



Warehouses Without Workers the Operational and Strategic Implications of Autonomous Fulfilment

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ABSTRACT

The growing capability of artificial intelligence, autonomous mobile robots, robotic picking, digital twins, and intelligent warehouse systems is accelerating the transition towards fulfilment environments requiring progressively less direct human intervention. This conceptual article examines the operational and strategic implications of workerless warehousing and questions whether maximum automation necessarily represents the most effective future of fulfilment. Drawing on recent literature concerning autonomous warehouse technologies, intelligent decision systems, human-robot collaboration, workforce transformation, and technological resilience, the analysis identifies substantial opportunities for greater speed, consistency, resource utilisation, and operational responsiveness. At the same time, extensive autonomy can concentrate dependency on software, data, connectivity, robotic infrastructure, cybersecurity, specialist expertise, and reliable power systems. Workforce reduction can also remove contextual knowledge and adaptive capability while increasing the importance of technical supervision, exception management, and human-centred work design. The article argues that autonomous fulfilment should therefore be approached as a continuum rather than an inevitable progression towards zero workers. It proposes selective automation, accountable algorithmic governance, workforce capability transformation, human-centred operating design, and resilient technological architecture as interconnected priorities. The article contributes a strategic perspective that reframes warehouse autonomy around sustainable operational value, adaptability, recoverability, and organisational control rather than labour elimination alone.

Keywords: Autonomy, Fulfilment, Warehousing, Resilience, Robotics

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1. INTRODUCTION

The prospect of warehouses operating with little or no direct human intervention is moving from technological ambition towards an increasingly credible model of fulfilment. Advances in artificial intelligence, autonomous mobile robots, robotic picking, machine vision, digital twins, intelligent scheduling, and interconnected warehouse management systems are progressively transferring activities once dependent on human labour to autonomous technologies. Rather than automating isolated tasks, contemporary systems are beginning to coordinate storage, movement, picking, routing, sequencing, monitoring, and operational decision making within integrated digital environments. van Geest et al., (2022) explain that smart warehouses are designed to improve service quality, productivity, and efficiency while reducing costs and failures through extensive automation and intelligent technologies. More recent evidence demonstrates how this technological trajectory is accelerating. AI-based order picking can reduce both travel distance and picking time (Rad et al., 2025), while deep reinforcement learning can dynamically optimise warehouse order picking under fluctuating demand conditions (Mahmoudinazlou et al., 2025). These developments indicate that autonomy is no longer confined to mechanising physical movement. It increasingly encompasses analytical and decision functions that determine how fulfilment systems perceive operational conditions, allocate resources, and respond to changing requirements. This development also reinforces the strategic importance of aligning warehouse capability with wider supply chain performance rather than evaluating technological advancement through isolated operating gains (Abdullah et al., 2020).

Behind the appeal of autonomous fulfilment lies a compelling operational proposition. Warehousing has traditionally depended heavily on labour for activities involving travel, retrieval, handling, sorting, packing, replenishment, and exception management, creating persistent exposure to labour availability, physical fatigue, productivity variation, and increasing fulfilment expectations. Cheng et al., (2024) demonstrate that robotic mobile fulfilment systems can reduce warehouse costs and improve operational efficiency by changing conventional material flow and resource allocation. Yet the progression towards full autonomy should not be interpreted as a straightforward substitution of machines for employees. Human-robot collaborative order picking can simultaneously address operational cost and ergonomic safety (Keshvarparast et al., 2025). Evidence also indicates that collaborative configurations can outperform traditional human-only picking across important responsiveness measures (Yu & Srinivas, 2025). These findings suggest that technological advancement may produce several viable fulfilment architectures rather than a single inevitable workerless model. Risk perception and managerial judgement remain important when automation decisions introduce new forms of operational uncertainty alongside expected efficiency improvements (Yusof & Razali, 2020). Autonomous warehouses must consequently be examined according to the operational capabilities they create and the human capabilities they remove, redistribute, or transform.

Strategically, removing workers from routine fulfilment processes changes far more than warehouse productivity. It alters the organisation's cost structure, capital intensity, technological dependency, skills requirements, risk profile, scalability, and capacity to respond when automated routines encounter unfamiliar circumstances. A warehouse dominated by autonomous technologies may reduce recurring labour dependence and achieve greater consistency, yet simultaneously become more dependent on software integrity, data quality, network connectivity, power infrastructure,

specialist maintenance, cybersecurity, and technology vendors. Rodríguez García et al., (2026) identify numerous technology-related vulnerabilities within highly automated warehouse systems, including cyberattacks, technological sabotage, technology failures, power and network outages, and human-machine interaction. Such findings expose an important paradox surrounding workerless fulfilment. Removing human involvement from operational execution does not eliminate vulnerability but can relocate it towards increasingly interconnected technological infrastructures. Successful AI adoption similarly depends on technological capability, system integration, organisational alignment, implementation costs, and resistance to change (Rad et al., 2025). Consequently, the strategic value of autonomous fulfilment cannot be assessed exclusively through labour savings or throughput improvement. Organisations must also possess sufficient technological governance, recovery capability, infrastructure, and managerial competence to sustain autonomous operations as decision authority increasingly shifts towards intelligent systems (Yusof & Abd Wahab, 2021).

Equally profound are the workforce implications created by the transition from labour-intensive warehousing towards machine-intensive fulfilment. The disappearance of particular manual activities does not necessarily imply the disappearance of human contribution because technological sophistication can eliminate certain occupations while creating demand for new forms of technical, analytical, supervisory, maintenance, and exception-management expertise. Industry 5.0 scholarship increasingly challenges purely technology-centred interpretations of warehouse advancement by positioning human centricity alongside resilience, sustainability, and intelligent technological development. Kumar et al., (2026) argue that emerging technologies are reshaping warehouse activities while strengthening the importance of human-machine collaboration within future warehouse systems. Evidence from collaborative picking reinforces this perspective. Workers and autonomous mobile robots can be dynamically coordinated to improve fulfilment responsiveness (Yu & Srinivas, 2025), while appropriately designed human-robot configurations can combine economic performance with ergonomic considerations (Keshvarparast et al., 2025). Human-centred work design also remains relevant during technological change because performance depends not only on equipment capability but on how remaining human roles are configured (Abd Wahab & Yusof, 2020). The technologically feasible warehouse may therefore be capable of removing progressively more human labour, but the strategically desirable warehouse may still require carefully positioned human capabilities for judgement, oversight, innovation, recovery, maintenance, and intervention.

