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Smart Warehouse Operations for Saudi Vision 2030: A Framework for ERP, WMS and Workforce Augmentation

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Abstract- The logistics transformation in Saudi Arabia calls for warehouses that are not only automated but also operationally integrated, human-oriented and capable of being governed. This review draws on literature published between 2020 and 2025 in order to establish a framework for smart warehouse operations that links enterprise resource planning (ERP), warehouse management systems (WMS) and workforce augmentation. The evidence used consists of 28 refereed publications and two Saudi policy documents, while the attached WMS sustainability and security 4.0 reviews serve as methodological and conceptual reference models. The literature was analysed using an integrative review protocol based on PRISMA logic, thematic coding and cross-source comparison. Four recurring requirements were identified: reliable data flows from enterprise level to execution level; real-time sensing and algorithmic decision support; safe collaboration between humans and machines; and governance that ties operational metrics regarding resilience, sustainability and workforce capability. The review introduces a layered Saudi Smart Warehouse Integration Framework in which ERP oversees enterprise commitments, the WMS/WES translates these commitments into warehouse tasks, a trusted integration fabric links the cyber-physical events, and augmented workers work alongside automation having transparent decision rights. A five-stage maturity pathway—digitize, integrate, orchestrate, augment and adapt—is also offered. The framework maintains that the most lasting productivity gains are achieved when technology adoption is carried out in sequence with improvements in data quality, cybersecurity, ergonomics, skills development and change management. For Saudi Vision 2030, this approach can help to improve the quality of logistics services, enhance supply-chain visibility, build local digital capability and ensure safer and more resilient warehouse work.

I. INTRODUCTION

In today's supply chains, warehouses have taken on the role of active control points instead of merely acting as passive buffers between production and the market. The rise of e-commerce, shorter fulfilment times, the greater variety of products and the increased risk of disruption have all raised the importance of having accurate inventory, the ability to carry out orders quickly and the capacity for real-time exception management. As a result, recent research into smart warehouses sees information interconnection, equipment automation, process integration and sustainability as interdependent design issues rather than as separate technologies [3]. The systematic review by Minashkina and Happonen attached to this paper does likewise show that the WMS is becoming more closely integrated with other warehouse subsystems and that more attention should be paid to social and environmental outcomes [1]. This change is significant for Saudi Arabia since the country's logistics strategy includes integration, service quality and the adoption of technology as part of its broader aim of strengthening its status as a global logistics hub [29].

Smart warehouses are often illustrated by means of various visible technologies—such as autonomous mobile robots, RFID, sensors, computer vision, artificial intelligence, smart glasses, and digital twins. However, the presence of these technologies by itself does not lead to operational intelligence. A warehouse can have state-of-the-art equipment and yet still face problems like inconsistent master data, disconnected planning, slow handling of exceptions, inadequate change controls, or work designs that pass on variability to the operators. The literature on Industry 4.0 applications shows that value in a warehouse comes from the coordinated application of digital technologies throughout the various processes [4,5]. Reference architectures also stress the importance of interoperable layers that link enterprise applications to sensing and to physical execution [6]. For this reason, the integration of ERP and WMS becomes a fundamental issue: ERP stands for the enterprise's commitments and financial accuracy, while WMS converts these commitments into specific decisions regarding inventory, location, labour, and tasks.

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The human aspect is just as important. Even in highly automated warehouses, order picking and exception recovery still require a lot of manual labour, and research involving cobots, human-robot collaboration and head-worn displays indicates that performance is influenced by factors such as acceptance, workload, ergonomics, training and trust [10–14]. By building on this, Safety 4.0 research demonstrates how IoT, AI, RTLS, wearables and predictive analytics can help with proactive risk control, even as they introduce challenges relating to cybersecurity, skills and integration [2]. As a result, Industry 5.0 research rethinks digitalisation in terms of human-centricity, resilience along with sustainability rather than focusing on replacing people with machines [17–21]. For warehouses, the principle of workforce augmentation is more appropriate than simple labour substitution; technology should enhance perception, movement, decision quality and learning while still keeping human authority over ambiguous or safety-critical exceptions.

The review looks at the integration problem that arises. Although there are existing studies which offer valuable knowledge of smart warehouse technologies, WMS, ERP, automation and the human factors involved, these areas are generally treated separately. The paper presents an operating framework that is tailored to the Saudi context and incorporates ERP, WMS and workforce augmentation within a single sociotechnical architecture. It also specifies the various stages of implementation and identifies measurable governance priorities that are appropriate for organisations aiming to bring their warehouse modernisation in line with the Vision 2030 logistics objectives.

