



RESEARCH REPORT

Advancing Intelligent Data Capture in Modern Logistics Operations

Driving digital transformation and ROI through migration from 1D to 2D barcodes

IN COLLABORATION WITH VDC RESEARCH

AUTHORS

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COST DRIVER EXAMPLES IN LOGISTICS OPERATIONS*

Misshipments are the largest cost driver



\$696K/year in shipment errors

Scan failures create hidden labor drag



\$87.8K/year in rescan labor

Relabeling is recurring rework (labor + materials)



\$31.9K/year in relabeling labor

Compliance/traceability raises the cost of bad data



3% preventable inventory loss

*Based on survey-weighted average inputs from respondent facilities; annualized dollar estimates are calculated using the GS1 Cost Benefit Calculator's stated assumptions (labor rates, operating days, shifts, and unit costs).

Logistics teams are under pressure to move faster, share better data, and support traceability. As many operations consider a shift beyond legacy 1D-based workflows, phasing in data-rich 2D barcodes can reduce avoidable costs from rescans and labeling errors and improve productivity and consistency.

This VDC Research report, commissioned by GS1 US®, explains how intelligent data capture—such as 2D barcodes and global standards—can modernize warehouse workflows and improve data quality across trading partners.

The research is based on a survey of 400 U.S.-based Tier 1–2 organizations (primarily 501–10,000+ employees) along with 10 in-depth interviews with senior logistics, operations, IT, DC/warehouse, and traceability decision-makers conducted in Q3/Q4 2025.

Executive Summary

Key points

- *Warehouse and distribution center teams face pressure from rising SKU counts, higher speed/accuracy expectations, and tighter traceability rules and regulations.*
- *Legacy 1D barcodes and scanning workflows struggle with readability and the capture of attribute-level data (lot code, expiry, serial), driving scan failures, relabeling, and limited visibility.*
- *2D barcodes enable a single symbol to carry GTIN plus key attributes with more reliability — supporting better verification, data integrity, and automation readiness.*
- *External forces are accelerating change, including FSMA 204 traceability requirements (food) and DSCSA serialization/verification mandates (pharma).*
- *A successful transition requires a phased, coordinated, supply-chain-wide approach—new labels and scanners alone are not sufficient.*
- *This white paper is grounded in VDC primary research (400 US-based survey respondents) plus in-depth stakeholder interviews.*

Warehouse and distribution center operations are experiencing unprecedented pressure. SKU counts continue to rise, customer expectations for speed and accuracy are heightening, and regulatory bodies are increasing their demands for traceability and data integrity. However, many of the data-capture and labeling methods used inside today's warehouses were originally designed for environments that were far simpler. Linear barcodes and 1D scanners, while incredibly reliable, were built to serve workflows that did not require the capture of granular product attributes, real-time verification, or visibility across complex multi-party supply chains.

VDC's research indicates that this gap between operational reality and data capability is widening. Warehouses continue to rely heavily on 1D barcodes and legacy scanning equipment, even as labeling complexity increases and the industry moves towards more data-rich requirements.

Workflows disintegrate not because warehouses lack discipline, but because their foundational data structures are no longer aligned with modern data needs. Warehouse operations face growing strain from inefficient labeling practices such as multiple barcodes, scan failures, and relabeling, and from missing product data like lot, expiry, and serial numbers. These gaps slow workflows, raise labor costs, and reduce accuracy. As a result, warehouses operate with limited visibility, hindering automation, traceability, and coordination across the supply chain.

“A key challenge is combating counterfeit products that bad actors introduce on e-commerce platforms. 2D barcodes deliver their full value when suppliers apply serialization at the case level, enabling identity verification and product authentication. This approach allows brands and retailers to confirm that each item reaching the customer is authentic and traceable.”
– ***Leading DIY Retailer***

Data capture modernization, particularly the shift toward 2D barcodes and more structured data, offers a compelling solution and a meaningful path forward. But VDC’s primary research suggests that new labels and scanners alone won’t be sufficient to achieve the digital transformation goal.

It will require a concerted and coordinated effort across the supply chain along with a phased, pragmatic approach based on current operational realities and a shared understanding of where value will be created. The transition today is being accelerated by external forces, particularly regulatory requirements and retailer compliance programs.

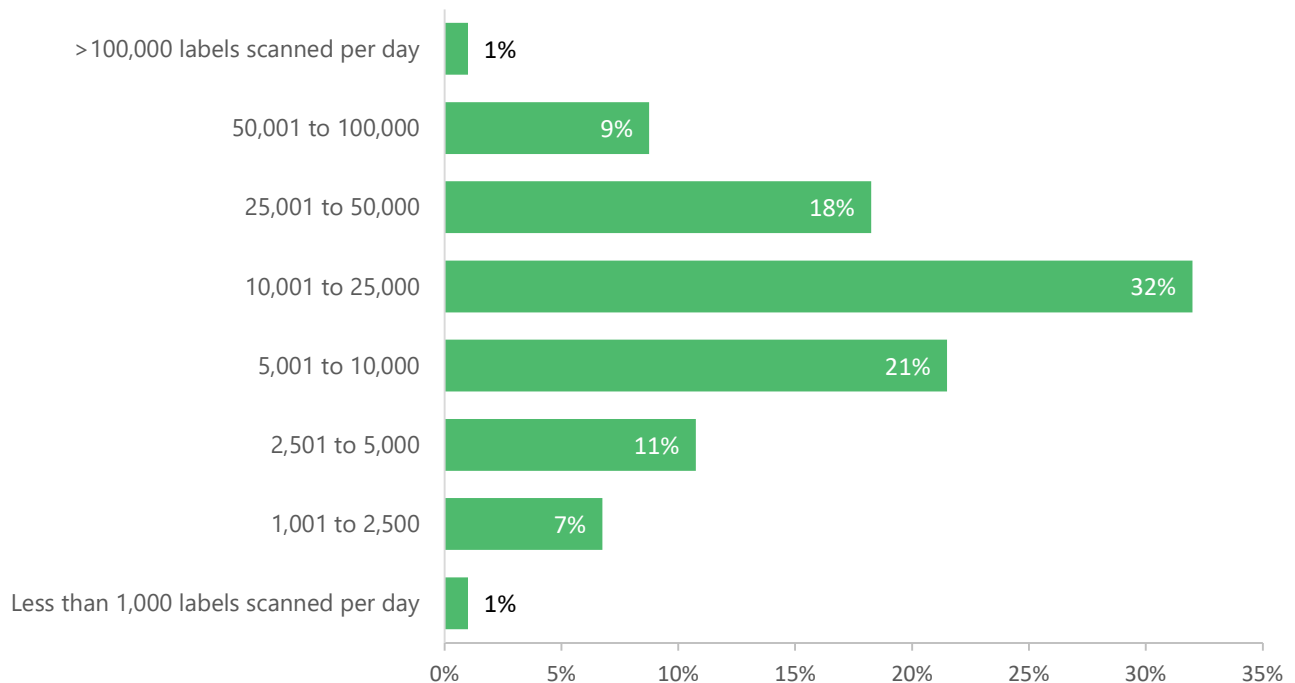
Food manufacturers face FSMA 204 traceability rules requiring more granular, event-based data capture and pharmaceutical industry participants must comply with DSCSA serialization and verification mandates. These regulations effectively require attribute-level data, which 1D barcodes cannot provide on their own.

