loading. The variation in load times, ranging from 3 to 20 minutes, is difficult to predict, making it a potential target for automation requirements.

The current process requires at least seven employees to handle each piece of merchandise. To facilitate the introduction of automation, the metrics to pursue must be identified. In this case, order throughput, picking efficiency, and labor efficiency can be used to determine which automated technologies to pursue.

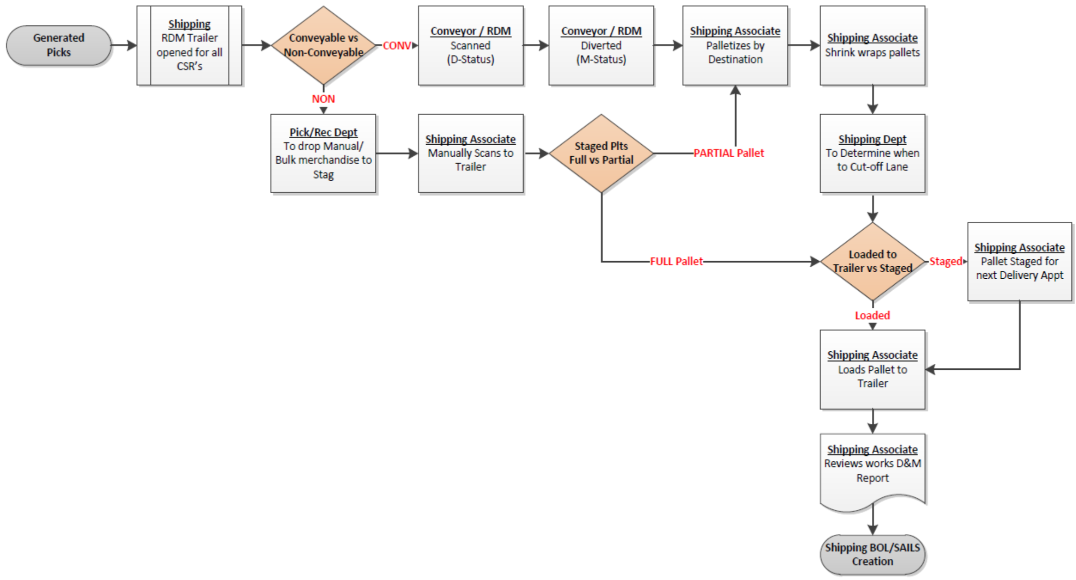

Figure 1. West Coast Distribution Center Shipping Process. Source: Weisgerber et al. (2024).

More broadly, onsite observation showed a heavy dependence on manual labor to transport merchandise to and from storage areas. Figure 2 illustrates the current conveyor system used at WCDC.

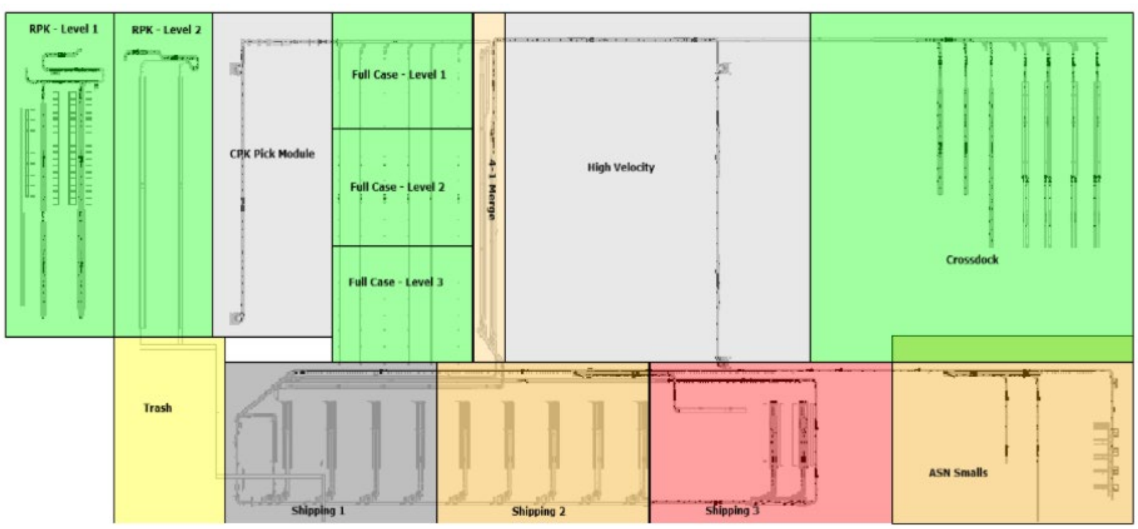

Figure 2. Chino Conveyor System. Source: Kassfy (2025r).

The following are explanations of each zone:

1. Replenishment Pick Module (RPK)
2. Case Pick Module (CPK)
3. Full Case
4. High Velocity
5. Cross-dock
6. A-1 Merge
7. Shipping 1, 2, and 3
8. Advanced Shipping Notice (ASN) Smalls

Manual labor in the current system is crucial in every process that relies on physical handling, movement, or decision-making that the conveyor and sortation network cannot perform. Workers unload trailers, break down inbound freight, and manually store merchandise across full-case, high-velocity, RPK, and CPK zones. The picking functions—each picking, case picking, and pallet-level full-case picking—represent the largest share of labor, requiring operators to walk aisles, select items, load totes or cartons onto conveyors, and manage exceptions. Additional labor is required in cross-dock and ASN Smalls, where employees sort, re-stack, verify labels, and prepare items for outbound flow. At the A-1 merge and induction points, workers clear jams, correct misfeeds, and handle non-conveyable items. Finally, shipping operations depend heavily on manual pallet building, wrapping, staging, and trailer loading. To identify practical solutions, it is essential to understand the range of commercially available automation technologies. The following section presents the results of our market research.

A. MARKET RESEARCH

Through our research, we identified a wide range of commercial products that could lead to significant efficiency gains at WCDC. Although the term "automation" encompasses a spectrum of technologies, ranging from simple conveyor belts to advanced AI, modular products are available that can ease transitions and generate ROI over time.

1. Goods-to-Person and Automated Storage and Retrieval System

Major advancements in warehouse automation have been particularly marked by shifts from picker-to-product to product-to-picker processes. Individual employees moving items from storage to workstations for further processing have traditionally been a bottleneck for warehouse operations (Ma et al., 2023). This is the standard picker-to-product model. New technologies, however, enable product-to-picker, where merchandise is moved directly from storage to workstations, eliminating the need for redundant labor and saving time, both of which result in cost savings (Weisgerber et al., 2024). Industry generally refers to this model as goods-to-person (G2P).