II. AIM, OBJECTIVES AND REVIEW QUESTIONS

This review aims to summarize the most recent evidence and to establish a practical framework for smart warehouse operations that is suitable for the Saudi context, the framework being one in which ERP governance, WMS execution and workforce augmentation work together as a coordinated operating system; in this case, the focus is not on selecting a particular technology stack but rather on determining how information, automation and human capability should interact.

The study is guided by five objectives: first, to define the functional boundaries and the essential information flows between the ERP and the WMS; second, to review the evidence from 2020 to 2025 regarding automation, IoT, AI, real-time location systems, wearables, and human-robot collaboration in warehouse operations; third, to identify the workforce, safety, cybersecurity, data-governance, and interoperability requirements that affect adoption; fourth, to develop an integration framework in stages, taking into account Saudi logistics transformation; and fifth, to suggest implementation metrics and a research programme for data-driven validation. The following three review questions are addressed: RQ1, how should the responsibilities of the ERP and WMS be combined without leading to duplication of operational control? RQ2, which augmentation technologies generate value when used in conjunction with human work design? RQ3, what governance and maturity conditions enable smart warehouse transformation to be sustainable in the Saudi context?

III. REVIEW METHODOLOGY

An integrative review approach was chosen since the subject area involves information systems, operations management, human factors, safety and logistics policy. The protocol adopts the transparency principle of PRISMA as used in the attached WMS review [1], yet it does not assert that a statistical meta-analysis has been carried out since the evidence consists of conceptual reviews, case studies, experiments, architecture papers and policy documents which have non-comparable outcome measures. The second of the attached reviews influenced the thematic sections on enabling technologies, organizational functions, limitations and future research [2].

The time frame for the review was set to cover the period 2020 to 2025 in order to take into account current ERP, WMS, Industry 4.0/5.0 and warehouse-automation circumstances. The search terms included words relating to warehouses (such as smart warehouse, warehouse 4.0, order picking, warehouse management system) as well as those relating to integration and enhancement (including ERP, WMS, IoT, AI, robotics, cobot, RTLS, augmented reality, workforce, human factors, safety and sustainability). When conducting Saudi-specific searches, the terms Saudi Arabia, Vision 2030, logistics and transport were also included. Only English-language, peer-reviewed articles that directly dealt with warehouse systems, the integration of enterprise logistics information, warehouse automation, the augmentation of workers or human-centric operations were considered eligible. Papers that were entirely technical in nature and did not have any connection with warehouse management or the workforce, publications from before 2020, duplicate records and promotional material for commercial purposes were excluded. The two official sources relating to Saudi strategy were kept in because it is not possible to determine the nation's logistics priorities solely from international academic literature.

The evidence base that has been finalised includes 28 peer-reviewed sources and two official sources from Saudi Arabia. Each of these sources was evaluated using six categories: enterprise planning, warehouse execution, cyber-physical visibility, automation/decision intelligence, workforce augmentation, and governance/outcomes. Through cross-source synthesis it was possible to determine where the evidence converged, where trade-offs occurred and where there is a need for contextual interpretation when implementing the solution in Saudi Arabia. This method allows for the development of a conceptual framework without producing fabricated effect sizes or making unsupported causal claims. The framework that results should therefore be regarded as a design proposal based on existing evidence and require further validation in real-world settings.

The evaluation stressed relevance and transferability rather than relying on a single numerical score. In order to identify the main concepts and gaps, review papers were consulted; empirical studies were looked at with regard to setting, technology, the level of worker involvement and the operational outcomes that were reported; architecture papers were employed to define the system perimeters; and Saudi policy documents were used merely to set out the strategic direction. When carrying out the synthesis, a claim was only included if it could be backed by the relevant source type. For instance, evidence from laboratory studies on smart glasses was regarded as evidence concerning task performance under regulated conditions, not as proof of a return on investment across the whole enterprise. Similarly, conceptual papers on Industry 5.0 were used to establish human-focused design principles rather than to estimate warehouse productivity. This approach, which takes into account the characteristics of the sources, helps to avoid a typical problem in reviews whereby evidence from different types of sources is presented as if it were of equal strength.