“We have learned that industry-wide technology transitions must be grounded in robust business cases, with careful consideration of operational realities and the readiness of supporting systems.”
– F&B Brand

This white paper explores the operational realities shaping the need for modernization, the bottlenecks created by legacy data capture methods, the role of 2D barcodes in supporting next-generation warehouse performance, and the practical barriers that organizations must navigate. VDC aims to offer a realistic migration pathway grounded in primary research with 400 US-based survey respondents across retail, hospitality (food distributors), logistics, and manufacturing (consumer packaged goods, food & beverage, and pharmaceuticals), in addition to several in-depth interviews with key stakeholders at large enterprises in these sectors.

Average number of barcode labels scanned/facility

(Average: 22,145)



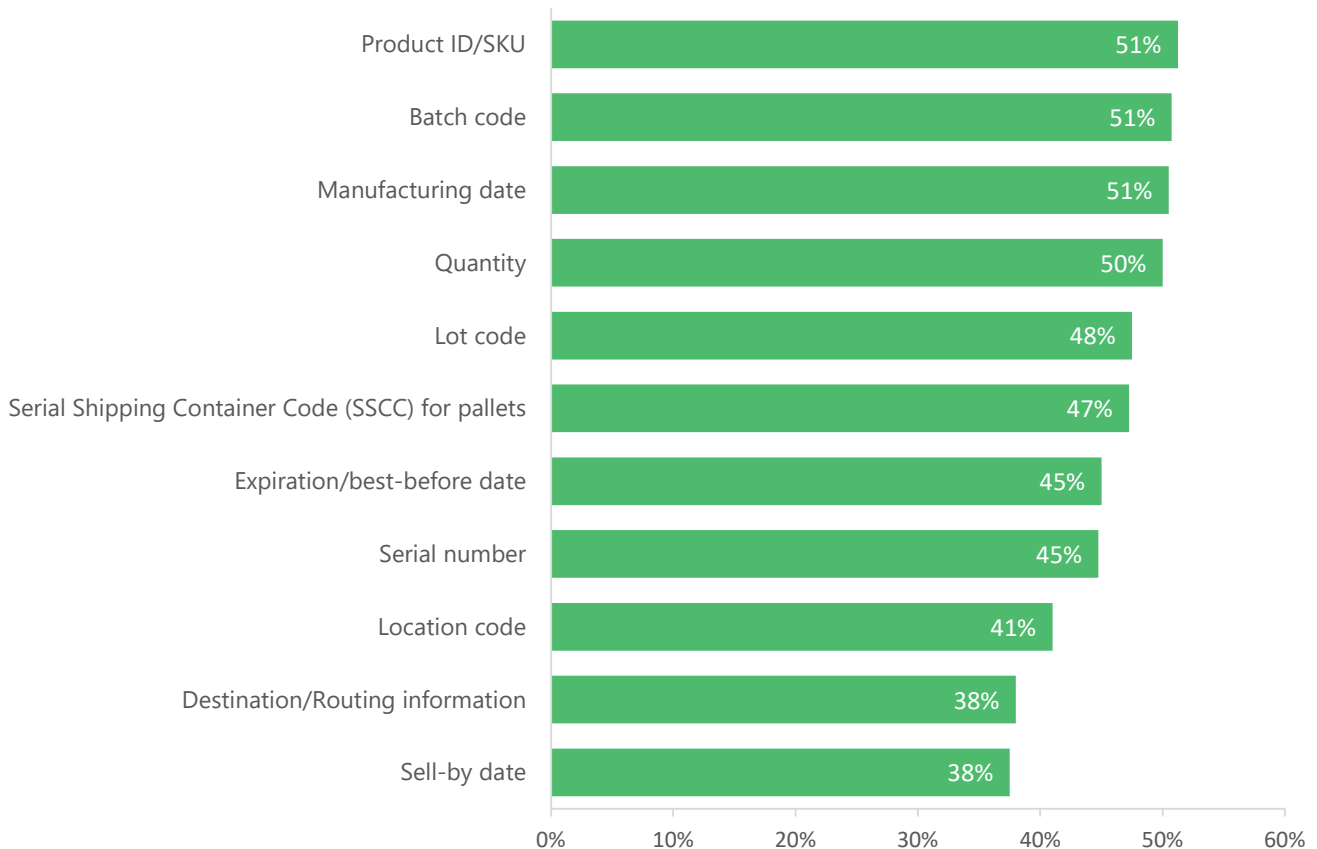
The Need for Modernization in Today’s Warehousing Environment

Key points

- Omnichannel and e-commerce compress fulfillment cycles and reduce tolerance for errors.
- Warehouses must move more inventory with fewer people while maintaining real-time accuracy and responsiveness.
- Data requirements now extend beyond SKU/GTIN IDs to include lot/batch IDs, expiration dates, serial numbers, and customer-specific labeling needs.
- Many WMS/enterprise systems still store only SKU-level identifiers—forcing manual or paper-driven workarounds.
- Inbound labels with multiple barcodes slow receiving as workers interpret which symbol and data format to scan.