Evolving from the G2P model, AS/RS has further advanced automation integration and is a cornerstone of the modern automated warehouse (Ma et al., 2023). By utilizing sophisticated AI and robotics, these systems quickly and efficiently replace manual storage and picking operations while maintaining a higher level of traceability (Eduard et al., 2022). At WCDC, these manual operations lead to inefficiency and pose potential safety hazards to employees. Rather than humans performing these actions, machines have been shown to produce safe and consistent results.

In their article exploring the use of AS/RS and its potential for solving footprint concerns in urban warehouses, Eduard et al. identified five primary types:

- Pallet handling systems store and retrieve items on pallets, usually using a cart system to travel on conveyors between storage and picking areas. Modern iterations utilize double-deep storage racks, with one cart assigned to each aisle. These systems are often large and cannot be easily fitted into existing warehouses.
- Miniload systems work similarly to pallet handling systems; however, they are intended for smaller items.
- Shuttle systems transport boxes or bins with various storage depths. Typically, there are more shuttles than aisles.
- The AS/RS unit Autostore™ by Kardex consists of an aluminum grid holding stacks of bins with rails. Robots move across the grid using the rails to deliver bins from storage to workstations, where they are either replenished or the merchandise is shipped. When interfaced with a WMS, this system offers the highest storage density and space efficiency among modern solutions. (Eduard et al., 2022)
- AGVs move entire racks, shelving units, or pallets to and from storage locations (Eduard et al., 2022). Amazon's Hercules and Titan AGVs use 3D imaging to navigate specially marked floor space, independently finding efficient and safe paths to deliver merchandise to employees for further processing (Greenwalt, 2024).

These systems, although advanced, have significant trade-offs, particularly in terms of adaptability and ease of installation, as shown in Table 1. On-site observations showed that the ease of installation will be a major challenge when implementing these highly automated systems. Future research will be needed to deploy advanced technology in this area. Although these technologies may be difficult to install initially, they demonstrate the industry's shift away from manual merchandise transportation as seen at WCDC.

Table 1. Primary Automated Storage and Retrieval System Characteristics. Source: Eduard et al. (2022).

	Pallets	Miniload	Shuttle	Autostore	AGVs Based AS/RS
Visual					
Speed	85 cycles/hour/carriage (60 for the double depth ones)	120 to 200 cycles/hr/carriage	500 cycles/hr/alley	Speed of 1.6 m/s and 30 bins/hour/robot	
Flow rate	Low (single input/output position)	Low (single input/output position)	High (5 times higher than miniload)	Medium	High (3 times more order lines processed per hour than a traditional storage system)
Supported weights	Between 230 and 1815 kg	Maximum 230 kg	Maximum 90 kg	Maximum 30 kg	Between 450 and 1360 kg
Maximum height	Very high (max 50 m)	Very high	Medium	Medium (max 7 m, between 4 and 16 bin heights)	Very low (maximum 2 m)
Type of products	Heavy and bulky	Small and medium weights	Small and light	Small and light	Small
Installation costs	High	High	High	Medium	Low
Operating costs	Medium (high maintenance costs due to poor reliability but low infrastructure costs due to high rack storage)	Medium	Medium	Low (high reliability)	High (decried reliability, need for floor space)
Density	Average (8 times higher than a traditional storage system)	Medium	Medium	High	Medium (removes traffic lanes but does not use height)
System flexibility	Very low	Low	High	High	High
Ease of installation	Low	Low	Medium	High	High
Adaptability	Very low	Low	Low	Medium	Low

2. Motor Driven Rollers

Warehouse automation in high-volume distribution centers relies on advanced technologies such as 24-volt MDR econveyors for totes and cartons (Itoh, 2023). These are combined with various pressure accumulation systems (medium-pressure, zero-pressure, and zero-contact) to control merchandise flow (Kraus, 2015). Each system uses zoned MDRs to regulate the distance between individual items: medium-pressure with constant backflow, zero-pressure with backflow elimination, and zero-contact with precise control (Kraus, 2015). Among these, zero-pressure accumulation (ZPA) offers the best balance of efficiency and complexity (Kraus, 2015). Amazon fulfillment centers, for example, extensively implement Honeywell Intelligrated's conveyor and sortation systems, with miles of conveyor installed end-to-end featuring sliding-shoe and crossbelt sorters (Honeywell Intelligrated, 2018). Similarly, retail giants like Walmart deploy large-scale conveyor and sorting systems to enhance delivery operations (Walmart Corporate, 2016). Key system integrators providing these solutions include Honeywell Intelligrated, Dematic, Vanderlande, Daifuku/Wynright, and TGW. Component suppliers, such as Interroll, Itoh Denki, Hytrol, Intralox, and Habasit, supply essential components like rollers, belts, and motors. For example, Interroll publicly cites major customers like Amazon, Walmart, and DHL, highlighting their market prominence (Interroll, 2025).

Cost considerations for conveyor components vary significantly. Gravity roller conveyors typically cost about $13 to $40 per linear foot (FY Conveyor, 2023). MDR and belt-driven conveyor sections range from $150 to $200 per linear foot (JH Foster, 2023). Turnkey installed conveyor projects usually budget around $500 per linear foot, depending on scope and quantity. MDR sections featuring ZPA can cost up to $5,000 per linear foot (FY Conveyor, 2023).

Best practices suggest using belt-on-slider or roller conveyors with adjustable speeds for infeed, gapping, and merging operations in specific distribution center zones (Hytrol, 2025). The Hytrol "Gapper" conveyor operates at speeds up to approximately 550 feet per minute (Hytrol, 2025). High-quality fabric belts from Habasit are recommended for compatibility (Habasit, 2012). Modular plastic belts from Intralox suit various application needs (Intralox, n.d.). Interroll's drum motors are commonly employed to streamline system drives and enhance hygiene (Interroll, 2020).

Between work cells, 24 V MDR zero-pressure accumulation technology such as Interroll's EC5000 or Itoh Denki models offers quiet and safe operation with about 90% energy savings compared to traditional belt conveyors (Interroll, 2025). Itoh Denki motors offer similar benefits in terms of energy efficiency and operation (Itoh Denki, 2023). For long conveyor runs and inclines, belt-on-roller conveyors powered by drum motors or gear motors are recommended (Interroll, 2020). Fabric belts like Habasit Transilon deliver durability and optimal friction (Habasit, 2012).

Sortation technologies should be selected based on required throughput. Sliding-shoe sorters by Honeywell, TGW, or Hytrol handle about 10,000 to 24,000 items per hour (Honeywell Intelligrated, 2018). Crossbelt sorters from Dematic, Interroll, BEUMER, or Körber support up to 80,000 items per hour and are gentle on soft goods (Dematic, n.d.). Tilt-tray sorters from EuroSort or Ferag accommodate small items and returns with capacities around 40,000 items per hour (NPI Sorters, 2023).