IV. THEMATIC SYNTHESIS

4.1 ERP–WMS Integration as the Operational Spine

ERP and WMS function at different levels of decision granularity. ERP is generally responsible for enterprise master data, purchasing, sales commitments, accounting, inventory valuation and high-level resource planning. The WMS, on the other hand, deals with the physical location of inventory, the way receiving and put-away are carried out, which stock is allocated, how picking waves are released, and how exceptions in packing and dispatch are managed. Research into the integration of ERP and WMS indicates that the systems can result in a more coherent digital factory provided that responsibilities are clearly defined and the data are synchronised [7]. Studies of ERP in supply chains also link integrated enterprise information with better coordination and management that is oriented towards sustainability, although the quality of implementation varies according to organizational fit and process discipline [22,23].

The main design risk is duplication of authority; if both the ERP system and the WMS are able to make independent changes to the same operational state, then reconciliation can no longer provide real-time control. It is therefore necessary to have a system of transactional ownership, with the ERP responsible for commercial and financial commitments and the WMS in charge of location-level execution, the two systems exchanging approved master data, demand signals, receipts, confirmations and any exceptions. Smart WMS designs include real-time connectivity with sensors and devices so that physical events can update the execution logic without circumventing enterprise governance [8]. Further research into IoT has demonstrated that warehouse optimisation is increasingly based on continuous data from assets, inventory and the conditions of the processes [9]. Integration should thus be structured as an event-driven control loop not as a series of nightly file transfers.

Data quality is a necessary condition for this loop; errors in unit of measure, duplicate items, inconsistent location structures, or delayed confirmations can result in unreliable advanced analytics. That integration layer must therefore incorporate master-data stewardship, API version control, message monitoring, identity management and audit trails; this foundation establishes a single operational truth against which automation and human decision support can safely function.

The design of exception handling also has to be careful when it comes to ERP–WMS integration. The interfaces should be able to tell the difference between normal confirmations and those situations which call for business judgement, for example discrepancies in quantity, blocked stock, conflicts involving serial numbers, short picks or cancelled orders which have already been sent to the floor. Such events must have clear ownership, defined rules regarding their severity and specified response times. Otherwise, automated integration will just pass unresolved problems more quickly from one system to another. A modern event architecture allows exceptions to be placed in queues with a traceable status, and dashboards can indicate whether the cause lies in master data, process execution, equipment or an external dependency. This transforms the integration from a simple measure of technical connectivity into a management-control mechanism and also enables continuous improvement since recurring exceptions can be recorded, measured and eliminated rather than having to be dealt with repeatedly by means of informal messages or adjustments in spreadsheets.

4.2 Sensing, Automation and Decision Intelligence

Smart warehouse technologies can be sorted by the kind of uncertainty they lower. Identification tools like barcode and RFID make it easier to know what an item is. RTLS helps track where things are. Sensors show the state of equipment and the environment. Robotics cuts down on changes in how things move. Analytics helps with planning and handling exceptions. Reviews of Industry 4.0 in warehouses list IoT, autonomous systems, cloud platforms, analytics, and digital connectivity as common tools [4,5,25]. Research on automated order picking also shows that performance depends more on how the system is set up and the work setting than on the equipment itself [27].

In mixed environments involving both people and machines, real-time location tracking is particularly important. It enables the monitoring of inventory, handling equipment and personnel and helps with route analysis, providing visibility into congestion and issuing safety alerts [2]. Artificial intelligence can then analyse the high-frequency events to predict equipment failures, detect abnormal flows or suggest priorities for tasks. Nevertheless, the algorithms need to include constraints that take into account the service commitments and the actual conditions in a warehouse. A slotting suggestion which reduces the amount of travel could increase the risk of lifting; a labour schedule that aims to maximise utilisation might eliminate the capacity required to deal with exceptions. Recent research into storage assignment therefore incorporates considerations of order-picking efficiency alongside worker safety [15]. This shows a general rule that smart optimisation should have multiple objectives.

Digital twins and simulation apply this idea by enabling the evaluation of proposed layouts, automation rules, and demand scenarios before any physical changes are made. They are most useful when connected to reliable WMS and sensor data, rather than when they are kept as separate visual models. In well-developed warehouses, the level of intelligence should shift from simply providing descriptive visibility to offering predictive and prescriptive assistance while still maintaining traceability. It is essential that operators and supervisors understand which data led to a recommendation, which constraint was taken into account, and when a human override is anticipated. Since this kind of explainability is necessary for operations, it should be regarded as an operational control, not just as an issue concerning AI ethics.