A deeper examination of workerless warehousing must therefore move beyond the conventional narrative that greater automation automatically produces superior operational performance. Autonomous fulfilment represents a strategic redesign of the warehouse as a cyber-physical operating system in which machines, algorithms, data, infrastructure, and organisational capabilities become tightly interconnected. Digital twin technologies illustrate the direction of this evolution. Zhang et al., (2026) demonstrate that digital twin-driven warehouse control can integrate heterogeneous operational information, detect disturbances, and adaptively reconfigure plans in real time, producing improvements in responsiveness, storage efficiency, system stability, and resilience. At the same time, increasing technological interconnectedness can amplify exposure to cascading disruption, making resilience and recoverability essential components of autonomous system design (Rodríguez García et al., 2026). The emerging debate should therefore not be reduced to whether

warehouses can operate without workers. Warehouse management systems can reinforce supply chain resilience and competitiveness when digital coordination is embedded within wider operational capability (Yusof et al., 2025). A more consequential question is whether organisations can construct autonomous fulfilment ecosystems that remain economically viable, operationally adaptive, technologically secure, strategically resilient, and capable of managing circumstances beyond predetermined automated routines. This article consequently examines autonomous fulfilment through the interconnected dimensions of operational performance, technological dependency, workforce transformation, organisational resilience, and long-term strategic competitiveness.

2. LITERATURE REVIEW

Autonomous fulfilment represents a major evolution in warehouse management as automation moves beyond individual mechanised tasks towards integrated systems capable of sensing, coordinating, executing, and supporting operational decisions with less human intervention. Smart warehouse development has traditionally focused on productivity, service quality, efficiency, and cost reduction while recognising challenges involving integration, security, and organisational readiness (van Geest et al., 2022). Recent research expands this perspective through cyber-physical systems, digital twins, collaborative robots, reinforcement learning, resilience, and sustainability (EL Kadmiri et al., 2026). Human-machine collaboration has also become increasingly important within Industry 5.0 warehouse development (Kumar et al., 2026). Consequently, autonomous fulfilment should not be viewed simply as labour replacement. It represents a broader transformation involving operational performance, intelligent decision capability, workforce restructuring, technological dependency, and organisational resilience within increasingly automated fulfilment environments.

2.1 Warehouse Automation Evolution Shaping Autonomous Fulfilment Capability

Automation has historically concentrated on reducing manual effort associated with storage, retrieval, transportation, sorting, and picking, but contemporary technological development is moving warehouse operations towards substantially greater levels of autonomy. Smart warehouse architectures combine robotics, information systems, sensors, artificial intelligence, and interconnected physical resources to create environments capable of coordinating activities with limited direct intervention. van Geest et al., (2022) identify robotics and automation among the defining technologies supporting smart warehouse development and associate their implementation with improvements in productivity, efficiency, service quality, and operational reliability. Evidence from Alibaba's smart warehouse demonstrates that successful artificial intelligence applications require the coordinated deployment of data, algorithms, robots, facilities, information systems, and human resources (Zhang et al., 2021). These findings are particularly important because warehouse autonomy does not emerge merely from acquiring advanced machinery. It requires an organisational capability to orchestrate technological and physical resources within an integrated fulfilment architecture. The progression towards autonomous fulfilment should therefore be interpreted as a systemic transformation in which execution, information processing, and operational coordination increasingly migrate from fragmented manual activities towards interconnected digital and robotic environments.

Recent scholarship extends this development towards Warehouse 5.0, where technological sophistication is expected to coexist with resilience, sustainability, and human-centred design. Kumar et al., (2026) identify augmented reality, virtual reality, mixed reality, human-machine collaboration, real-time information, and intelligent technologies as increasingly important components of next-generation warehouse management. Emerging technologies such as cyber-physical systems, digital twins, cobots, and reinforcement learning can similarly strengthen monitoring, optimisation, and autonomy-related warehouse capabilities (EL Kadmiri et al., 2026). This evolution complicates the idea of a completely workerless warehouse. Although technological capabilities increasingly permit machines and algorithms to undertake activities previously performed by employees, recent literature does not consistently position complete human elimination as the optimal endpoint. Instead, autonomy appears to exist along a continuum ranging from task automation to highly coordinated machine-dominated fulfilment. Integrated safety management remains particularly relevant as warehouse technologies, work processes, and control responsibilities become more closely connected (Yusof, 2022). The appropriate degree of autonomy ultimately depends on operational complexity, investment capability, technological maturity, resilience requirements, product characteristics, and the continuing strategic value of human judgement.

2.2 Autonomous Technologies Transforming Warehouse Operational Performance Capability

Operational performance provides the strongest economic rationale for autonomous fulfilment because warehouse activities remain highly sensitive to travel distance, task sequencing, processing speed, labour availability, and resource coordination. Autonomous mobile robots can fundamentally alter conventional picker-to-parts systems by transferring transportation responsibilities from employees to robotic resources. Yu and Srinivas (2025) demonstrate that collaborative human-robot order picking can outperform traditional human-only picking across average order completion time, total tardiness, and worker travel distance when interventionist strategies are appropriately configured. Collaborative robotic systems can also improve warehouse order picking while incorporating operational cost and ergonomic considerations into system design (Keshvarparast et al., 2025). Smart automation and optimisation further strengthen picking and packing efficiency when technologies are appropriately matched with operational requirements (Yusof et al., 2025). These findings indicate that automation creates value not simply by replacing labour but by restructuring how responsibilities are distributed across warehouse resources. Transportation, routing, repetitive movement, and computationally intensive decisions can increasingly be allocated to technologies possessing comparative advantages in consistency and speed, allowing human capability to concentrate on responsibilities requiring greater flexibility and judgement.

Fuller autonomy, however, requires operational coordination considerably more sophisticated than the automation of isolated activities. Intelligent fulfilment systems must continuously align order arrivals, inventory locations, equipment availability, routing decisions, processing priorities, and capacity constraints. AI-enabled fulfilment capability emerges through the orchestration of complementary resources rather than algorithms operating independently (Zhang et al., 2021). Qin et al., (2026) further demonstrate through robot digital twin research that increasingly intelligent robotic systems require architectures capable of integrating physical systems with digital representations to support monitoring, optimisation, prediction, and adaptive decision making. These developments suggest that operational autonomy should be assessed according to system-level

performance rather than the number of employees removed from individual tasks. A warehouse containing hundreds of robots may still depend heavily on human operators for coordination, maintenance, recovery, and exception management, whereas a more integrated architecture may achieve substantially greater autonomy with fewer technological assets. Fragmented automation can improve individual processes, but genuine autonomy requires an intelligent operating architecture capable of sustaining coordinated performance across interconnected warehouse activities.

2.3 Artificial Intelligence Strengthening Autonomous Warehouse Decision Capability

Artificial intelligence represents a decisive technological transition because it extends warehouse automation from physical execution into forecasting, planning, learning, optimisation, and operational decision making. Zhang et al., (2021) identify forecasting, planning, and learning among the critical AI capabilities created within Alibaba's e-commerce fulfilment operations and emphasise that these capabilities depend on coordinated access to data, algorithms, robots, facilities, and existing information systems. Traditional mechanisation allows machines to perform predetermined actions, whereas intelligent automation increasingly enables systems to determine how resources should be deployed according to changing operational information. Reinforcement learning further expands this possibility by enabling decision systems to improve through interaction with dynamic environments. Its growing role in optimisation and autonomy-related warehouse capabilities reflects the wider movement towards increasingly adaptive fulfilment systems (EL Kadmiri et al., 2026). As artificial intelligence becomes embedded in routing, batching, resource allocation, inventory positioning, and predictive maintenance, operational authority progressively shifts from human supervisors towards algorithmically mediated decisions. The strategic consequence is substantial because warehouse performance becomes dependent not merely on functioning machinery but also on the quality, transparency, reliability, and responsiveness of the digital intelligence coordinating that machinery.