Pallet handling usually employs chain-driven live-roller conveyors and transfers by Hytrol or Interroll's energy-efficient ZPA conveyors (Hytrol, 2025). Major system integrators such as Honeywell Intelligrated, Dematic, Vanderlande, Daifuku/Wynright, and TGW oversee projects involving large-scale warehouse automation (Honeywell Intelligrated, 2018). These integrators also provide comprehensive warehouse execution software suites like Honeywell's Momentum and Vanderlande's VISION platform (Vanderlande, n.d.).

When specifying components or retrofitting systems, recommended products include Interroll MDR EC5000 units, Itoh Denki brushless DC motors, and Hytrol conveyors (Interroll, 2025). Intralox modular plastic belting and Habasit fabric belts are also common choices (Intralox, n.d.). Controls should interface openly with WES for routing and congestion management (Dematic, n.d.). Safety standards require compliance with ASME B20.1-2024 and OSHA regulations covering guarding, lockout, and power transmission (ASME, n.d.).

Where advanced AS/RS systems require costly, intrusive installation processes, MDR systems are highly adaptable and configurable to various warehouse floor plans and flexible to new demands (Hristov et al., 2024). MDRs offer a middle ground between automation and manual handling, potentially enabling a hybridized G2P system that limits human involvement in the transportation of merchandise. Evaluating these technologies requires a clear understanding of the performance metrics that define operational success at WCDC. The following analysis focuses on these key metrics.

B. PERFORMANCE METRICS ANALYSIS

This section explores the performance metrics identified through data analysis. This analysis focuses on key measures, including throughput, accuracy, uptime, responsiveness, and environmental conditions, which directly affect system efficiency, reliability, and safety. By scrutinizing scrubbed and validated data directly from WCDC, the analysis identifies both strengths and bottlenecks in current operations and highlights practical areas for improvement, and quantifies achievable gains through targeted automation and system enhancements. This evaluation provides a factual basis for aligning technology investments with warehouse performance goals, ensuring that decisions support realistic productivity gains while maintaining compliance with safety and quality standards. Table 2 summarizes the individual metrics identified. Each metric will be discussed in relation to how it contributes to increased efficiency through eventual automation.

Table 2. List of Performance Metrics Identified

Metric	Description	Measurement Method	Relevance to NEXCOM
Order Throughput	Orders processed per hour/day	Track orders processed daily/hourly	Achieve 20–30% throughput increase
Labor Efficiency	Units processed per labor hour	Measure output per worker hour	Reduce reliance on full-time labor
Inventory Accuracy	Precision of inventory records	Conduct cycle counts, compare records	Improve accuracy to 99%+
Order Fulfillment Time	Time from order to shipment	Track average fulfillment time	Enhance service speed
Picking Efficiency	Items picked per hour	Measure picks per hour	Optimize labor-intensive tasks
Mechanical Reliability	Frequency/duration of interruptions	Track mean time between failures	Ensure operational continuity

1. Order Throughput

The first metric identified was order throughput, primarily measuring the efficiency of merchandise flow. Weisgerber et al. proposed a cross-docking solution that moves merchandise directly from receiving to shipping, bypassing storage and increasing throughput (Weisgerber et al., 2024). WCDC adopted this approach, but still depends on manual labor during cross-docking. Automation has been proven to significantly boost warehouse throughput, as seen in systems used by Amazon (Laber et al., 2020). This gain is mainly due to error reduction, improved package sorting, and faster item recognition (Ferreira et al., 2023). To measure throughput accurately, records of receiving, picking, and shipping were cleaned of incomplete and inconsistent data, allowing precise measurement of units processed per hour. This clarity helps identify bottlenecks and focus automation efforts to speed up operations. Throughput, such as pieces per hour (PPH), is a valuable performance metric. Data cleaning showed that automation could increase throughput by 20–30%. The baseline throughput rates indicate strong productivity but also reveal manual bottlenecks, especially in picking and shipping, where tasks like RF scanning and manual sorting consume considerable time.

For example, the average 90-second pick operation can be significantly shortened by mechanizing the picking of small items, which account for approximately 30% of total picks. Data also shows variability in load times and occasional congestion that slows the flow. Improving reliability and minimizing stoppages through automation further raises effective throughput by increasing uptime and reducing idle labor. While accuracy in these operations remains high (above 99%), a 20–30% increase in throughput is realistic, considering the current state of operations and potential implementation challenges.

2. Labor Efficiency

The next metric revealed was labor efficiency. Weisgerber et al. found labor hours, especially in picking, to be a notable concern for NEXCOM (Weisgerber et al., 2024). The manual labor and travel time pickers spend moving merchandise was identified as a drain on employee productivity (Weisgerber et al., 2024). By analyzing and organizing relevant workforce and operational time data, we were able to estimate how effectively staff perform their tasks. Removing incomplete records, duplicates, and anomalies from files detailing pick times, load variability, and staff counts produced clean data that provided accurate cycle times and operator throughput. Table 3 shows the departmental breakdown within WCDC.

Table 3. West Coast Distribution Center Personnel by Department. Source: Kassfy (2025l).

Department Breakdown for Warehouse Staff	
Management	14
Administrative	2
Human Resources	1
Labeling, Picking and Shipping	7
Inventory	7
Maintenance	10
Receiving, Small Packages	5
Receiving	28
Cross-Dock	8
Replenishment, Storage Third Shift	10
Pickers, Storage	24
Shipping	14
Motor Vehicle Operator	2
Overseas Lawson Department	9
Fashion, ASN, Small Packages	10
Annex San Diego	8
San Diego Will Call Center	7
Total	166

The departmental breakdown, which shows that 63% of the 166 staff in direct material handling operations at WCDC (labelling/ picking and shipping, inventory, receiving/ small packages, receiving, cross-dock, replenishment/storage third shift, pickers/ storage, shipping, vehicle operators, and fashion/ASN/small packages), highlights the significant labor required to sustain the current throughput. The scrubbing also exposed variability in manual processes—such as 3–20 minute loading fluctuations—and untracked productivity gaps, indicating inconsistencies in labor utilization. Automation itself has been shown to reduce such variances in warehouse operations by standardizing actions and performing them with high precision (Chinthala, 2021).

3. Inventory Accuracy

This document has extensively discussed the claimed accuracy of automated systems, but the data show that increased accuracy can specifically lead to efficiency gains. High accuracy reduces the need for manual interventions caused by incorrect picks, wrong routing, or scanning errors (Laber et al., 2020). This means staff spend less time troubleshooting misrouted items or fixing inventory discrepancies, directly saving labor hours. Additionally, fewer errors lead to smoother workflows and less downtime from jams or process disruptions caused by inaccurate handling (Laber et al., 2020). The data indicate that even small improvements in accuracy can decrease operational variability, resulting in steadier throughput and better resource planning. Weisgerber et al. explained that error was a concern for WCDC, as many stores and follow-on locations lack space for excess or incorrect merchandise (Weisgerber et al., 2024). Strategies like cross-docking can help reduce material handling and lower error rates (Weisgerber et al., 2024). By reducing error-related delays and rework, accuracy improvements lead to faster, more predictable process flows. This efficiency boost not only improves productivity metrics such as throughput and cycle time but also lowers overall operational costs, making a strong case for investing in precise automation technologies. For example, analysis of the error rates file found 461 errors costing about $41,000, mainly due to incorrect picks and quantity discrepancies (Kassfy, 2025m). In these cases, humans had to manually correct the errors. Although available, these personnel were taken from their primary tasks, which directly impacts labor efficiency.