The orchestration layer also needs to handle the way in which fixed automation interacts with flexible resources. Although conveyors and automated storage

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systems have a high capacity their routes are limited; AMRs are more flexible but occupy the same space as people; manual teams are able to deal with unusual orders but are vulnerable to the effects of travel and cognitive demand. The logic used in the WMS/WES should therefore plan the work taking into account bottlenecks, cut-off times, replenishment risk and the capacity of the safe zones rather than just aiming to maximise the use of one type of asset. Simulation can be used to determine whether adding more robots actually alleviates a bottleneck or instead just shifts the congestion to packing, staging or the lifts. This broad system-level approach is in line with smart-warehouse research which regards integration and operations management as closely related problems [3,6] and it also stops local automation successes from causing instability further down the line.

4.3 Workforce Augmentation and People-Centered Operations

Warehouse automation almost never gets rid of all human work; instead it alters the distribution of physical, mental and coordination tasks. Cobots can be used to carry totes or to go with pickers, thus reducing the need to walk while still having people carry out recognition, grasping and the decision-making in exceptional situations. Evidence from case studies indicates that for cobots to be successfully implemented it is necessary to have good communication, strong leadership, a suitable organizational culture and effective management of resistance to change [10]. Furthermore, experimental and modelling studies also show that human discomfort and workload must be taken into account when assigning collaborative picking tasks [11,12]. These findings contradict transformation programmes which assess automation solely in terms of increased throughput and labour-hour savings.

Augmentation technologies also have an effect on cognition. Smart glasses can give hands-free instructions, verification prompts and navigation, but their value is dependent on the quality of the interface, the complexity of the task, the visual load and user acceptance [13,14]. RTLS and wearables can enhance safety and improve workflow transparency, but uninterrupted monitoring may become intrusive if the purpose of the data, the length of time it is stored and access to it are not regulated. User-centered design therefore involves a clear exchange: workers get useful assistance, safer working conditions and better information; management obtains operational visibility within clearly defined and transparent limits.

The concept presented in Industry 5.0 literature serves as a useful point of reference. As far as research into human-centric logistics is concerned, productivity, ergonomics and meaningful work should all be designed in conjunction with one another [17]. The more general Industry 5.0 framework integrates human-centricity with resilience and sustainability [18–21]. When applied to warehouses, this leads to four design rules. The first is to automate repetitive travel, instances of dangerous exposure and high-frequency calculations before carrying out the automation of judgement. Second, recoverability should be maintained so that workers can understand the situation and be able to safely intervene should automation fail. Third, training should be considered an integral part of the technological system, covering computer literacy, the ability to diagnose exceptions and cyber-safe behaviour. Fourth, work quality should be measured together with output, taking into account ergonomic risk, cognitive demand, training completion, near misses and operator acceptance.

Human augmentation also helps with the localization of digital capabilities. A warehouse which relies completely on external integrators for any changes to its configuration may be technologically advanced but will be operationally fragile. When internal super-users, process engineers, data analysts and maintenance specialists are developed, organizational learning is achieved. This kind of capability is especially relevant to Saudi Arabia's transformation since logistics modernization has to be maintained after the initial implementation and should not be treated as a one-off automation project.

It is just as important to bring about a change in the way things are governed during the commissioning phase. Before a new automation cell becomes production critical, operators should take part in workflow trials, acceptance testing, and the setting of escalation rules. The insights they gain frequently point out practical problems that technical tests fail to identify, such as restrictions on visibility, awkward replenishment procedures, unclear alerts, and unsafe steps for recovery. Supervisors too will need to have their roles revised since real-time systems shift management away from assigning tasks and towards monitoring the flow, coaching in cases of exceptions, and interpreting the data. Training programmes should differentiate between routine users, super-users and technical administrators, with competency assessments tied to the actual functions of the system. In this way, a sustainable operating model is established rather than there being a temporary reliance on the project teams.

4.4 Safety, Sustainability, Resilience And Cybersecurity

Smart warehousing brings with it both advantages and risks. A warehouse management system can contribute to sustainability by enhancing the sequencing of tasks, making better use of space, reducing travel distance, improving inventory accuracy and increasing visibility of processes, and at the same time sustainability-oriented research stresses that social outcomes should receive equal attention to environmental ones [1]. Safety 4.0 includes practice monitoring sing sensors, AI, wearables and predictive maintenance [2]. Although these technologies can reduce exposure to hazards and enable earlier detection of abnormal conditions, they also lead to a greater dependence on networks, data and software.

Cybersecurity should therefore be designed as an operational safety requirement, since the failure of the WMS to be available or the compromise of device identity or the corruption of the location signal could halt the automated movement of materials or lead to unsafe interactions. The controls that should be put in place include role-based access control, network segmentation, device inventories, patch governance, secure APIs, backup procedures and tested manual fallbacks. Moreover, the resilience literature suggests that digitalization is beneficial only when it enhances visibility and response capability rather than simply centralizing dependencies; human operators are still an element within resilience since they are able to identify conditions that historical models might not cover.