Digital twins provide an additional foundation for autonomous decision capability by connecting physical warehouse resources with continuously updated digital representations. Qin et al., (2026) describe robot digital twin architectures as increasingly important for developing smarter and more adaptive robotic systems. Their applications connect technological integration with system-level intelligence and create opportunities for more sophisticated operational coordination. Digital twins can also support monitoring, optimisation, and autonomy within resilient smart warehouse environments (EL Kadmiri et al., 2026). Properly integrated digital environments therefore offer capabilities extending beyond visualisation by supporting predictive assessment, simulation, resource reconfiguration, and faster responses to changing warehouse conditions. Yet increasing algorithmic authority creates new managerial requirements involving data governance, model reliability, cybersecurity, technological accountability, and system validation. Broader governance research similarly reinforces the importance of ethical accountability when organisational development becomes increasingly dependent on complex technological and managerial systems (Yusof et al., 2026). Autonomous decision capability must therefore balance machine independence with sufficient oversight to ensure that algorithmic decisions remain reliable when operating circumstances depart from expected patterns.

2.4 Workforce Transformation Preserving Human Capability Within Autonomous Warehousing

Worker reduction represents one of the most visible consequences associated with autonomous fulfilment, yet contemporary research suggests that the relationship between warehouse automation and human labour is considerably more complex than direct substitution. Human-robot collaborative systems illustrate how technological adoption can redistribute work rather than simply eliminate it. Keshvarparast et al., (2025) develop an order-picking model integrating economic and ergonomic considerations, demonstrating that collaborative robots can support efficiency while reducing some physical burdens associated with conventional warehouse activities. Yu and Srinivas (2025) similarly assign transportation responsibilities to autonomous mobile robots while workers continue performing pick-and-place activities, producing stronger performance than traditional human-only systems across several operational measures. Poorly designed collaboration can nevertheless expose employees to physical and psychological strain, whereas appropriate batching and workload allocation can reduce rack visits and improve workload balance (Li et al., 2026). These findings challenge interpretations of automation in which technological advancement is measured primarily through headcount reduction. The strategic issue increasingly concerns which activities should be automated, which responsibilities require human involvement, and how remaining work should be redesigned around capabilities that machines cannot reliably or appropriately perform.

Human centricity consequently remains prominent even as warehouses become increasingly autonomous. Kumar et al., (2026) explicitly position human-machine collaboration within Industry 5.0 warehouse development, where technological advancement is integrated with human-centred and resilient operating principles. Warehouse 5.0 research similarly suggests that technological innovation and human-centric approaches can generate complementary forms of organisational value. These perspectives indicate that the warehouse workforce is likely to undergo qualitative transformation as routine physical activities decline and responsibilities involving technological supervision, maintenance, troubleshooting, analytics, exception management, and continuous improvement become increasingly important. Completely removing employees could eliminate contextual knowledge and adaptive judgement that remain valuable during irregular circumstances. At the same time, preserving human participation without redesigning work risks maintaining unnecessary labour intensity despite technological advancement. Innovation-oriented development research supports the strategic importance of connecting technological capability with organisational priorities and performance outcomes (Yusof & Salleh, 2021). Autonomous fulfilment should therefore be judged by whether human and technological resources are configured according to their strongest capabilities rather than simply by the number of employees remaining within the warehouse.

2.5 Strategic Resilience Defining Workerless Fulfilment Operational Limits

Technological dependency represents perhaps the most consequential strategic limitation of highly autonomous fulfilment. As physical execution, information processing, and operational decisions become concentrated within interconnected technologies, disruptions affecting those technologies can influence multiple warehouse activities simultaneously. Rodríguez García et al., (2026) identify five major categories of disruption within highly automated warehouse systems: cyberattacks, technology sabotage, technology failures, power and network outages, and human-machine interaction problems. Their review further identifies vulnerabilities spanning software, data,

automation hardware, networks, infrastructure, organisational arrangements, and operational processes. Such evidence demonstrates that workerless operation does not remove warehouse risk but changes its composition and concentration. A labour-intensive warehouse may experience absenteeism, fatigue, inconsistent performance, or workforce shortages, while a highly autonomous facility can become increasingly dependent on electricity, connectivity, software integrity, robotic availability, cybersecurity, specialist maintenance, and technology providers. Organisations pursuing extensive autonomy must therefore ensure that technological architecture provides sufficient redundancy, recoverability, and alternative operating capability to prevent isolated failures from escalating into fulfilment paralysis.

Resilience scholarship provides a necessary counterbalance to narratives presenting maximum autonomy as the inevitable destination of warehouse development. EL Kadmiri et al., (2026) argue that smart warehousing should integrate emerging technologies with resilience, sustainability, performance measurement, and decision support rather than evaluate technological advancement independently. Technology-related vulnerabilities similarly require organisational capabilities encompassing prevention, detection, mitigation, and recovery (Rodríguez García et al., 2026). Earlier smart warehouse research already identified integration, security, safety, and transition challenges as important dimensions of technological implementation (van Geest et al., 2022). The most advanced warehouse may therefore not necessarily be the facility employing the fewest workers. Competitive advantage is more likely to emerge from an architecture that achieves high autonomous performance while retaining sufficient technological redundancy, recovery capability, specialist expertise, and organisational adaptability. Green innovation research likewise demonstrates that technological and sustainability initiatives can contribute to competitive advantage when embedded within coherent organisational priorities (Jamaludin et al., 2024). Workerless fulfilment should consequently be treated as a strategic design possibility rather than an unquestionable performance objective, with the appropriate level of autonomy determined by the organisation's ability to maintain control, recover from failure, and respond effectively beyond automated expectations.

3. OPERATIONAL VULNERABILITIES SHAPING AUTONOMOUS FULFILMENT SYSTEM PERFORMANCE

Rodríguez García et al., (2026) demonstrate that highly automated warehouses face disruptions involving cyberattacks, technological failures, power and network outages, and human-machine interaction. These risks show that the rapid movement towards autonomous fulfilment creates managerial challenges beyond the promise of faster, leaner, and less labour-dependent operations. Highly automated facilities can improve throughput, routing, inventory movement, and responsiveness, yet they also increase dependence on software, sensors, networks, robotic fleets, and specialised technical expertise. Fully autonomous robotic environments remain exposed to collision risks, congestion, scheduling inefficiencies, sensor dependence, and real-time adaptability constraints (Ou, 2026). These vulnerabilities become increasingly significant as direct human intervention decreases and operational control becomes concentrated within interconnected technologies. Autonomous fulfilment must therefore be evaluated through efficiency, technological concentration, decision limitations, workforce capability, and organisational resilience (Yusof et al., 2025).