Additionally, the inventory accuracy data reports a 99.53% correctness rate. However, the cycle count variances reveal a net shortage of 45,000 units over several months, indicating hidden discrepancies that require manual follow-up (Kassfy, 2025c). Improving scan and routing accuracy would reduce these variances, cutting the need for time-intensive audits and corrections. The conveyor data show 74 unsent replies tied to communication issues acting as proxies for jams or misroutes. Since jams cause downtime and manual clearing, accurate sensor detection and sorting logic minimize these disruptions, keeping throughput steady (Kassfy, 2025f). As mentioned previously, picking productivity shows 60-second variability (Kassfy, 2025g). This may be due to such inefficiencies. Many delays stem from scanning challenges or handling errors that slow operators. Enhanced automated scanning accuracy and consistent label orientation reduce these delays, speeding up and standardizing picks.

4. Order Fulfillment Time

As Amazon has illustrated, the faster orders can be fulfilled, the greater the competitive business advantage and the stronger the efficiency metric (Laber et al., 2020). Weisgerber et al. discovered through interviews with NEXCOM management that a priority was maximizing value to its limited customer base and strategies such as G2P could reduce order fulfillment time (Weisgerber et al., 2024). The data revealed this by capturing cycle times, processing durations, and workflow bottlenecks. For example, the order cycle times file shows an average fulfillment cycle of 12.9 days, with some outliers exceeding 30 days, highlighting opportunities to shorten lead times (Kassfy, 2025h). This metric reflects the time from order receipt through picking, packing, and shipping, so long cycles signal inefficiencies or delays. Receiving and putaway data, combined with the picking and shipping files, provide daily volumes processed. However, differences between these rates and cycle times indicate flow constraints or workload imbalances that impact the speed of orders (Kassfy, 2025d; 2025e; 2025h).

Load variability and manual intervention delays, as noted in the process flow documents, highlight how human factors can extend fulfillment times. Through scrubbing and analyzing these data sources, fulfillment time emerged as a measurable metric that integrates throughput, labor efficiency, and process reliability—crucial for assessing overall warehouse performance and identifying focus areas for improvement.

5. Picking Efficiency

As previously discussed, the picking process is a clear bottleneck in the WCDC operation. Weisgerber et al. found through interviews that labor hours spent on picking are a major concern for NEXCOM, highlighting inefficiencies and opportunity costs in the current system (Weisgerber et al., 2024). Specifically, if picking is made more efficient through automation, subsequent processes will also benefit, as employees would be available to handle other necessary tasks (Weisgerber et al., 2024). Analyzing the picking and replenishment data, along with the volume of lines waved daily—about 5,000 lines—and failure rates, uncovers operational stress points (Kassfy, 2025a; 2025d). The predominance of less-than-case (LTC) picks, which require more detailed handling, further emphasizes the complexity and labor-intensive nature of picking, making efficiency improvements essential.

6. Mechanical Reliability

The data reveals mechanical reliability as a vital performance metric. Equipment uptime, fault occurrences, and operational disruptions are closely tied to mechanical components and, therefore, the operational effectiveness of the warehouse. The equipment downtime file provides a clear picture of system availability, showing an average uptime of around 72% when excluding planned maintenance (Kassfy, 2025k). This indicates significant unplanned outages, likely due to mechanical faults, that reduce overall productivity. The conveyor metrics report 8,300 daily divert actions and 74 unsent replies, which serve as indirect indicators of jams or mechanical communication failures (Kassfy, 2025f). Such events cause stoppages that require manual intervention, slowing throughput and increasing labor demands.

Error rates and fault logs from maintenance records show recurring issues with rollers, belts, and driver cards, emphasizing the impact of mechanical components on system continuity. These faults influence mean time to repair (MTTR), which, when minimized, supports faster recovery and higher reliability. Furthermore, the scrubbed data, which reveals repair times and spare parts usage, connects mechanical health to operational efficiency, showing that well-maintained components reduce downtime, leading to higher throughput and greater efficiency.

In summary, the data helped identify the actual bottlenecks and inefficiencies in the operation. By understanding the current state of efficiency, we can target and minimize specific areas through the implementation of automated systems. Based on the performance metrics and market research findings, we propose specific requirements and recommendations for future automation acquisitions at WCDC.

C. MODULAR HYBRID CONVEYOR SYSTEM REQUIREMENTS

Based on the established performance metrics, several recommendations can be made to meet operational requirements and improve efficiency within the WCDC. Upgrading to a modular hybrid conveyor with ZPA system for the current MDR setup is recommended. This solution fulfills warehouse needs without requiring significant infrastructure changes and also considers practical implementation concerns. Each system requirement is directly linked to the relevant performance metric to ensure focused operational improvements.

1. Selection of Modular Hybrid Conveyor Systems

Multiple widely available MDR conveyor products are suitable for use in modular hybrid systems within contemporary warehouses. Examples of such platforms include Interroll's Modular Conveyor Platform (MCP), FMH BestConnect, Ultimation MDR, and PULSEROLLER MDR. These systems are designed with modularity in mind, allowing for rapid reconfiguration and scalable expansion to support high-volume warehouse operations.

These systems improve material flow, labor efficiency, and system reliability within high-volume distribution environments. In WCDC's current configuration, many zones—especially RPK, CPK, cross-dock, and Shipping—rely heavily on manual intervention to regulate flow, prevent jams, and coordinate movement into the A-1 merge and sorter. This reduces throughput, causes frequent congestion, and relies on operators acting as human buffers. By contrast, a modular hybrid conveyor architecture uses standardized, plug-and-play conveyor sections combined with flexible non-conveyor transport to create a system that can be reconfigured as volume, SKU mix, or operational priorities change. When paired with ZPA logic, each conveyor zone becomes an intelligent, self-regulating buffer that ensures cartons accumulate with gaps and without pressure, eliminating many of the jams, choke points, and stop-start disruptions common in fixed conveyor systems.

Operationally, ZPA optimizes the flow of goods through the facility by stabilizing merges and automatically pacing products. Pick modules, full-case storage, high-velocity zones, and ASN/Cross-dock areas can feed onto conveyors without operators needing to manually time or meter placements. Accumulation occurs in controlled zones upstream of bottlenecks, preventing overflow into pick aisles or receiving docks. This leads to a smoother, safer, and more predictable flow into critical downstream systems such as the A-1 merge and outbound sortation. Since products arrive pre-spaced and consistently metered, the sorter functions closer to its designed capacity, with fewer mis-sorts, fewer emergency stops, and reduced variability between peak and off-peak periods. Additionally, ZPA decreases product damage by preventing cartons from compressing under back pressure, and it reduces energy use by powering only the zones actively conveying items.