Warehouse operations today are very different from even a decade ago. As omnichannel commerce expands and customer expectations evolve, warehouses must move more inventory with fewer people and with greater precision.

Information captured from labels



E-commerce fulfillment cycles have compressed the acceptable tolerance for errors. Retailers (and their customers) expect real-time accuracy and immediate responsiveness. Regulators are demanding more detailed, item-specific tracking. At the same time, supply chains are more geographically dispersed, involving a larger and more diverse set of suppliers with varying levels of technology maturity. Warehouse technology investments powering packing, picking, putaway, receiving, and shipping workflows have not kept pace with operational expectations. Linear barcodes, and systems designed to support the same, remain the dominant format even today.

“Pallet tracking via GS1-128 SSCC is vital, but data integrity challenges drive our interest in QR and Data Matrix codes for higher information density, error correction, and improved operational efficiency.”
– ***Leading 3PL Operator***

VDC’s research suggests that data requirements are now immense as operators are increasingly faced with rapidly changing assortments, complex lot requirements, expiration-sensitive goods, and customer-specific labeling demands. Many warehouse management systems (WMS) and other enterprise application platforms continue to only store SKU-level identifiers as they were never configured to handle additional information.

Without attribute-rich identification, warehouses are forced to rely on error-prone manual and largely paper-driven processes to manage the flow of goods. Lot numbers, batch IDs, expiration dates, serial numbers, and supplier-specific details are becoming essential.

“We use large, customer-specific labels with extensive data, but are considering shifting to 2D barcodes that offer greater data capacity, improved inventory control, and seamless WMS integration. This is driven by customer demand for operational efficiency.”
– ***Leading 3PL Operator***

Receiving teams often encounter labels with multiple barcodes, each representing slightly different data structures, formats, or supplier conventions. Workers must stop to interpret these labels, determine which symbol to scan, or attempt several scans before obtaining a proper read. These interruptions appear small in isolation, but they accumulate into quantifiable slowdowns across thousands of scans per shift.