3.1 Technological Concentration Creating Emerging Warehouse Operational Vulnerabilities

Rodríguez García et al., (2026) identify 48 technology-related vulnerabilities across software systems, data management, automation hardware, digital networks, physical infrastructure, organisational factors, and warehouse operations. Such vulnerabilities become increasingly important when large portions of routine human activity are removed and operational responsibility is concentrated within interconnected technological systems. Warehouse management software, autonomous mobile robots, automated storage and retrieval systems, sensors, cloud platforms, charging infrastructure, and control algorithms can become mutually dependent components of a single fulfilment architecture. Autonomous robotic systems also remain sensitive to hardware malfunction, battery loss, communication delay, sensor noise, congestion, and coordination complexity (Ou, 2026). This concentration fundamentally changes the nature of warehouse risk. Individual employees in labour-intensive operations can often be replaced, reassigned, or temporarily supported, whereas failure within a central autonomous control system may disable several processes simultaneously. Workerless fulfilment can therefore reduce labour dependency while creating concentrated technological dependencies capable of producing wider and faster operational consequences.

Connectivity intensifies this vulnerability because autonomous fulfilment depends on continuous communication between physical equipment and digital information environments. Uckelmann et al., (2011) explain how the Internet of Things provides an architectural foundation for connecting identifiable physical resources with digital representations and facilitating information exchange. Stronger interconnection, however, creates additional interfaces that must remain secure, accurate, and continuously available. Security, integration, technological reliability, and organisational readiness consequently remain important challenges within smart warehouse development (van Geest et al., 2022). Organisations pursuing worker-independent operations require backup communications, redundant controls, spare hardware, alternative routing, cybersecurity protection, and appropriate contingency procedures. Without these safeguards, technological interconnectivity can increase exposure to cascading operational disruption. The same digital architecture responsible for exceptional efficiency may therefore create conditions in which a single infrastructure failure immobilises inventory movement across an entire fulfilment process (Rodríguez García et al., 2026).

3.2 Autonomous Decision Capability Facing Dynamic Operational Constraints

Mahmoudinazlou et al., (2025) demonstrate that deep reinforcement learning can improve dynamic order picking by adapting routes to fluctuating order arrivals and strengthening fulfilment performance under high-demand conditions. Algorithmic control is consequently becoming increasingly capable of performing decisions traditionally assigned to warehouse planners and supervisors. Real-time warehouse information, cart capacity, and operator workload can also be incorporated into intelligent models capable of generating rapid solutions across numerous practical picking situations (Wang et al., 2025). Nevertheless, autonomous decision quality remains dependent on accurate state representation, appropriate training data, reliable sensors, computational availability, and assumptions embedded within the model. A workerless warehouse therefore introduces an important governance challenge because operational authority may migrate towards algorithms faster than organisations develop mechanisms for recognising inappropriate automated decisions. High performance under expected circumstances does not guarantee appropriate

responses when unusual combinations of demand, equipment failure, congestion, inventory errors, or infrastructure disruption emerge.

Complete autonomy is further complicated by the requirement to balance multiple operational objectives simultaneously. Autonomous warehouse management involves task allocation, path planning, energy scheduling, collision avoidance, congestion management, and real-time coordination across multiple robotic resources (Ou, 2026). An algorithm optimised for one objective can therefore produce undesirable consequences elsewhere. Autonomous systems may maximise throughput while increasing energy consumption, minimise travel while creating congestion, or maximise robot utilisation while reducing recovery capacity. Yu and Srinivas (2025) demonstrate the value of interventionist strategies in which robot and picker assignments can be modified as operating conditions change. Such evidence challenges the assumption that intelligent operations necessarily require complete elimination of human intervention. Autonomous systems may create greater value when they operate independently during predictable conditions while retaining mechanisms for escalation, override, and reconfiguration. Determining the appropriate boundary between autonomous authority and contextual human judgement consequently remains a fundamental managerial responsibility (Ou, 2026).

3.3 Workforce Reduction Creating Capability Loss Beyond Headcount Savings

Neumann et al., (2021) argue that humans remain an essential component of increasingly automated operational systems despite the expansion of Industry 4.0 technologies. This consideration is particularly important because the economic appeal of workerless fulfilment frequently concentrates on reduced labour dependence while overlooking organisational capabilities that may disappear through extensive workforce reduction. Collaborative order picking demonstrates how human item retrieval can operate alongside autonomous mobile robot transportation, allowing organisations to exploit complementary capabilities (Srinivas & Yu, 2022). Experienced employees also possess contextual knowledge concerning inventory exceptions, damaged goods, congestion, unusual orders, customer priorities, and process irregularities that may not be completely codified within autonomous systems. Human labour therefore cannot be evaluated simply as a homogeneous cost category. Removing employees without preserving their operational knowledge can create capability erosion that becomes visible only when technological failures or unusual circumstances demand judgement beyond predetermined automated routines.

Tam and Yusoff (2025) identify both opportunities and organisational challenges associated with automated storage and retrieval system adoption, demonstrating that warehouse automation requires preparation beyond equipment acquisition. Greater autonomy increases demand for technicians, data specialists, robotics engineers, cybersecurity expertise, maintenance personnel, and employees capable of interpreting automated system behaviour. At the same time, organisations may experience a declining pool of workers familiar with manual fulfilment procedures. Manual picking can retain important advantages through operational flexibility, resilience during system failure, and human capacity to manage complex situations intuitively (Azadeh et al., 2025). Removing labour may therefore lower recurring operating expenditure while excessive workforce reduction increases dependence on specialised technical personnel and external technology providers. Workforce transformation should consequently be understood as a redistribution of competencies rather than simply a reduction in employee numbers. Autonomous fulfilment can become strategically fragile

when traditional operational knowledge disappears faster than organisations develop the technical and adaptive capabilities required to replace it (Azadeh et al., 2025).

3.4 Residual Human Work Creating Intensified Sustainability Challenges

Neumann et al., (2021) caution that human factors remain insufficiently integrated into the design of advanced operational technologies despite their continuing importance to system performance. Autonomous technologies can reduce walking, transportation, lifting, and repetitive material movement, but employees remaining within highly automated warehouses may encounter a different and more concentrated pattern of work demands. Removing transportation activities, for example, can increase the frequency of picking activities and potentially create new ergonomic exposure and fatigue concerns. Automation may therefore eliminate physically demanding activities from substantial portions of the workflow while simultaneously intensifying repetitive, cognitively demanding, or closely monitored responsibilities for a smaller workforce. Lower headcount should not automatically be interpreted as evidence of a more human-centred working environment. The quality, pace, autonomy, ergonomics, and cognitive demands associated with residual jobs become increasingly important as automated systems determine a larger proportion of operational rhythm and task sequencing.