From a labor and ergonomics standpoint, the hybrid ZPA-equipped system reduces non-value-added walking, manual spacing, and jam-clearing activities—freeing operators to focus on core picking, receiving, or shipping tasks. The need for constant supervisory oversight of flow is reduced, and safety improves due to fewer backup-related hazards. The modularity of the system also yields long-term scalability: new pick zones, temporary peak-season conveyors, or reconfigured shipping lanes can be integrated rapidly without reprogramming a centralized PLC architecture. In summary, integrating a modular hybrid conveyor system with ZPA enhances throughput, increases system resilience, improves worker safety and efficiency, and provides the operational flexibility necessary for modern, high-mix distribution centers.

2. Key Features and Benefits

- Utilization of low-voltage brushless DC motors, which enhances safety and delivers substantial energy savings—up to 90% compared to traditional belt-driven conveyors.
- Incorporation of zone-based logic, enabling precise accumulation and effective throughput management. This results in quieter and more efficient warehouse environments.
- Seamless integration with PLC and WES, facilitating their adoption in automated workflows and improving overall operational efficiency.

3. System Scope and Requirements

The system requirements outlined serve to define expectations across several dimensions, including functional, performance, mechanical, electrical, controls, software, safety, testing, documentation, and support. The modular hybrid conveyor is intended to serve five shipping lines, four receiving lines, and two picking/storage transfer lines within the 500,000-square-foot WCDC facility. For ease of reference, these requirements have been abbreviated.

4. System-Level Requirements

- **SYS-1:** Modular hybrid architecture (24V MDR ZPA with sorter) delivering a turnkey operational system.
- **SYS-2:** Supports five shipping, four receiving, two picking/storage lines; provisions to add two shipping and two receiving without core panel replacement.

Performance Metric Traceability: Order throughput.

- **SYS-3:** Interoperable with Owner WMS/WES, scanners, inline scale/ dimensions, and print/apply.

Performance Metric Traceability: Order fulfillment time.

- **SYS-4:** Design life ≥ 10 years under standard maintenance.

Performance Metric Traceability: Mechanical reliability.

5. Operations Requirements

- **OPS-1:** Shipping line (each): Peak 5,500 pph; Sustained 4,000 pph; speeds 60–300 FPM.
- **OPS-2:** Receiving line (each): Peak 4,000 pph; Sustained 2,800 pph; speeds 60–250 FPM.
- **OPS-3:** Picking/Storage (each): Peak 3,000 pph; Sustained 2,000 pph; speeds 35–200 FPM.

Performance Metric Traceability (OPS-1 to OPS-3): Order throughput.

- **OPS-4:** Uptime ≥ 99.5% (30-day period, excluding planned maintenance).

Performance Metric Traceability: Mechanical reliability.

- **OPS-5:** Accuracy ≥ 99.9% to intended destination; jam rate ≤ 1 per 10,000 units; mean jam recovery ≤ 60 s.

Performance Metric Traceability: Inventory accuracy.

- **OPS-6:** Noise ≤ 80 dBA at 1 m during sustained operation.

Performance Metric Traceability: Labor efficiency.

- **OPS-7:** Operable in 50–95°F and ≤ 80% RH (non-condensing).

Performance Metric Traceability: Mechanical reliability.

6. Product Handling

- **PH-1:** Product size range: min 6”×6”×1”; max 36”×24”×24.”
- **PH-2:** Weight range: 0.5–70 lb without loss of control or sensing accuracy.

- **PH-3:** Maintain label orientation/gap for scanning ≥ 99.5% read rate at rated speeds.
- **PH-4:** Finger-safe transfers and minimized catch points; polybag handling validated where applicable.
- **PH-5:** Use modular plastic in wet/debris zones; provide drainage where required.

Performance Metric Traceability: Picking efficiency.

7. Mechanical

- **MECH-1:** Standard widths 24/30/36 in; MDR bed length 10–12 ft; belted straights 10 ft standard.
- **MECH-2:** Modular curves/merges/diverters; 90° MDR curves maintain throughput and noise target.
- **MECH-3:** Belting: fabric for high-speed straights; modular plastic for wet/debris; antistatic and fire-rated per code.
- **MECH-4:** Incline/decline braking & hold-back to prevent runaway/back-drive.
- **MECH-5:** Seismic-rated supports; bolt-up adjustability; integrated guardrails; service platforms as needed.
- **MECH-6:** Drip pans at SW/DW/DM and print/apply; guarded rotating/ pinch points per ASME B20.1.

Performance Metric Traceability: Mechanical reliability.

8. Electrical and Power

- **ELEC-1:** 480V/3ph mains; 120/208V auxiliaries; segregated 24V DC MDR buses with local disconnects.
- **ELEC-2:** UL508A-listed panels; SPDs on mains; labeled LOTO points per OSHA 1910.
- **ELEC-3:** Auto sleep/wake and dynamic speed scaling for energy savings.
- **ELEC-4:** Cable management to maintain clear egress and proper bend radii; trays where exposed.

Performance Metric Traceability: Mechanical reliability.

9. Controls and Sensing

- **CTRL-1:** Rockwell or Siemens PLC with distributed I/O; configurable MDR ZPA zone lengths.
- **CTRL-2:** HMI with role-based access, diagnostics, guided recovery; alarm/event logs ≥ 30 days.

- **CTRL-3:** IP-rated sensors; redundant sensing at critical merges and sorter infeeds.
- **CTRL-4:** Automatic jam detection; zone block/unblock; safe restart logic.
- **CTRL-5:** Configurable rules for gap creation, slug release, and lane balancing.

Performance Metric Traceability: Order throughput.

10. Safety

- **SAFE-1:** Comply with ASME B20.1 and OSHA 1910; guard all hazards and provide LOTO points.
- **SAFE-2:** E-stops and pull cords every ≤ 30 ft and at hazards; stop time ≤ 1.0 s where feasible.
- **SAFE-3:** Provide risk assessment and safety validation (FAT/SAT); retain records.
- **SAFE-4:** ANSI Z535 signage and floor markings; safety user manual and training included.

Performance Metric Traceability: Labor efficiency.

11. Maintainability and Support

- **SUP-1:** MTTR ≤ 20 minutes for common faults; tool-less/quick-release designs preferred.
- **SUP-2:** Initial spares ≥ 2% for MDR rollers, belts, photo eyes, driver cards; one spare belt per critical zone.
- **SUP-3:** PM checklists (daily/weekly/monthly) with torque specs and lubrication schedules.
- **SUP-4:** Training for operators/maintenance; competency checklists and refreshers.
- **SUP-5:** SLA options with remote diagnostics and on-site response; escalation paths documented.