Reasons for having multiple barcodes on the same label

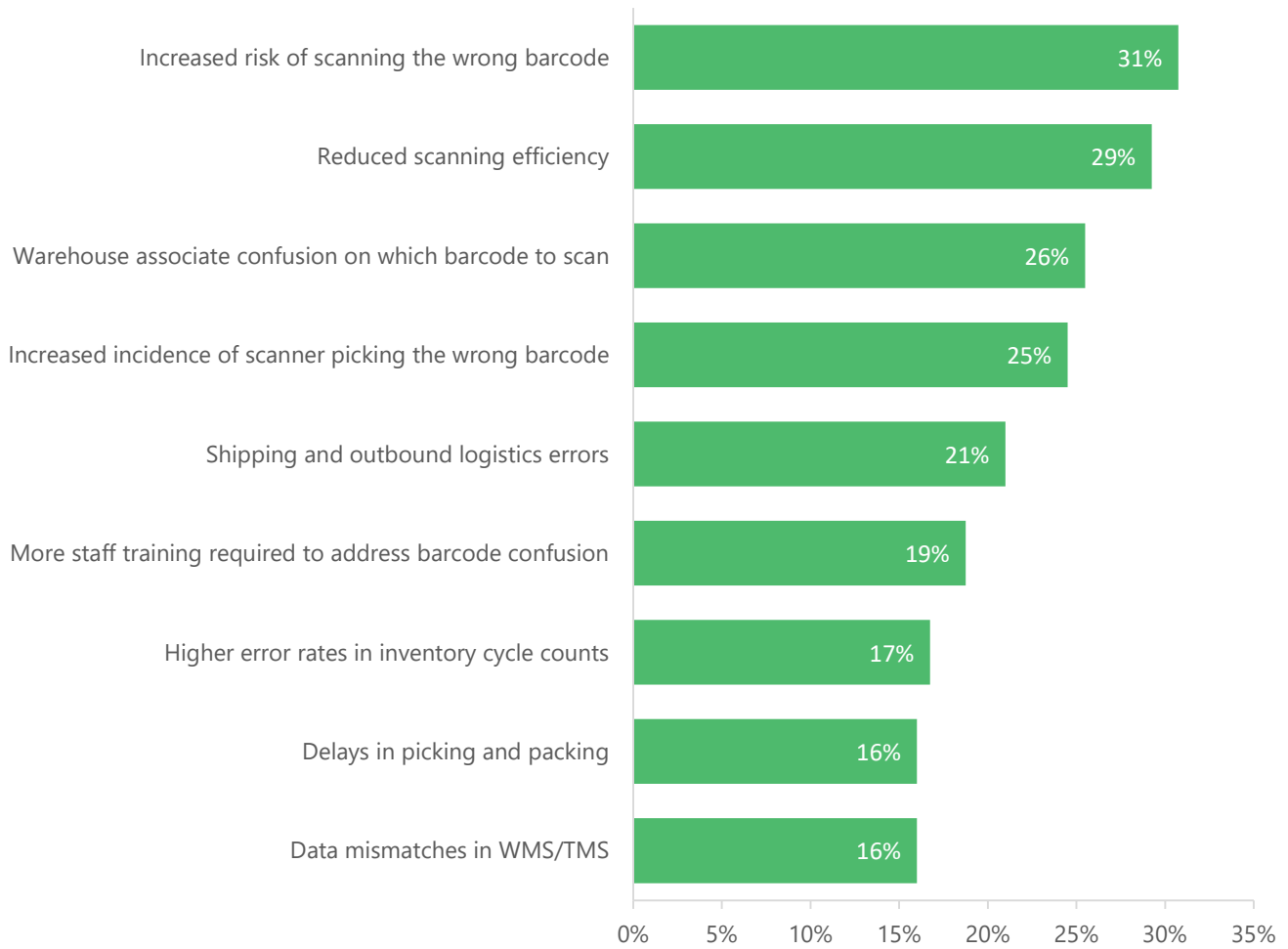


Operational Inefficiencies Stemming from Labeling Complexity

Key points

- *Inconsistent or missing upstream product data shifts effort downstream to warehouse teams.*
- *Multiple barcodes, varied symbologies, and damaged/poor-quality labels increase scan failures and time lost to re-scans.*
- *Relabeling (unreadable codes, missing attributes, customer mandates) adds labor, process variability, and—in regulated sectors—additional QA steps.*
- *Missing data and labeling inconsistency contribute to preventable inventory loss (survey respondents cited nearly 3%), including expiry issues and mixed lots.*
- *These gaps undermine automation initiatives that depend on consistent and structured data.*

Operational impact of having multiple barcodes on the same label

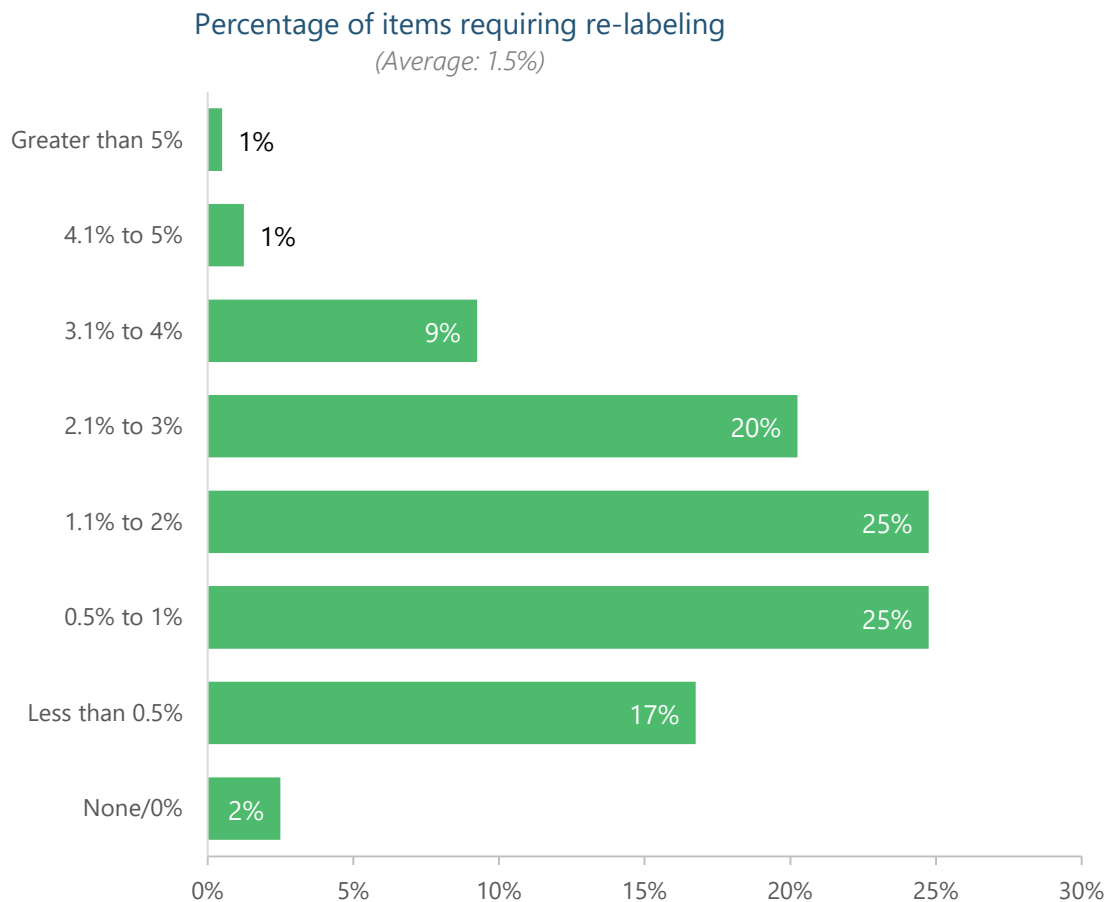


Data gaps undermine organizations’ digital transformation efforts and initiatives. Automated cycle counting, exception-based replenishment, AI-driven forecasting, and machine-vision quality checks all require consistent and structured data. When upstream suppliers use inconsistent data formats or omit attributes entirely, the burden shifts downstream to warehouse teams. Labeling inconsistency is a critical point of failure.

“Supplier labeling noncompliance forces us to break down pallets, manually identify items, and handle poor-quality data, slowing warehouse efficiency and requiring extra training to manage multiple labels and prevent scanning errors.”
– Leading 3PL Operator

Warehouses frequently receive cases and pallets with multiple barcodes packed into limited label space; this typically includes an assortment of linear symbologies, proprietary codes, and retailer- or supplier-specific formats. Operators must visually inspect labels, determine which barcode matches warehouse processes, and rely on their data capture device and underlying systems to interpret the format. Scan reliability declines even further when print quality is poor or labels are damaged for myriad reasons. A failed scan forces the operator to reattempt the process or seek manual verification.

In high-volume operations, these small moments accumulate into significant time lost across a full shift, representing substantial productivity loss, as evidenced by VDC’s research. Warehouses serving diverse supplier networks, particularly in consumer goods, food and beverage, and automotive parts, face higher variation in label formats and data structures.