Hybrid warehouse research provides further evidence that human and robotic performance must be designed jointly rather than optimised independently. Azadeh et al., (2025) demonstrate that the effectiveness of human-robot collaborative picking configurations varies according to order size and resource configuration. Dynamic intervention can similarly strengthen responsiveness because picker and robot assignments can be modified as operational conditions change (Yu & Srinivas, 2025). Residual human involvement therefore provides flexibility that fully deterministic autonomous arrangements may struggle to reproduce. Such flexibility should not, however, result in employees becoming permanent buffers for technological limitations. If remaining workers must continuously resolve exceptions, respond to system failures, supervise robots, maintain demanding picking rates, and compensate for algorithmic weaknesses, automation may transfer operational complexity to people rather than eliminate it. Workerless fulfilment consequently creates an ethical and operational challenge concerning whether automation genuinely improves working conditions or concentrates greater responsibility and pressure among fewer employees (Neumann et al., 2021).

3.5 Absolute Autonomy Challenging Warehouse Operational Resilience Capability

Rodríguez García et al., (2026) demonstrate that technology-related disruptions in highly automated warehouses require capabilities spanning prevention, detection, mitigation, and recovery. Resilience therefore presents a major challenge to the assumption that complete worker independence should represent the ultimate objective of warehouse automation. Highly autonomous systems can achieve substantial utilisation and throughput, but operational resilience requires more than efficient performance under expected conditions. Autonomous warehouse frameworks incorporate fault tolerance, dynamic task redistribution, sensor-noise management, path replanning, and recovery mechanisms because actual operating environments inevitably experience equipment and information failures (Ou, 2026). The strategic problem emerges when extensive automation removes alternative operating modes while technological dependency simultaneously increases. A warehouse may achieve considerable productivity improvements yet lose its ability to perform essential activities when robots, software, communications, or power become unavailable. Resilience

consequently requires both reliable autonomous technologies and alternative options through which critical operations can be reconfigured during unexpected disruption.

Absolute autonomy may consequently be less strategically desirable than selective autonomy supported by deliberately retained adaptive capacity. Manual picking can provide flexibility and resilience during system failure even though fully automated alternatives may generate higher throughput under suitable operating conditions (Azadeh et al., 2025). Srinivas and Yu (2022) demonstrate how collaborative configurations can combine human flexibility with robotic transportation, while dynamic intervention can strengthen responsiveness under changing demand conditions (Yu & Srinivas, 2025). Intelligent algorithms provide another source of adaptability through their capacity to respond rapidly to dynamic warehouse states (Wang et al., 2025). The strategic debate should therefore move beyond a binary choice between human-operated and workerless warehouses. Organisations require sufficient machine intelligence to improve speed and consistency while retaining human expertise, technological redundancy, alternative procedures, and decision flexibility. The most advanced fulfilment model may ultimately be one capable of operating autonomously without becoming operationally helpless when autonomy itself fails (Rodríguez García et al., 2026).

4. STRATEGIC ARCHITECTURE STRENGTHENING RESPONSIBLE RESILIENT WAREHOUSE AUTONOMY

Autonomous fulfilment should be understood as a strategic redesign of warehouse capability rather than a technological race towards eliminating human labour. Greater autonomy can improve speed, consistency, routing, and resource utilisation, but it can also concentrate operational risk within interconnected digital and robotic infrastructures. Highly automated warehouse systems remain exposed to cyberattacks, technology failures, power and network outages, and human-machine interaction problems (Rodríguez García et al., 2026). This creates a need to balance technological independence with organisational control and recovery capability. Collaborative configurations provide another important dimension because human and robotic resources can strengthen fulfilment performance when their responsibilities are appropriately coordinated. The strategic objective is therefore not simply achieving workerless operations but developing responsible autonomy that improves economic performance without weakening adaptability, workforce capability, or operational resilience (Yu & Srinivas, 2025).

4.1 Full Autonomy Evaluated Through Strategic Warehouse Value

Rodríguez García et al., (2026) demonstrate that highly automated warehouse systems introduce vulnerabilities across software, data, hardware, networks, physical infrastructure, organisational factors, and operational processes. Such exposure is particularly important when labour scarcity, high order volumes, predictable workflows, and strict fulfilment requirements make extensive automation economically attractive. Reducing direct labour dependency can simultaneously increase dependence on technologies that may be difficult to substitute when critical systems fail. Human-robot research provides an important counterpoint. Warehouse efficiency is influenced by the configuration of autonomous mobile robots and human pickers as well as physical layout characteristics such as cross aisles (Garg et al., 2025). The strategically strongest warehouse may therefore not be the facility with the lowest possible headcount but the one achieving an appropriate balance between autonomous execution and retained human capability. Autonomy should

consequently be treated as a continuum shaped by warehouse scale, product characteristics, demand volatility, technological maturity, capital availability, and recovery requirements rather than as a universal destination.

Economic justification must also include the cost of technological dependence rather than focusing solely on labour savings and throughput improvement. Highly autonomous fulfilment requires continuous investment in robotics, software, sensors, cybersecurity, technical support, energy infrastructure, network availability, maintenance, and system upgrades. Rodríguez García et al., (2026) show that greater supplier involvement, cloud reliance, and complex multi-robot networks can expand the cyber-risk surface and amplify cascading disruption. Collaborative configurations, by comparison, can retain flexibility while generating significant operational benefits. Yu and Srinivas (2025) report that interventionist human-robot systems can outperform traditional human-only picking across order completion time, tardiness, and worker travel distance. Organisations should therefore compare autonomous and hybrid configurations through total lifecycle value rather than narrow labour-substitution calculations. Capital expenditure, maintenance complexity, downtime, technology replacement, cybersecurity, workforce transition, and recovery capability all influence long-term value. A fully autonomous warehouse may be economically superior under particular operating conditions, but its justification should rest on sustainable system value rather than the symbolic achievement of workerless fulfilment (Rodríguez García et al., 2026).

4.2 Algorithmic Autonomy Requiring Accountability Boundaries Human Escalation

Yu and Srinivas (2025) demonstrate the value of interventionist strategies because collaborative systems can revise ongoing tasks as new orders arrive rather than remain bound to initial allocations. This flexibility becomes important as greater operational autonomy transfers decision authority from supervisors and employees towards algorithms. Algorithmic control can improve speed and consistency where routing, sequencing, batching, and task allocation involve numerous possible combinations, but autonomous decisions remain dependent on data quality, sensor accuracy, system assumptions, and model capability. Routine operational choices may reasonably be executed without direct human approval, whereas abnormal inventory conditions, repeated system conflicts, safety concerns, deteriorating service performance, and uncertain data should trigger supervisory review. Clearly defined escalation thresholds can preserve the speed advantages of algorithmic control without allowing technically valid but contextually inappropriate decisions to propagate throughout fulfilment operations. Autonomous decision capability should therefore expand alongside appropriate boundaries defining where machine authority ends and human intervention becomes necessary.