Performance Metric Traceability: Mechanical reliability.

12. Documentation and Deliverables

- **DOC-1:** Stamped drawings (where required), single-line layouts, elevations, power loads, load reactions, IO lists, and network topology.
- **DOC-2:** FDS, ICDs, and configuration backups for PLC/HMI/WES interfaces.
- **DOC-3:** As-built within 30 days of Final Acceptance (DWG/PDF and editable PLC/HMI sources).

- **DOC-4:** RAM model with MTBF/MTTR assumptions and recommended spares plan.
- **DOC-5:** Risk register, method statements, and QA/QC plan.

Performance Metric Traceability: Mechanical reliability.

13. Quality, Testing, and Acceptance

- **TEST-1:** FAT: 100% I/O, safety chain, MDR logic; throughput at 110% sustained for 30 minutes without a critical fault.
- **TEST-2:** SAT: 2-hour sustained runs per line type with Owner mix; accuracy ≥ 99.9%; noise ≤ 80 dBA; OEE live.
- **TEST-3:** 7-day burn-in: uptime ≥ 99.5%; punchlist closed prior to Final Acceptance.
- **TEST-4:** Deliver written procedures and results; Owner approval required.

Performance Metric Traceability: Order throughput.

14. Environmental and Ergonomics

- **ENV-1:** Corrosion-resistant finishes; belts/lubricants suitable for warehouse use; no harmful VOCs.
- **ENV-2:** Ergonomic workstation heights; ADA considerations for HMI reach and visibility.
- **ENV-3:** Mitigate lighting shadows at workstations and inspection points.

Performance Metric Traceability: Labor efficiency.

15. Expandability and Future Options

- **EXP-1:** Reserve MCC capacity, stubs, and network ports for +2 shipping and +2 receiving lines.
- **EXP-2:** Allow adding print/apply, smalls sorter, and pallet conveyor with minimal downtime.
- **EXP-3:** Software/device capacity headroom of ≥ 20% for future growth.

Performance Metric Traceability: Order throughput.

16. Warranty and Life cycle

- **WARR-1:** Warranty: ≥ 24 months parts / 12 months labor from SAT acceptance; includes MDR, drum motors, PLC/HMI, sensors.
- **WARR-2:** Provide a 10-year life cycle parts list with recommended replacement intervals and budgetary costs.

Performance Metric Traceability: Mechanical reliability.

D. SUMMARY

This chapter examined WCDC’s current operations and found that manual, labor-intensive processes are the primary source of inefficiency. By analyzing critical performance metrics—including order throughput, labor efficiency, inventory accuracy, order fulfillment time, picking efficiency, and mechanical reliability—the chapter established clear targets for operational improvement through automation. Market research identified several relevant automation technologies, such as G2P solutions, AS/RS, and MDR conveyors. While these technologies differ in complexity, installation requirements, and adaptability, they each offer considerable potential to boost speed and accuracy and reduce reliance on manual labor.

The performance metrics analysis pinpointed key bottlenecks, most notably prolonged manual picking and loading times, workflow inconsistencies, and mechanical downtime. Data supported the potential for automation to increase throughput by 20–30%, enhance labor utilization, minimize errors, and reduce the frequency of mechanical failures. In response, the chapter recommends implementing a modular hybrid conveyor system based on MDR technology with ZPA zone logic. This balances the desire for performance improvements and practical considerations, including ease of implementation and integration with existing warehouse management systems. The system requirements are closely linked to the identified performance metrics, emphasizing high throughput, reliability, safety, maintainability, and future expandability. Gradually replacing manual transport tasks with automation, this approach systematically reduces variability and sets the stage for ongoing gains in operational efficiency and warehouse performance. These recommendations set the stage for the study’s conclusions, which address the research questions and highlight opportunities for future research.

V. CONCLUSION AND FUTURE RESEARCH OPPORTUNITIES

This study endeavored to recommend automation solutions to WCDC based on performance metrics and market research. This chapter addresses the hypotheses and research questions and explains the key findings. The research findings then inform recommendations for future research.

A. HYPOTHESES FINDINGS

1. H1

If automation performance metrics are utilized to establish acquisition requirements for NEXCOM WCDC, commercially available products will satisfy those requirements.

The analysis shows that clear, data-driven performance metrics effectively align with commercially available automation solutions. Products such as modular MDR conveyors and scalable AS/RS systems meet the specified throughput, accuracy, and reliability goals. This confirms that existing technologies can fulfill NEXCOM WCDC's operational needs when acquisition requirements are carefully defined using performance data.

2. H2

Performance metrics at NEXCOM WCDC will show the same or increased output with fewer resources, such as manpower or time required.

The data supports the hypothesis that automation can boost throughput by 20–30% while reducing manual labor variation and cycle times. By automating key labor-intensive tasks such as picking and merchandise transport, NEXCOM WCDC can maintain or improve output with fewer personnel hours and less process unpredictability. This offers labor efficiency gains without sacrificing accuracy or fulfillment speed.

3. H3

Bureaucratic and regulatory practices within the DoD inhibit NEXCOM WCDC in its pursuit of greater automation.

While automation technologies align with operational needs, regulatory and bureaucratic factors present identifiable challenges to adoption. The NAF environment and the difficulty in justifying capital investment in automation impede its adoption. While the private sector, motivated by profit optimization, is on the cutting edge of minimizing the time and resources required to move merchandise through processes, the public sector primarily seeks to maximize outcomes, allocating resources as needed. For a NAF organization that aims to "break even" financially over time, the benefit of a marginal reduction in resource consumption is not readily apparent, provided the mission continues to be accomplished. We found that even in such an organization, private-sector-like drives toward efficiency create greater value for taxpayers by using existing technologies to operate more cheaply.

B. RESEARCH QUESTIONS FINDINGS

1. Primary Research Question

Do commercially available warehouse automation technologies exist that would create measurable increases in efficiency at WCDC?

Yes, the research confirmed that commercially available automation technologies exist that can deliver significant efficiency improvements at WCDC. Technologies such as MDR conveyors, G2P systems, and advanced AS/RS match the operational scale and complexity of WCDC. These solutions have been proven to reduce manual labor, increase throughput by 20–30%, and improve operational consistency. The modular nature of MDR systems enables phased automation deployment within existing warehouse layouts, delivering measurable efficiency gains without major infrastructure changes.

2. Secondary Research Question

What performance metrics should be used to evaluate the efficiency of current processes versus automated processes at WCDC?