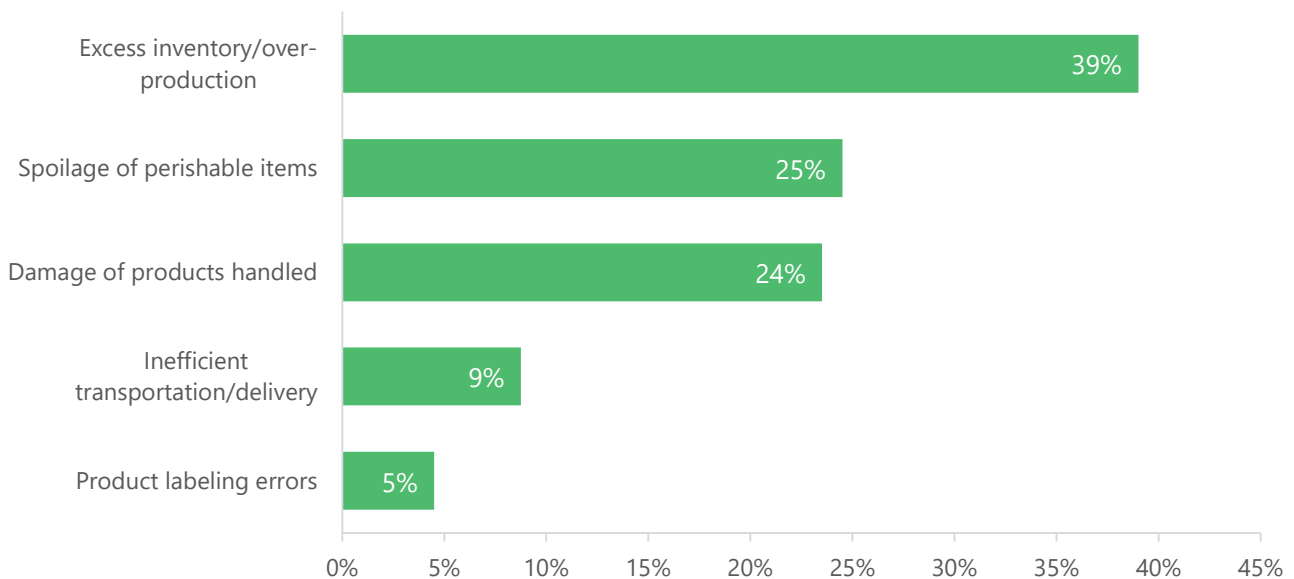


Larger facilities are strongly impacted as scan failures extend across thousands of inbound pallets or cases each day. Smaller operations also experience deep disruption due to lean staffing, even as they process fewer units.

Relabeling emerges as another operational burden directly tied to labeling inconsistency. When barcodes are unreadable, when key data such as lot or expiration information is missing, or when customer mandates require specific formats, operators must intervene manually to correct or replace labels.

This rework introduces additional time, variability, and, in regulated industries, extra layers of quality assurance. Even a relabeling rate of 1-2% translates into substantial labor time when inbound volumes are high. Inventory waste from spoilage, over-production, or damage, remains a persistent challenge across warehouse environments. Survey respondents indicated that nearly 3% of inventory loss can be attributed to missing data, inconsistent labeling, or the inability to track and rotate goods effectively. The operational consequences are tangible: receiving expired product, mixing lots unintentionally, or reworking pallets due to unclear date information. Errors in lot-specific fulfillment can lead to rejected orders, rework, or costly returns.

Primary contributor to supply chain waste



Where 2D Barcodes Fit in Warehouse Operations

Key points

- 2D barcodes support data-rich identification by encoding GTIN plus expiry, lot, serial, and other attributes in one symbol.
- Consolidation reduces label clutter and ambiguity, improving scan efficiency and first-pass read reliability.
- Attribute capture enables better rotation, recalls, verification, and cross-party traceability.
- 2D is a foundation for next-generation warehouse performance and future automation.

“We’re strategically adopting 2D codes for high-value and complex tracking, leveraging their data capacity and damage resilience to boost warehouse performance without disrupting existing barcode infrastructure.”
– Leading 3PL Operator

VDC's research suggests that 2D barcodes represent a dimensional shift in how data on cases and pallets can be captured, stored, interpreted, and communicated – these offer capabilities that linear barcodes cannot match. 2D barcodes have the potential to remove the ambiguity and clutter that plague current label designs by encoding expiration dates, GTINs, lot numbers, serial identifiers, and other key attributes within a single symbol.

Operationally, 2D symbologies reduce the need for multiple barcodes on a single label, which can significantly minimize operator confusion, while also eliminating error-prone manual workflows that slow down inventory movement.

“In warehouses, 2D’s biggest advantage is enabling serialization for safe consignment. For instance, preventing counterfeit batteries from being mixed with genuine ones that share the same UPC-A code but lack unique identification.”
– ***Leading DIY Retailer***

For industries with high traceability expectations, the value is even more pronounced. VDC's primary research conversations highlight some of the following benefits:

- *Food & Beverage distributors see improvements in expiry-based rotation and recall traceability.*
- *General merchandise retailers highlight 2D as a serialization enabler, preventing counterfeit options from being mixed with authentic/certified products.*
- *Pharmaceutical warehouses point to DSCSA compliance as a major driver, given that serialization requirements align directly with 2D capabilities.*