Accountability becomes equally important because workerless environments can blur responsibility for operational outcomes. A routing error may originate from incorrect data, defective sensors, algorithmic rules, poor software integration, vendor updates, or inappropriate managerial configuration. Disruption vulnerabilities frequently span several technological and organisational categories rather than originating from one isolated component (Rodríguez García et al., 2026). Governance arrangements must therefore specify responsibility for algorithmic performance, system validation, anomalous behaviour, operational intervention, and suspension of autonomous processes. Human oversight should function as a governance capability rather than merely a technical backup. Warehouses moving towards greater autonomy should maintain decision logs, exception records,

validation procedures, override mechanisms, and clearly assigned accountability for critical algorithms. Managers must also recognise that a system functioning exactly according to its programming can still produce undesirable outcomes when objectives or assumptions are inappropriate. Autonomous fulfilment becomes strategically credible only when organisations retain sufficient capability to question, interpret, and intervene in machine-generated decisions.

4.3 Workforce Transformation Prioritising Capability Renewal Beyond Labour Elimination

Zheng et al., (2025) argue that warehouse robotics should be understood from a sociotechnical perspective because technological, task, human, and organisational factors remain closely interconnected. The movement towards workerless fulfilment should therefore reshape workforce strategy rather than simply reduce employee numbers. As manual tasks disappear, organisational knowledge requirements shift towards robotics maintenance, system integration, cybersecurity, analytics, troubleshooting, operational supervision, and exception management. Robots can alleviate physical workload while simultaneously creating new mental and psychosocial demands. Experienced warehouse employees may consequently be repositioned into technology supervision, exception resolution, continuous improvement, maintenance coordination, and recovery roles where contextual knowledge remains valuable. Organisations should deliberately preserve and upgrade critical operational knowledge rather than allow technological adoption to remove it unintentionally. The strategic objective should therefore be workforce transformation rather than workforce disappearance, ensuring that technological capability expands without simultaneously eroding the organisational knowledge required to sustain and recover autonomous fulfilment operations.

Reskilling becomes particularly important because technical requirements within autonomous warehouses are likely to evolve faster than traditional warehouse job structures. Employees previously specialising in picking, replenishment, or material handling may require new competencies involving robot interaction, data interpretation, software troubleshooting, equipment diagnostics, and digital safety. Poorly balanced human-robot environments can create physical and psychological strain, while improved batching and allocation can strengthen workload equity (Li et al., 2026). Keshvarparast et al., (2025) similarly integrate ergonomic considerations with operational cost, demonstrating that technological efficiency and workforce quality can be pursued simultaneously. Automation investment should therefore be accompanied by structured workforce-transition programmes involving redeployment, technical certification, cross-functional capability, and continuous learning. This capability becomes particularly important when technological failures require temporary manual or semi-automated operations. A warehouse that eliminates direct labour without retaining employees who understand fundamental operating processes may achieve short-term efficiency but become strategically brittle when autonomous technologies fail (Zheng et al., 2025).

4.4 Human Centricity Preserving Value Within Near Workerless Operations

Zheng et al., (2025) find that warehouse robotics can reduce physical workload while simultaneously introducing mental and psychosocial challenges. A lower number of employees therefore does not automatically create better working conditions for those who remain. Residual jobs within highly automated environments can become more technically demanding, cognitively intensive, closely monitored, and dependent on machine-generated work rhythms. Human pickers may also experience physical and psychological strain when workload distribution requires them to continuously keep

pace with robotic teammates (Li et al., 2026). These findings challenge the assumption that automation automatically improves job quality. Organisations should evaluate residual warehouse roles according to ergonomic exposure, cognitive workload, task autonomy, responsibility concentration, safety, and psychological demands. Employees should not become permanent exception handlers responsible for compensating for every technological limitation. Near-workerless environments should instead use automation to remove hazardous and repetitive activities while designing remaining roles around meaningful decision authority, manageable workloads, technical competence, and genuine operational contribution.

Operational design should also avoid forcing human employees to function merely as extensions of robotic systems. Recent collaborative picking research demonstrates that human and machine resources require careful balancing rather than independent optimisation. Garg et al., (2025) show that autonomous mobile robot and picker allocations have significant implications for economic and operational efficiency, indicating that increasing robot numbers does not automatically produce proportional performance improvements. Warehouse autonomy is consequently a system-design problem rather than simply a technology-adoption problem. Organisations must optimise interactions between technological assets and remaining human resources instead of continuously increasing automation density. Where human participation remains necessary, system pace, task allocation, and operational responsibility should reflect realistic human capabilities. Residual workers should possess sufficient authority to stop, redirect, or question autonomous processes when safety or operational integrity is threatened. Such arrangements allow organisations to preserve human adaptability while technologies perform repetitive and computationally intensive activities for which they possess stronger capabilities (Garg et al., 2025).

4.5 Resilient Autonomy Strengthening Strategic Warehouse Performance Capability

Rodríguez García et al., (2026) demonstrate that cyberattacks, technology failures, sabotage, network outages, and human-machine interaction problems can disrupt highly automated warehouse systems. The strongest argument against pursuing workerless fulfilment as an absolute objective therefore concerns resilience. A fully autonomous warehouse can achieve exceptional productivity during normal operations yet become highly vulnerable when critical processes depend on common technological infrastructure. Autonomous systems must consequently be designed around failure as well as performance. Critical robotic and digital systems require redundancy, alternative communication routes, backup power, recovery procedures, spare equipment, cybersecurity controls, and clearly defined degraded operating modes. Human intervention should also remain available where it provides economically justified recovery capability. A warehouse capable of continuing critical order processing at reduced capacity following technological disruption may possess greater strategic autonomy than one operating without employees under ideal conditions but becoming completely inactive when a central system fails.

Resilient autonomy also requires reconfigurability rather than static technological perfection. Allowing active human and robotic tasks to change during dynamic order arrivals can improve responsiveness compared with non-interventionist configurations (Yu & Srinivas, 2025). System performance therefore depends on balancing human and robotic resources according to operational conditions rather than imposing one fixed configuration universally. From a risk perspective, highly automated warehouses similarly require mitigation and recovery capabilities alongside disruption

prevention (Rodríguez García et al., 2026). These findings support a model of resilient autonomy in which automated systems operate independently during stable conditions while retaining technological, organisational, and human options for reconfiguration during disruption. Such an approach avoids the false choice between completely manual and completely workerless warehousing. The decisive competitive advantage is more likely to arise from systems capable of operating with minimal human intervention while retaining the ability to recover, adapt, and preserve critical fulfilment when normal technological assumptions fail.

5. STRATEGIC PATHWAYS STRENGTHENING SUSTAINABLE AUTONOMOUS WAREHOUSE DEVELOPMENT

Moving towards autonomous fulfilment requires organisations to reconsider what technological progress should ultimately achieve within warehouse operations. Removing workers may reduce dependence on manual labour, but workforce elimination should not become the primary measure of technological maturity. Rad et al., (2025) demonstrate that AI-based order picking can improve travel distance and processing time, although implementation remains influenced by technological and organisational conditions. Greater automation can simultaneously create new technological, organisational, human, and resilience requirements. Highly automated warehouse systems are particularly exposed to cyberattacks, equipment failures, network disruption, and cascading operational consequences (Rodríguez García et al., 2026). Organisations therefore require strategies built around selective automation, accountable decision systems, workforce capability transformation, human-centred operational design, and technological resilience. These priorities provide a more sustainable pathway towards autonomous warehousing without creating excessive technological dependence.