Sustainability assessments ought to go beyond consideration of energy use; appropriate warehouse indicators are avoidable travel, equipment idle time, packaging waste, damaged inventory, worker exposure, overtime volatility and rework. The integrated framework described in this paper views these as operational results that result from both the system's configuration and the way work is designed, enabling improvement teams to prevent focusing on one measure while neglecting another.

4.5 Saudi Vision 2030 Context

Saudi logistics policy provides a strong demand-side rationale for smart warehouse capability. The National Transport and Logistics Strategy identifies integration across transport modes and logistics services as a central mechanism for achieving Vision 2030 ambitions [29]. Academic analysis of Saudi logistics transformation similarly highlights digital government, automation and supply-chain transparency as enabling factors [28]. At the national level, logistics performance improvements reported in the Vision 2030 Annual Report 2025 show continued emphasis on capacity, connectivity and faster trade processes [30]. Warehouses are operational nodes within this system: port, airport, industrial and e-commerce flows cannot become more responsive if storage and fulfilment remain digitally fragmented.

The Saudi context also makes staged capability building important. Greenfield logistics zones may support advanced automation from inception, while established warehouses often contain legacy ERP configurations, manual handling, spreadsheets and heterogeneous equipment. A common national aspiration should not imply a common technical sequence. Organizations need an architecture that can scale from basic transaction discipline to predictive operations while preserving interoperability and workforce readiness. The framework below is intended to provide that sequence.

Table 1. Evidence synthesis and Saudi implementation implications.

Theme	Representative evidence	Synthesis	Saudi implementation gap
ERP–WMS integration	[7,8,22,23]	Separate enterprise commitments from warehouse execution; synchronize through governed events and master data.	Legacy interfaces, duplicated ownership and inconsistent master data can block real-time control.
Smart sensing & automation	[3–5,9,25,27]	IoT, RTLS, robotics and analytics create value when attached to process decisions and trusted data.	Technology pilots need scalable integration, cyber controls and measurable value realization.
Workforce augmentation	[10–17]	Cobots, smart glasses and AI should reduce travel, risk and cognitive burden while preserving human judgement.	Skills, acceptance, bilingual interfaces, ergonomics and monitoring governance need local evidence.
Human-centric resilience	[18–21]	Industry 5.0 links productivity with human-centricity, resilience and sustainability.	Operational scorecards often undermeasure recovery, job quality and learning capability.
Vision 2030 alignment	[28–30]	Integrated logistics and digital capability strengthen service quality, visibility and national logistics performance.	Warehouse-level maturity evidence is less developed than national infrastructure and policy reporting.

V. SAUDI SMART WAREHOUSE INTEGRATION FRAMEWORK

The framework being proposed has four operating layers which are linked together by a trusted data and integration fabric (see Figure 1). The first layer is known as enterprise orchestration, and it is responsible for setting up demand, confirming supplier commitments, applying financial controls, managing the approved list of items and partners as master data, establishing workforce budgets and carrying out enterprise-wide reporting. It must not interfere in a detailed manner with tasks at the location level. The second layer is execution intelligence, and this involves the use of the WMS, together with a warehouse execution system (WES) where appropriate, turning enterprise demand into instructions for receiving, put-away, replenishment, picking, packing and dispatch. This layer is in charge of the inventory status at the operational level, sequences the tasks, balances the resources and keeps a record of any exceptions.

Layer 3 involves cyber-physical visibility and automation; it is achieved through the use of Internet of Things sensors, RFID technology, machine vision, conveyors, AMRs, AS/RS systems, sortation methods, and RTLS which generate events that reflect the physical world. Signals from devices only have significance when they are linked to governed entities such as the item, location, asset, order, and worker role. Layer 4 refers to the augmented workforce, comprising operators, supervisors, technicians, and planners who interact with automation via mobile terminals, smart glasses, dashboards, cobots, and AI-assisted recommendations. The allocation of decision-making powers is clear in that the system takes care of stable and high-frequency decisions while people are in charge of dealing with ambiguity, customer-sensitive exceptions, safety issues, and learning.