Key performance metrics identified include:

- Order Throughput measures units processed per hour, reflecting speed and volume capacity
- Labor Efficiency assesses manpower utilization against output to capture productivity improvements
- Inventory Accuracy monitors error rates and discrepancies, indicating reliability of handling and sorting

- Order Fulfillment Time tracks total cycle time from order receipt to shipment, capturing process flow speed
- Picking Efficiency focuses on the time and error rates during item selection to reveal bottlenecks
- Mechanical Reliability evaluates equipment uptime and fault rates, showing operational stability

These metrics provide a comprehensive framework for quantitatively comparing manual and automated workflows. These allow for targeted automation implementation. Metrics can also be used to justify and evaluate the performance of new systems, ultimately demonstrating ROI.

3. Tertiary Research Question

What requirements based on performance metrics should be integrated into future automation acquisitions at WCDC?

Requirements must target the operational goals that the metrics define. These include:

- Throughput support systems must support peak and sustained processing rates aligned with shipping, receiving, and picking lines.
- Accuracy should achieve ≥ 99.9% sorting and routing accuracy to reduce manual error correction.
- Reliability uptime targets of ≥ 99.5% with fast mean time to repair are essential for continuous operations.
- Safety and compliance systems must meet OSHA and ASME standards, incorporating safeguards and ergonomic designs.
- Modularity and expandability of equipment should allow easy reconfiguration and future scaling based on growth projections.
- Integration interfaces with existing WMS and WES are required for seamless control.
- Energy efficiency and noise control designs should minimize power use and maintain noise levels at or below 80 dBA to support worker comfort.

These requirements are derived directly from performance insights and guide effective technology selection to enhance WCDC's operational efficiency. Targeting specific metrics through performance requirements allows contractors to develop solutions efficiently, informed by the desired outcome rather than design specifics. While this study provides actionable insights, several areas remain for further investigation to realize the benefits of automation at WCDC fully.

C. FUTURE RESEARCH OPPORTUNITIES

1. Formal Cost-Benefit Analysis

While this research focused on market analysis and generating performance requirements, further research is necessary to estimate implementation costs and ROI. With this data, NEXCOM can make better-informed decisions and provide stakeholders with peace of mind. The private sector has demonstrated significant ROI from automation, but that information must be translated for the government in a way that emphasizes the value of adopting additional automation.

2. Implementation of Advanced Robotics

The MDR design bridges the gap in current capabilities while balancing the challenges associated with large-scale infrastructure changes. MDR is only one component of the modern automated warehouse. AS/RS systems, which will eventually replace human pickers and stowing personnel, represent the next step in fully modernizing WCDC. However, this would require significant modifications to the warehouse infrastructure. Storage, floor plans, and employee transit routes would all need redesigning. This research would serve as a starting point for NEXCOM, prompting exploration of what automation, when fully implemented, would look like and cost.

3. Impact of Automation on Personnel

Our research showed that the question of automation replacing staff, possibly reducing the number needed in warehouse operations, is complex. While some manual jobs can be fully automated, the level of human oversight and control depends on the specific facility. Automated warehouses will likely require staff with different training and skills. This personnel shift may impact hiring processes, employee pay, and education. This research will provide NEXCOM with the information needed to decide how to manage staff during the transition to and operation of automated warehousing.

LIST OF REFERENCES

ASME. (2024). B20.1 safety standard for conveyors and related equipment. https://www.asme.org/codes-standards/find-codes-standards/b20-1-safety-standard-conveyors-related-equipment?utm

Bastian Solutions. (2022). Sorting through sorters: Your guide to sortation conveyor. https://www.bastiansolutions.com/blog/sorting-through-sorters-your-guide-to-sortation-conveyor/?srsltid=AfmBOorKXMTKTtZo5RQWP42Hc---tKmagvyWJRm3-PzDiTHNMHrjcE5x&utm

Calabrese, D. (2023, April 28). *Warehouse operators seek ROI and advantages in automation*. Transport Topics. https://www.ttnews.com/articles/warehouse-automation

Chinthala, L. K. (2021). Future of supply chains: Trends in automation, globalization, and sustainability. *International Journal of Scientific Research and Engineering Trends, 7*(6), 2395–566. https://www.researchgate.net/publication/391667388_Future_of_Supply_Chains_Trends_in_Automation_Globalization_and_Sustainability

Condri Ves. (2025). Hytrol 190-E24EZ O-ring driven zero-pressure live roller. https://www.condrives.com/product/hytrol-190-e24ez-o-ring-driven-zero-pressure-live-roller/?utm

Condri Ves. (2025). Hytrol gapper high-speed belt conveyor. https://www.condrives.com/product/hytrol-gapper-high-speed-belt-conveyor/?utm

Daifuku. (n.d.). McGraw-Hill case study. https://www.daifukuia.com/case-studies/mcgraw-hill?utm

DC Velocity. (2023). The new Ferag Denisort tilt-tray sorter. https://www.dcvelocity.com/articles/59308-the-new-ferag-denisort-tilt-tray-sorter-load-capacities-up-to-66-lbs-quieter-design?utm

Defense Standardization Program Office. (2009). *SD-15 Guide for Performance Specifications*. Fort Belvoir, VA: Defense Standardization Program Office. Retrieved from https://assist.dla.mil

Dematic. (2025). Conveyor products. https://www.dematic.com/en-us/products/conveyor/?utm

Department of Defense Logistics IT Strategy. (2024). *Logistics information technology strategy*. U.S. Department of Defense. https://www.dla.mil/Portals/104/Documents/DLMS/Summit/Resources/OSD_Logistics_IT_Strategy_2024.pdf

Edouard, A., Sallez, Y., Fortineau, V., Lamouri, S., & Berger, A. (2022). Automated storage and retrieval systems: An attractive solution for an urban warehouse's sustainable development. *Sustainability, 14*(15), 9518. https://doi.org/10.3390/su14159518

Epps, K. (2024). *Proposed topics for NPS thesis/capstone projects*. Naval Supply Systems Command.

Eurosort. (2025). Quad tilt tray sorter. https://www.eurosort.com/product/quad-tilt-tray-sorter/?utm

Ferreira, B., & Reis, J. (2023). A systematic literature review on the application of automation in logistics. *Logistics*, *7*(4), 80. https://www.mdpi.com/2305-6290/7/4/80

FY Conveyor. (2023). How much do conveyor systems cost? FY Conveyor. https://www.fyconveyor.com/resources/how-much-do-conveyor-systems-cost.html

Gravier, M. (2024, February 25). *Selected lessons from implementing a warehouse automation system*. New SCMR. https://www.scmr.com/article/selected_lessons_from_implementing_a_warehouse_automation_system

Greenawalt, T. (2024, October 9). *Meet the 8 robots powering your Amazon package deliveries*. About Amazon. https://www.aboutamazon.com/news/operations/amazon-robotics-robots-fulfillment-center

Habasit. (2025). Material handling: Distribution centers. Habasit. https://www.habasit.com/en-US/Industries/Material-Handling/Distribution-Centers

Halim, L., Santosa, W., & Dewayana, T. (2024). The effect of work process automation, warehouse management system, and experts on company operational efficiency with smart warehousing mediation in e-commerce warehouses in Jakarta. *Indonesian Interdisciplinary Journal of Sharia Economics (IIJSE)*, *7*(3), 7819–7839. https://e-journal.uac.ac.id/index.php/iijse/article/view/5668

Harty, E. (2018). Honeywell Intelligrated powers new Amazon fulfillment center. Honeywell Intelligrated. https://automation.honeywell.com/us/en/news/featured-stories/warehouse-automation/honeywell-intelligrated-powers-new-amazon-fulfillment-center

Hristov, V., & Chekurov, I. (2024, October 10–12). Laboratory set-up for the research of roller conveyors for logistics warehouses. *International Conference Automatics and Informatics 2024 (ICAI'24)*, Varna, Bulgaria.