5.1 Selective Autonomy Prioritising Operational Value Creation Potential

Organisations should determine the appropriate level of warehouse autonomy through systematic evaluation of operational value rather than assuming that maximum automation represents maximum performance. Processes characterised by repetitive movement, stable demand patterns, predictable product characteristics, high transaction volumes, and limited exceptions provide stronger conditions for extensive automation. Rad et al., (2025) demonstrate that AI-based order picking can improve travel distance and picking time, although technological and organisational challenges can restrict implementation success. Conversely, operations involving substantial variability, irregular products, frequent exceptions, or contextual judgement may continue to benefit from human participation. Future warehouse development increasingly reflects Industry 5.0 principles in which technological advancement is combined with human centricity and resilience (Kumar et al., 2026). Management should therefore assess automation candidates according to transaction volume, process stability, labour intensity, safety exposure, exception frequency, investment requirements, technological maturity, and recovery complexity. Such evaluation allows investment to concentrate on processes where autonomous technology produces demonstrable operational value rather than automatically replacing activities where flexibility and human judgement remain strategically important.

Selective autonomy should also be periodically reassessed because warehouse conditions and technological capabilities continuously evolve. An operation currently requiring human participation may become suitable for autonomous execution as machine vision, robotics, artificial intelligence, and sensor technologies improve. Successful AI adoption nevertheless depends on organisational

and technological factors extending beyond technical system performance (Rad et al., 2025). Changes in products, customers, order profiles, service requirements, or operational risks may also create circumstances in which greater human involvement becomes appropriate again. Organisations should consequently establish an autonomy portfolio classifying activities as fully autonomous, collaboratively operated, human controlled, or suitable for future automation. Investment reviews can then determine whether existing configurations remain appropriate as labour markets, technologies, service expectations, and operating conditions change. This approach transforms automation from a one-time capital decision into an evolving strategic capability. Autonomous fulfilment can consequently expand where evidence supports greater independence without forcing every warehouse process towards workerless operation regardless of changing operational circumstances (Kumar et al., 2026).

5.2 Governance Accountability Strengthening Autonomous Decision Control Mechanisms

Rad et al., (2025) demonstrate the operational potential of AI-based order picking while identifying technological and organisational challenges that influence successful implementation. Decision authority transferred to artificial intelligence should therefore be accompanied by governance mechanisms establishing responsibility for autonomous system behaviour. Intelligent warehouse applications increasingly influence order batching, routing, prioritisation, inventory movement, resource allocation, and scheduling, allowing consequential operational decisions to occur without immediate human approval. Vulnerabilities within highly automated warehouses can simultaneously extend across software, data, networks, automation hardware, infrastructure, and organisational arrangements (Rodríguez García et al., 2026). Organisations should classify autonomous decisions according to operational significance and establish corresponding levels of control. Routine decisions operating within validated parameters may remain fully automated, whereas safety concerns, abnormal inventory conditions, uncertain data, severe service deterioration, or major disruption should trigger escalation. Governance arrangements should clearly specify algorithm ownership, modification authority, monitoring responsibilities, and intervention rights to prevent increasing machine autonomy from creating uncertainty over responsibility.

Control architecture should additionally preserve meaningful human intervention without requiring continuous supervision of every autonomous activity. Effective autonomy depends on machines executing routine decisions independently, but independence should not become irreversibility. Rodríguez García et al., (2026) identify prevention, detection, mitigation, and recovery as important dimensions of risk management within highly automated warehouses. Organisations should therefore implement decision logs, anomaly-detection mechanisms, escalation thresholds, emergency overrides, model-validation protocols, and periodic audits of algorithmic outcomes. Critical systems should also be tested against inaccurate information, unusual demand patterns, equipment shortages, network deterioration, and operating conditions beyond normal parameters. Responsibility for these activities should extend across operations, information technology, engineering, cybersecurity, and risk management rather than remain exclusively with technology specialists. Autonomous decision making becomes strategically sustainable when organisations understand what systems are deciding, why their decisions remain acceptable, and how managerial control can be recovered when automated behaviour exceeds acceptable operational boundaries (Rodríguez García et al., 2026).

5.3 Workforce Capability Transformation Reducing Excessive Human Dependence

Workforce transformation should precede extensive labour reduction because autonomous fulfilment changes required employee competencies rather than eliminating organisational dependence on knowledge. As robots and algorithms assume greater responsibility for transportation, retrieval, routing, monitoring, and repetitive decisions, organisations increasingly require expertise in equipment maintenance, data interpretation, exception management, technology supervision, cybersecurity, and system recovery. Kumar et al., (2026) emphasise human-machine collaboration within Industry 5.0 warehouse management, demonstrating that advanced warehouse development remains connected to human-centred operating principles. Warehouse robotics should similarly be approached as a sociotechnical system in which technology, tasks, human factors, and organisational outcomes remain interconnected (Zheng et al., 2025). Before reducing positions, organisations should map operational knowledge, identify competencies being replaced, and determine new capabilities required by autonomous environments. Experienced employees can then be redeployed into technology supervision, equipment coordination, inventory control, maintenance support, exception management, and continuous improvement rather than allowing valuable operational knowledge to disappear.

Structured reskilling should subsequently become a continuous component of autonomous warehouse strategy rather than a temporary programme during technology implementation. Employees working within increasingly automated environments require competencies extending beyond conventional warehouse activities, including robot interaction, digital literacy, equipment diagnostics, data interpretation, cybersecurity awareness, system recovery, and technological safety. Human-centred warehouse development becomes particularly important as employees increasingly operate as collaborators within intelligent technological systems (Kumar et al., 2026). Organisations should consequently establish competency frameworks aligned with different stages of autonomous development and provide progressive technical training as automation expands. Cross-training should also preserve sufficient operational knowledge to support temporary alternative procedures during technological disruption. A smaller workforce can remain strategically valuable when its capabilities become broader, more technical, and more adaptable. Workforce transformation should therefore convert automation-induced labour reduction into organisational capability enhancement instead of allowing technological advancement to produce irreversible losses of knowledge, flexibility, and operational recovery capacity (Zheng et al., 2025).