Integration fabric forms the control plane of the framework and consists of APIs and event streams, along with identity and access management, master-data governance, cybersecurity monitoring, time synchronization and analytical services. It stops point-to-point interfaces from becoming hidden dependencies and makes sure that audits can be carried out across the ERP, WMS and equipment systems. It also allows for closed-loop measurement; for example, a receiving delay can be traced from the supplier's commitment in the ERP through to the dock task in the WMS, then on to the equipment or labour conditions, and finally to the corrective action taken. The same approach applies to picking errors, congestion, near misses and power-hungry operating patterns.

The framework is based on three principles. The first of these is that there should be single ownership of operational truth, meaning that each important data object has one authoritative system with controlled replication. The second principle is that automation should be human-visible, so that recommendations, alerts and any autonomous actions can be explained at the level needed for safe intervention. The third is the balanced value realization should take place, with throughput, cost and service being assessed together with safety, workforce capability and environmental performance. It is because of these principles that an integrated smart warehouse can be distinguished from a simple collection of connected devices.

The framework is completed through exception learning. Each manual override, device fault, inventory discrepancy and safety intervention must result in structured information which can be used to improve the process rules, training or the system configuration. It does not imply that all deviations should be eliminated since some of them are due to legitimate variability in products, customers or operating conditions. The aim is to tell the difference between exceptions that are expected and those that are avoidable and to decide whether the way to resolve the situation should be included in the ERP rules, the WMS logic, the equipment control, the work instruction or in the process of the supplier or customer. A monthly cross-functional review of the most frequent exceptions can bring together the operations, IT, HSE, engineering and finance teams around common evidence. Gradually, this learning cycle decreases reliance upon individual experience while still retaining expert judgement for new situations. It also provides a practical means of passing on knowledge to local super-users and technical teams.

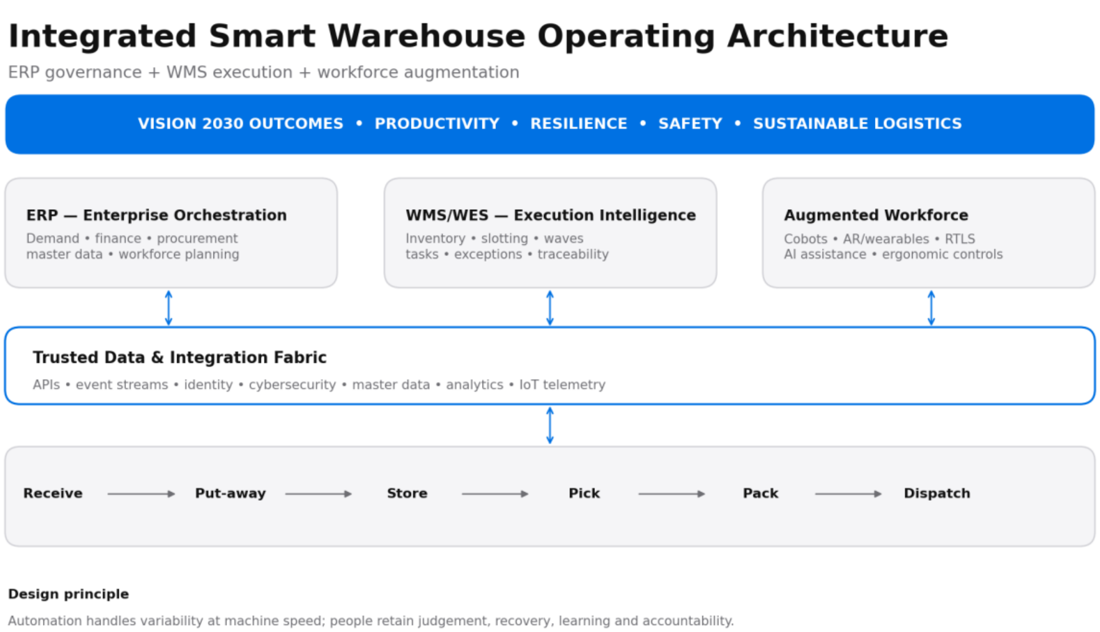

Figure 1. Integrated smart warehouse operating architecture

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VI. IMPLEMENTATION PLAN AND MEASUREMENT

Implementation should proceed according to a maturity sequence rather than on the basis of a technology shopping list (see Figure 2). In the first stage, Digitize, standard work is stabilised together with the use of barcodes and RFID, the organisation of locations and master data. In the second stage, Integrate, reliable interfaces between the ERP and WMS are set up, a shared identity is established, event monitoring is put in place and common definitions are adopted. In the third stage, Orchestrate, dynamic slotting, replenishment logic, task interleaving, labour planning and IoT visibility are applied. In the fourth stage, Augment, cobots, AR, RTLS and AI decision support are introduced where performance studies indicate a measurable benefit. In the fifth stage, Adapt, predictive analytics, simulation or digital twins and closed-loop control are used in order to respond to demand, congestion, equipment risk and workforce constraints.