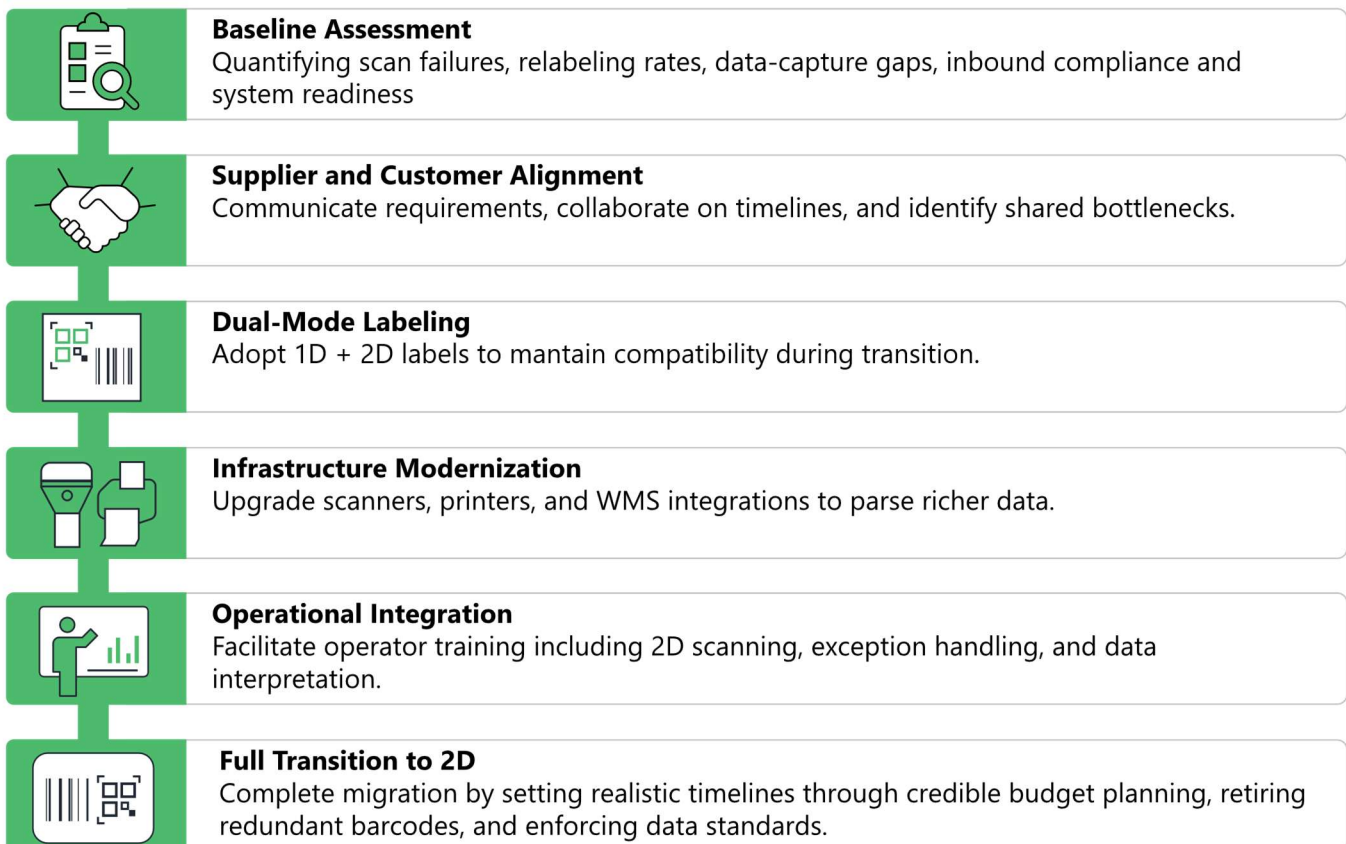
“We’re exploring a shift to 2D barcodes to eliminate multiple labels, reducing confusion. Adopting this would help prevent scan issues that cause products to be reclassified or removed from the line, reducing the labor currently spent resolving these problems.”
– ***Leading Department Store Retailer***

Modernization Readiness and the Path Toward Data-Rich Identification

Key points

- Adoption is shaped by budget cycles, staffing/training capacity, and multi-year refresh cycles for scanners and labeling infrastructure.
- A pragmatic starting point is a readiness audit: inbound label quality, scan failure drivers, and whether systems can parse and store structured attributes.
- WMS/ERP limitations and integration challenges can create workarounds unless back-end systems are updated for application identifiers and expanded attributes.
- Dual labeling (1D + 2D) during transition preserves legacy compatibility while allowing partners to capture richer data immediately.
- Standards and trading-partner alignment are essential so everyone interprets a label the same way.

2D Migration Roadmap



Many operators understand the long-term value of richer data and more intelligent workflows, but their ability to adopt new technology is shaped by budget cycles, staffing constraints, and the realities of large-scale operational change. Warehouses that have successfully begun migrating toward data-rich identification typically start by auditing inbound labeling quality, cataloging the frequency and causes of scan failures, and reviewing their system architecture to understand enterprise platforms' ability to parse structured data. VDC's interview feedback reinforces the importance of timing. Many warehouses replace data capture and labeling infrastructure on multi-year cycles. Attempting to accelerate these investments outside of existing cycles often meets resistance from budget owners who must prioritize across competing initiatives.

"If you're upgrading, absolutely invest in optical scanners. And if you're redoing a label, make it dual-mode – include a GS1-128 and a 2D code. That way, those ready to leverage incremental data digitally can do so, while others not yet in their capital refresh cycle or without the back-end systems to handle that data, aren't forced into extra costs."
– Leading F&B Brand

Most organizations time such upgrades with broader capital planning cycles, making rapid shifts impractical. System limitations remain a major barrier. Existing warehouse management platforms may not be configured to parse relevant application identifiers or store expanded product attributes with integration challenges compounding the issue. When systems cannot communicate, operators resort to workarounds, which introduce error and reduce confidence in reported data.

Even organizations enthusiastic about modernization caution against unrealistic timelines. Warehouses operate under tight staffing and performance requirements, and introducing new label formats, scanners, or workflows requires careful planning and training.

VDC's research consistently highlights printing both 1D and 2D codes during the transition as an effective strategy since it preserves compatibility with legacy systems while enabling partners to capture richer data immediately. Industry veterans repeatedly noted that warehouse environments cannot simply "flip the switch" on new standards—change must be incremental, validated, and aligned with operational rhythms.

VDC's primary research suggests that warehouses risk replacing one form of complexity with another if they don't adopt data labeling standards. It is imperative for every trading partner to interpret a label the same way, regardless of geographic location or underlying technology. Large organizations are committed to leveraging standards to ensure data commonality through their distributed digital supply networks.