5.4 Human Centric Principles Strengthening Autonomous Operating Design

Zheng et al., (2025) find that robotic technologies can reduce physical workload while simultaneously introducing mental and psychosocial challenges. Human centricity should therefore remain embedded within warehouse design even where automation substantially reduces the number of employees required for routine fulfilment. Fewer workers do not automatically create safer or more sustainable employment because residual roles may become more cognitively demanding, technologically dependent, and closely synchronised with machine-generated work rhythms. Advanced warehouse development similarly combines technological sophistication with human-centred and resilient principles rather than treating automation as an isolated objective (Kumar et al., 2026). Organisations should evaluate residual jobs through ergonomic exposure, cognitive workload, task autonomy, fatigue, safety, technological complexity, and responsibility concentration alongside conventional productivity indicators. Automated systems should not impose unsustainable

machine-determined work rates or turn remaining employees into permanent problem solvers for technological deficiencies. Instead, automation should remove hazardous and repetitive activities while allowing employees to concentrate on judgement, technical supervision, exception management, and operational improvement.

Human-machine interfaces should likewise make complex autonomous technologies understandable and manageable for employees responsible for supervising them. Intelligent warehouse environments require technologies that augment human capability rather than marginalise employees as automation expands. Kumar et al., (2026) position human-machine collaboration as an important component of Industry 5.0 warehouse management, reinforcing the continuing role of human capability within advanced operating environments. Organisations should therefore develop interfaces that communicate system conditions, warnings, operational priorities, equipment status, and recommended interventions in forms employees can interpret rapidly. Technology should provide sufficient explanation for abnormal behaviour instead of overwhelming supervisors with excessive information or opaque algorithmic recommendations. Human intervention mechanisms must also remain accessible during safety incidents and operational emergencies. Employee feedback should be incorporated into system redesign because frontline interaction can reveal usability problems and operational consequences that technical performance indicators may overlook. Human-centred design ultimately strengthens autonomous fulfilment by ensuring that employees retain sufficient information, authority, and competence to supervise sophisticated technological systems effectively (Zheng et al., 2025).

5.5 Resilience Recoverability Strengthening Autonomous Warehouse Infrastructure Capability

Resilience should be incorporated into autonomous warehouse architecture before technological dependence becomes so extensive that alternative operating options disappear. Highly automated systems can create exceptional productivity during stable conditions, but interconnected technologies can also allow local failures to propagate rapidly across warehouse operations. Rodríguez García et al., (2026) identify numerous technology-related vulnerabilities and major disruption sources involving cyberattacks, technology sabotage, technological failures, power and network outages, and human-machine interaction problems. Organisations should therefore map critical dependencies across warehouse management systems, autonomous robots, sensors, wireless networks, cloud platforms, charging infrastructure, power supplies, and technology providers before implementing extensive workforce reduction. Each dependency should be evaluated according to failure consequences, recovery time, substitutability, connectivity requirements, and operational criticality. Redundant communication channels, backup power, spare equipment, secure data recovery, cybersecurity controls, alternative routing, and emergency procedures should then be established according to potential disruption severity rather than introduced only after operational failures occur.

Recoverability should receive equivalent strategic attention because preventing every technological disruption is neither economically realistic nor operationally possible. Existing research on highly automated warehouses shows uneven development across prevention, detection, mitigation, and recovery capabilities (Rodríguez García et al., 2026). Organisations should consequently establish degraded operating modes capable of preserving critical fulfilment when normal autonomous

capacity becomes unavailable. Recovery exercises should simulate failures involving warehouse management software, robotic fleets, cloud connectivity, communication networks, cybersecurity incidents, and power infrastructure. Managers can assess recovery time, critical orders maintained, alternative processing capacity, data restoration performance, and emergency intervention effectiveness during these exercises. Technology procurement should additionally consider modularity, interoperability, vendor support, spare-parts availability, cybersecurity obligations, software continuity, and migration capability. These requirements reduce excessive dependence on individual technologies or suppliers. A genuinely autonomous warehouse should therefore demonstrate not only minimal human intervention during normal operations but also the ability to restore, reconfigure, and sustain critical fulfilment when the technological foundations supporting autonomy are disrupted (Rodríguez García et al., 2026).

6. CONCLUSION

Autonomous fulfilment is fundamentally changing the role and structure of warehouse operations. Advances in artificial intelligence, robotics, digital twins, intelligent scheduling, and interconnected information systems increasingly allow activities once dependent on employees to be executed or coordinated autonomously. The analysis developed in this article indicates that these technologies can strengthen operational speed, consistency, resource utilisation, responsiveness, and fulfilment capability. Yet technological advancement should not be measured simply by the number of workers removed from warehouse operations. Greater autonomy changes the entire operating architecture by redistributing responsibility across machines, algorithms, digital infrastructure, and remaining human capabilities. The strategic value of autonomous fulfilment therefore depends on whether technological independence produces sustainable operational performance rather than merely demonstrating that a warehouse can function with minimal labour.

The movement towards workerless warehousing also creates vulnerabilities that challenge the assumption that maximum automation automatically produces maximum performance. Labour dependency may decline while dependency on software, data quality, robotic equipment, connectivity, cybersecurity, power infrastructure, specialist maintenance, and technology providers increases. Human capability remains equally important because extensive workforce reduction can remove contextual knowledge, judgement, flexibility, and recovery expertise that autonomous systems may struggle to reproduce during unusual circumstances. The future warehouse workforce is therefore more likely to be transformed than completely eliminated. Fewer employees may be required for repetitive physical activities, but stronger capabilities will be needed in technological supervision, maintenance, analytics, cybersecurity, exception management, system recovery, and operational improvement. Human-machine configuration consequently remains a strategic consideration even within highly autonomous fulfilment environments.

The strongest pathway is therefore not absolute autonomy but resilient autonomy. Organisations should automate activities where technology creates clear operational value while retaining appropriate human expertise, governance mechanisms, alternative procedures, and recovery capacity where uncertainty remains significant. The article's strategic recommendations support selective automation based on process characteristics and operational value rather than treating maximum automation as a universal objective. Autonomous systems should also be designed around the possibility of failure through technological redundancy, cybersecurity, degraded operating modes,

human escalation, and reconfigurable resources. The warehouse of the future should consequently not be judged by whether it has successfully removed every worker. A more meaningful measure is whether it can operate intelligently with minimal intervention while remaining economically viable, adaptable, accountable, human-centred, and capable of sustaining critical fulfilment when technological assumptions fail. This perspective positions autonomous fulfilment as a strategic capability rather than simply a labour-replacement technology.

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2. Conflict of Interest

The authors declare that there are no financial, professional, personal, or other competing interests that could have influenced the preparation or publication of this article.

3. Author Contribution Statement

Nurul Hadi Abdul Halim: Conceptualization, literature review, development of the main arguments, and manuscript preparation.

Zakaria Mat Zin: Literature synthesis, analysis of autonomous fulfilment and warehouse technologies, and development of strategic insights.

Nooraha Abdul Razak: Critical analysis, development of strategic recommendations, manuscript review, and editing.

All authors have read and approved the final version of the manuscript.

4. Ethics Statement

This study was conducted in accordance with applicable ethical principles and research standards. As this is a conceptual study based on published literature, no human participants or primary data collection were involved. Therefore, ethical approval and informed consent were not applicable. All sources were appropriately acknowledged in accordance with academic research standards.

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