Hytrol Conveyor Company, Inc. (2025). Live roller conveyor. Hytrol. https://hytrol.com/products/transport/live-roller-conveyor/

Interroll Group. (2025). Drum motors. Interroll. https://www.interroll.com/products/drum-motors

Interroll. (2025). Increase safety and reduce cost with automated pallet conveyor systems. Interroll. https://info.interroll.com/blog/safety-cost-automated-pallet-conveyor-systems

Itoh Denki. (2023). Why MDRs are becoming a system of choice in belt conveyor applications. Itoh Denki. https://www.itoh-denki.com/why-mdrs-are-becoming-an-option-of-choice-in-belt-conveyor-application/

JH Foster. (2025). How much does it cost to install a conveyor system? John Henry Foster. https://jhfoster.com/automation-blogs/how-much-does-it-cost-to-install-a-conveyor-system/

Kassfy, A. (2025a). 2a – Wave Metrics (Orders Filled). [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025b). 2b – Receiving and Putaway Metrics Reports. [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025c). 2c – Cycle Count RDM Metrics Reports. [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025d). 2d – Picking and Replenishment RDM Metrics Reports. [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025e). 2e – Shipping RDM Metrics Reports. [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025f). 2f – Conveyor RDM Metrics Reports. [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025g). 5a – Picking Productivity. [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025h). 6a – Order Cycle Times (Delivery). [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025i). 8a – Inventory Accuracy (Cycle Counts Sum). [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025j). 8b – Cycle Counts Sum (Variances). [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025k). 9 – Equipment Downtime. [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025l). 11 – Departmental Breakdowns for Warehouse Staff. [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025m). 13 – Error Rates (QA Report). [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025n). a – Research Data. [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025o). DC Metrics (3 Months). [Unpublished raw data set]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025p). DC Processing Flow. [Unpublished internal document]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025q). DC Shipping Process – Flowchart. [Unpublished internal document]. NEXCOM West Coast Distribution Center.

Kassfy, A. (2025r). Conveyor System Diagram. [Unpublished internal document]. NEXCOM West Coast Distribution Center.

Körber Supply Chain. (2020). Crossbelt sorter. Körber Supply Chain. https://koerber-supplychain.com/supply-chain-solutions/supply-chain-material-handling/sorter/

Kraus, T., & Lim, J. (November 6th, 2015). *Selecting the right accumulation conveyor: Understanding the choices in accumulation technology leads to better solutions for operations*. Intelligrated.com

Laber, J., Thamma, R., & Kirby, E. D. (2020). *The impact of warehouse automation on Amazon's success*. Robotics and Mechatronics Engineering Technology, Central Connecticut State University. ISSN (Online) 2348. https://ijiset.com/vol7/v7s8/IJISET_V7_I8_07.pdf

Ma, B. J., Kuo, Y.-H., Jiang, Y., & Huang, G. Q. (2023). RubikCell: Toward robotic cellular warehousing systems for e-commerce logistics. *IEEE Transactions on Engineering Management*. https://doi.org/10.1109/TEM.2023.3327069

McClinton, T., & Cottrell, R. (2020). *Preparing for warehouse automation: A guide for the savvy supply chain director.* Hatmill. https://hatmill.com/wp-content/uploads/2020/08/Preparing-for-warehouse-automation-a-guide-for-the-savvy-supply-chain-director-Hatmill.pdf

Navy Exchange Service Command. (2023). *Annual report: Serving sailors and families*. https://www.navsup.navy.mil/Portals/65/NAVSUP%20ENTERPRISE/Navy%20Exchange%20Service%20Command/Documents/NEXCOM%202023%20Annual%20Report.pdf

Navy Exchange Service Command. (2025). *Who we are*. Retrieved October 2023, from https://www.mynavyexchange.com/nex/enterprise-info/who-we-are

NPI Sorters. (2023). Choosing a parcel sorter. NPI Sorters. https://npisorters.com/2023/03/16/choosing-a-parcel-sorter/

OSHA. (2025). 1910.212 General requirements for all machines. Occupational Safety and Health Administration. https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.212

Packer City Sales. (2025). Intelligrated 24V zero-pressure roller conveyor 33x12. Packer City Sales. https://www.packercitysales.com/listings/4350316-intelligrated-mdr-24-volt-zero-pressure-roller-conveyor-33-x-12-many-avail

TGW Group. (2022). Natrix sorter: Powerful, energy-efficient, flexible. TGW Group. https://www.tgw-group.com/en/news/detail/tgw-natrix-sorter-powerful-energy-efficient-flexible/

Tomorrow Desk. (n.d.). *Amazon's robot army: Warehouse automation is slashing distribution jobs!* https://tomorrowdesk.com/vigilance/amazon-robot-army

Vanderlande. (2025). VISION warehouse execution system. Vanderlande. https://www.vanderlande.com/us/software/vision/

Verified Market Research. (2025, February 11). *The warehouse automation market is expected to generate a revenue of USD 54.05 billion globally by 2031, at a 14.45% CAGR, according to Verified Market Research*. PR Newswire. https://www.prnewswire.com/news-releases/warehouse-automation-market-is-expected-to-generate-a-revenue-of-usd-54-05-billion-by-2031--globally-at-14-45-cagr-verified-market-research-302373428.html

Walmart Corporate. (2016). A behind-the-scenes look at how Walmart delivers. Walmart Corporate. https://corporate.walmart.com/news/2016/06/02/a-behind-the-scenes-look-at-how-walmart-delivers

Weisgerber, A. J., Chery, A., & Zervas, M. T. (2024). *A case study of the Navy Exchange Service Command West Coast Distribution Center's planning approach to automation and robotics* (NPS-LM-25-287). Naval Postgraduate School, Acquisition Research Program. https://dair.nps.edu/handle/123456789/5340

Womack, J. P., & Jones, D. T. (1996). *Lean thinking: Banish waste and create wealth in your corporation*. Simon & Schuster.

Acquisition Research Program
Naval Postgraduate School
555 Dyer Road, Ingersoll Hall
Monterey, CA 93943

www.acquisitionresearch.net