"We're holding off on making significant investments until the next generation of GS1 standards emerges. Without standardization, we risk spends that may not align with the final, widely adopted requirements."
–Leading DIY Retailer

ROI Considerations and Value Creation

Key points

- *Value drivers include fewer scan failures, less relabeling, improved rotation of perishable inventory, reduced mis-shipments, and faster exception resolution.*
- *Benefits can translate into reduced chargebacks, faster payments, fewer audits, and stronger business relationships.*
- *VDC's ROI calculator separates baseline "cost of business" under 1D workflows from projected "benefits realized" after 2D migration.*
- *Results should be tailored using local inputs (wages, scan volumes, fail/relabel rates) to reflect real operating conditions.*

Output is structured in two stages:

- *Stage 1 – Baseline: estimate the "cost of the business" under current 1D-heavy processes (time lost to rescans, relabels, and disruptions).*
- *Stage 2 – Benefits: estimate savings from 2D migration separately from baseline costs (e.g., reduced relabeling and lower failure rates), and show sensitivity to operational changes.*

Major retailers and 3PLs often mandate labeling changes, but partner compliance requirements alone do not drive enthusiasm. What resonates more strongly is a clear demonstration of value: reduced chargebacks, better inventory accuracy, faster payments, fewer manual audits, and improved business relationships.

***"The shift to omnichannel sparked discussions about more data-rich barcodes, but resistance often comes from operations. While technology evolves, supply chains are largely led by operational veterans who follow the 'if it's not broken, don't fix it' mindset."
– Leading Department Store Chain***

The financial case for modernization rests on quantifiable improvements in accuracy, efficiency, and data quality. Survey respondents identified clear cost drivers that 2D barcodes can help address: fewer scan failures, less relabeling, improved rotation of perishable inventory, reduced mis-shipments, and faster exception resolution. These improvements accumulate into measurable labor savings, lower write-off rates, and stronger customer satisfaction. VDC's ROI calculator is a dynamic decision-support tool designed to quantify operational costs today and the benefits realized when migrating from 1D-centric workflows to 2D barcodes.

2D OVER 1D Barcode Cost Benefit Analysis Calculator – Per Logistics Fulfillment Center

It benchmarks small to midsize, large, and very large organizations using research-based baseline assumptions such as average SKUs, number of workers, scans per day, first-pass fail rates, relabeling frequency, and time lost due to workflow disruptions. Users can tailor key inputs (like hourly wage, operating days per year, scan volumes, fail and relabel rates) to mirror their environment, enabling scenario testing that reflects real operational conditions. The values in the table below are the average values across all research respondents conducted by VDC Research. The cost benefit of 2D-centric operations over 1D-centric operations is measured in lost productivity due to missed scans, relabeling costs and shipment errors incurred.

Metric	Average Values (weighted avgs from survey)
Hourly labor cost (USD)	\$20.22
Operating days per year	292
Shifts per day	2.2
Pallets received per shift	680
Cases received per shift	13970
Labels scanned per day	23465
First-pass fail rate (CURRENT 1D)	7.0%
Time lost per failed scan (seconds)	36
Relabeling rate (CURRENT 1D)	1.5%
Time per relabel (seconds)	42
Cost per relabel (label cost)	\$0.015
Items shipped per shift	2,000
Picking/shipment error rate (CURRENT 1D)	1.5%
Picking/shipment error rate (CURRENT 2D)	0.6%
Cost per misshipment error (USD)	\$40.00

Cost to Operations: 1D Dominant Infrastructure

Metric	Value
Rescan labor time lost per year (Hours)	4,391
Rescan labor cost per year	\$87,826
Relabeling events per day	471
Relabeling labor lost per year (Hours)	1593.55
Relabeling labor cost per year	\$31,871
Relabeling label cost per year	\$2,049
Shipment error cost per year	\$696,000
TOTAL ANNUAL COST/FACILITY	\$817,746

Operations: 2D Dominant Infrastructure

Metric	Value
Rescan labor time lost per year (Hours)	627
Rescan labor cost per year	\$12,547
Relabeling events per day	157
Relabeling labor lost per year (Hours)	531.2
Relabeling labor cost per year	\$10,624
Relabeling label cost per year	\$683
Shipment error cost per year	\$278,400
TOTAL ANNUAL COST/FACILITY	\$302,253

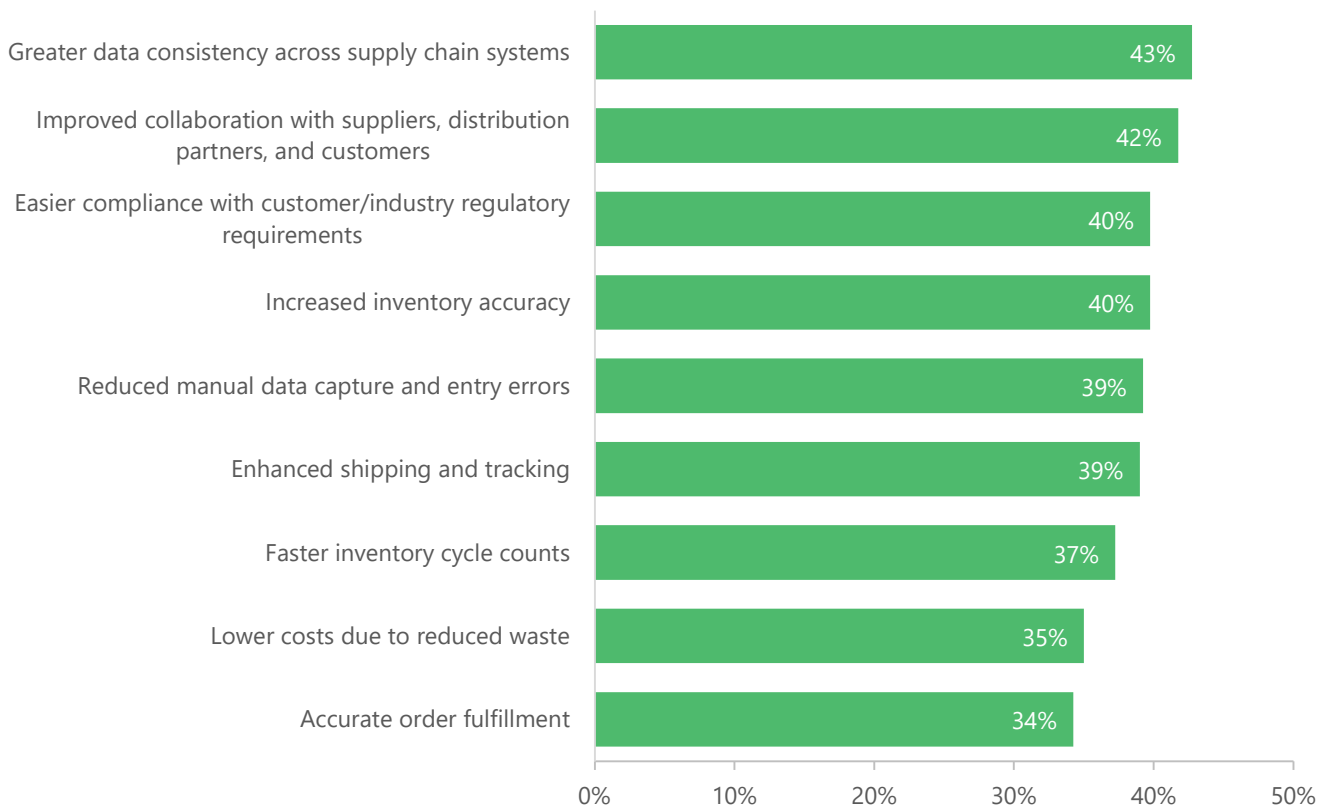
Cost Benefit of 2D Barcode Solutions over 1D Solutions per Facility: \$515,492