Advancement must be based on evidence. Table 2 presents a balanced scorecard that includes measures relating to service, inventory, productivity, integration reliability, safety, workforce capability, resilience and sustainability. Just as much importance should be attached to leading indicators as to lagging outputs: figures such as API failure rates, master-data defects, the frequency of overrides, training completion rates and trends regarding near-misses can show weaknesses in a system before customer service declines. Governance needs to designate an owner and set the review frequency for each metric in order that digital operations may remain accountable.

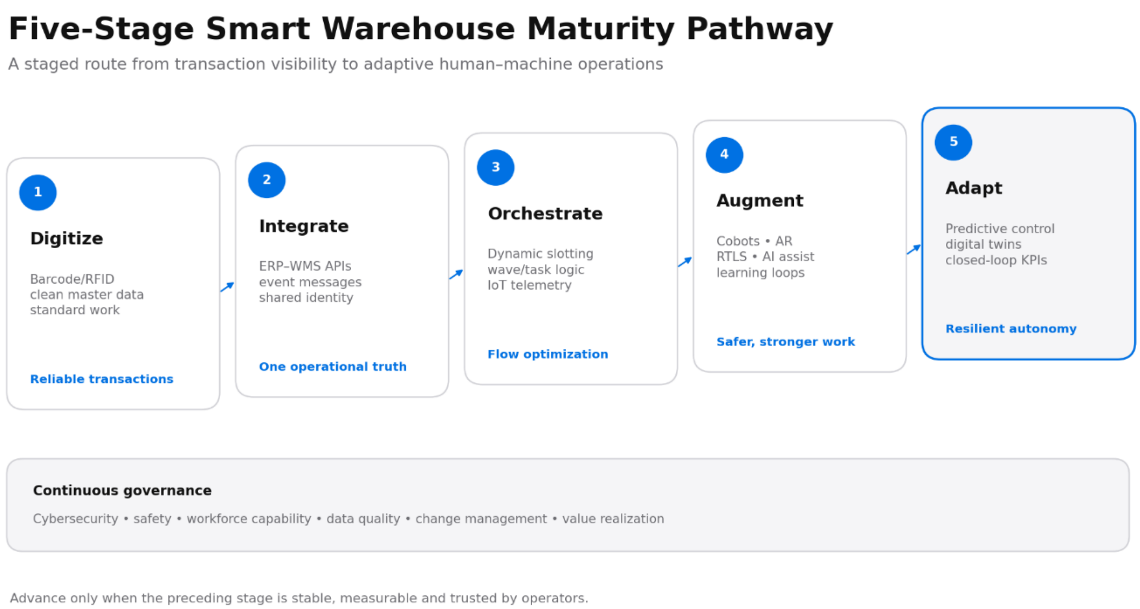

Figure 2. Five-stage maturity pathway for sequencing smart warehouse transformation.

Table 2. Balanced smart warehouse governance scorecard.

Dimension	Example KPI	Primary owner	Review cadence	Purpose
Service	Perfect order / on-time dispatch	Warehouse operations	Daily	Customer reliability
Inventory	Location accuracy; inventory variance	WMS process owner	Daily/weekly	Execution truth
Productivity	Lines per labour hour; travel per pick	Operations engineering	Daily/weekly	Flow efficiency
Integration	ERP–WMS message failure rate; latency	IT / integration owner	Real time/weekly	Digital reliability
Safety	Near-miss rate; ergonomic risk; unsafe proximity alerts	HSE + operations	Daily/monthly	Human-centred performance
Capability	Training completion; certified super-users; override quality	HR + operations	Monthly	Workforce augmentation
Resilience	Recovery time from WMS/device outage	IT + business continuity	Per incident/quarterly	Operational continuity
Sustainability	Avoidable travel; equipment idle time; packaging waste	Operations / sustainability	Monthly	Resource efficiency

VII. DISCUSSION AND IMPLICATIONS

The synthesis puts forward three main propositions. First, ERP–WMS integration entails more than merely being a back-office IT issue; it defines the line between enterprise intent and physical execution, and when this line is poorly designed reconciliation occurs, while clear ownership results in a stable basis for automation. Second, workforce augmentation is not something that is dealt with at a late stage in a change-management process; human factors influence whether robots, wearables and decision-support systems are able to achieve sustainable performance, as demonstrated by the cobot and collaborative-picking studies [10–12]. Third, the level of maturity attained in a smart warehouse is cumulative, meaning that advanced AI cannot compensate for weak location discipline, unstable interfaces or low operator trust.