A Dimensional Shift for the Warehouse of the Future

Key points

- Migration from 1D to 2D is a key step toward broader data modernization and digital transformation.
- Success depends on phased implementation, ecosystem alignment, and systems that can leverage richer data—not just new scanning hardware.
- Standards bodies like **GS1** can accelerate adoption through education, implementation guidance, and interoperability across trading partners. Warehousing is entering a new dimension – defined by richer data, deeper visibility, and rising operational demands. VDC believes the shift from 1D to 2D barcodes will be a fundamental stepping stone to data modernization and digital transformation across complex supply chains.

Benefits of GS1 standards-compliant labeling



Organizations will take a collaborative and phased approach to this transition, anchored in readiness assessment, dual labeling, ecosystem alignment, and infrastructure investments to ensure that warehouses can modernize without compromising daily performance.

VDC believes migration success will depend on clear communication of ROI, alignment across suppliers and trading partners, and the development of backend systems capable of leveraging richer data. Standards bodies like GS1 will be central to accelerating progress by creating educational resources, guiding adoption, and harmonizing data requirements across value chain participants.

Their ability to articulate the long-term value of 2D migration, provide consistent implementation frameworks, and ensure interoperability across global supply chains will ultimately determine how quickly and effectively organizations transition.

When combined with phased modernization strategies and strong supplier enablement, these efforts will help the industry move toward a more resilient, efficient, and data-driven warehouse ecosystem.

***“For us, supplier compliance with labeling, quality, and data standards is non-negotiable. This ensures consistent traceability, reduces operational risks, and reinforces that strategic alignment is essential to maintain business partnerships.”
– Leading Big Box Retail***

Methodology

This report is based on feedback from 10 in-depth interviews conducted by VDC Research for GS1 US, along with the results of a survey among 400 US-based Tier 1 and Tier 2 organizations with logistics and warehousing operations in hospitality, manufacturing, retail, and transportation sectors. The research was conducted during Q3/Q4 2025.

The respondents to the in-depth interview and online survey are senior technology investment decision makers with specific responsibilities around supply chain operations with insights into labeling practices.

Survey Respondent Composition:

Industries:

- *Hospitality (13%)*
- *Retail (32%)*
- *Transportation/Logistics (24%)*
- *Manufacturing (31%)*

Number of Employees at Company:

- *501 – 1,000 (17%)*
- *1,000 – 2,500 (20%)*
- *2,501 – 5,000 (23%)*
- *5,001 – 7,500 (14%)*
- *7,501 – 10,000 (19%)*
- *More than 10,000 (7%)*

Responsibilities:

- *VP, Supply Chain & Operations (39%)*
- *Traceability Systems Manager/Director (7%)*
- *Warehouse/ Distribution Center Operations Manager (19%)*
- *IT Manager/Director (35%)*

About the Authors

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*Executive Vice President,
Enterprise Mobility &
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David has more than ten years of experience covering the markets for enterprise and government mobility solutions, wireless data communication technologies and automatic data-capture research and consulting. David focuses on identifying the key drivers and enablers in the adoption of mobile and wireless solutions among mobile workers in the extended enterprise. David's consulting and strategic advisory experience is far reaching and includes technology and market opportunity assessments, technology penetration and adoption enablers, partner profiling and development, new product development and M&A due diligence support. David has extensive primary market research management and execution experience to support market sizing and forecasting, total cost of ownership (TCO), comparative product performance evaluation, competitive benchmarking and end user requirements analysis. David is a graduate of Boston University (BSBA).

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*Consultant,
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Richa is a Consultant working for VDC's AutoID & Data Capture practice. She has been tracking the markets for a range of AIDC technologies at VDC since 2010, including, but not limited to, barcode scanners and printers, labeling solutions, machine vision solutions, and robotics automation. Over the years, she has undertaken market opportunity sizing and forecasting, competitive landscape analysis, and offered strategic marketing assistance, while also providing valuable thought leadership for this technology segment. Richa holds a degree in Computer Engineering and an MBA from India.

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About VDC Research

Founded in 1971, VDC Research provides in-depth insights to technology vendors, end users, and investors across the globe. As a market research and consulting firm, VDC's coverage of AutoID, enterprise mobility, industrial automation, and IoT and embedded technologies helps our clients make critical decisions with confidence. Offering syndicated reports and custom consultation, our methodologies consistently provide accurate forecasts and unmatched thought leadership for deeply technical markets. Located in Southborough, Massachusetts, VDC prides itself on its close personal relationships with clients, delivering an attention to detail and a unique perspective that is second to none.

For more information, contact us at info@vdcresearch.com.