For researchers, the framework consolidates the different areas that are normally split between information systems, automation and ergonomics. Future empirical models should look at the effects at each level—for example, whether the reliability of the interface has an impact on the productivity gain of AMRs, or whether explainable task recommendations result in both higher acceptance and shorter recovery times. As regards managers, the practical implication is that integration and capability should be regarded as part of the core infrastructure rather than as additional costs linked to the automation hardware. Business cases have to consider training, cybersecurity, data stewardship, process redesign and fallback procedures.

For Saudi Arabia's policy-makers and the people working in the different sectors, the framework indicates that competitiveness in the logistics area to a certain degree depends on a number of reusable warehouse operation capabilities amongst companies, rather than merely on possessing large amounts of infrastructure. Introducing standardised data interfaces, developing digital skills, implementing cyber-resilience measures, and delivering support to small and medium-sized logistics operators could all help in extending the benefits of the national transformation programme. The model is designed to be technology-neutral so that organisations may select different vendors for their ERP, WMS and automation systems while at the same time retaining the same governance logic.

VIII. LIMITATIONS AND FUTURE RESEARCH

The review does have certain limitations. By concentrating on the period from 2020 to 2025, it puts a strong emphasis on more recent digital technologies and as a result may omit some of the fundamental principles of warehouse theory. Because the evidence is varied, the causal effect sizes cannot be pooled. While two Saudi policy documents are included to provide a strategic background, the number of peer-reviewed case studies on Saudi warehouses is still considerably less than that available in the international literature. For this reason, the framework proposed is only conceptual and not a validated maturity standard. Moreover, matters such as vendor economics, the engineering constraints particular to each facility, and sector regulations also need to be examined at the project level.

Research in the future should be carried out in the retail, industrial, pharmaceutical, cold-chain and third-party logistics sectors. Longitudinal studies must be conducted in order to compare performance at the starting point with performance after integration, and mixed-method studies could be used to link throughput data with results concerning operator workload, trust and safety. The research should also examine Arabic/English human-machine interfaces, cybersecurity behaviour within environments which have multiple vendors' automation, AI override governance, the accuracy of digital twins and the development of local warehouse technology skills. Comparative studies between greenfield logistics zones and existing facilities should assist in identifying which maturity paths are transferable and which depend on the specific context.

Field studies should not only note the average throughput but also examine how the system performs during times of high demand, in the case of equipment failure and when there is a lack of labour, since resilience is generally demonstrated by the way the system recovers rather than by its efficiency under normal conditions. Researchers have to separate out the effect of automation hardware from that of cleaner master data and redesigned processes, as these are often introduced simultaneously and might otherwise cause a misinterpretation of the results. A good way to validate the findings would be to compare the same warehouse areas both before and after the ERP and WMS system has been integrated, making sure that the layout, the product mix and the staffing rules remain as stable as possible from an operational standpoint. Experiments that focus on workers should look at their sense of control, mental workload, physical strain and trust together with travel distance and picking rate, allowing productivity as well as job quality to be considered as combined outcomes. When looking at AI-assisted task allocation, the research should report on the patterns of human overrides and the various categories of exceptions, since a high number of manual corrections may point to the existence of missing constraints, biased data or model drift which are masked by the overall accuracy figures. Cyber-resilience research should investigate how warehouses are able to receive, pick and ship goods when cloud connectivity, identity services or some of the automation cells are not available, and it should also verify whether the backup procedures remain usable under pressure. The Saudi case studies could also look into how local suppliers, integrators and the in-house technical teams share the responsibility for knowing how the system is configured during the commissioning phase, the stabilisation phase and the period of ongoing improvement. The economic aspects of augmentation deserve more attention, particularly in situations where cobots or wearable interfaces reduce fatigue and staff turnover even if there are only small direct savings in labour hours. Future maturity assessments should make a distinction between the technology that has been installed and the actual operational capability, since unused sensors, dashboards that are not trusted and unstable interfaces can create the false impression of digitalisation without any real control. A cross-sector comparison could show whether the requirements of pharmaceutical traceability, the constraints of the food cold chain, the variability of industrial spare parts and the need for fast e-commerce delivery lead to different optimal combinations of ERP, WMS and workforce augmentation. Continued validation should place greater emphasis on transparent metrics, repeatable methods, contextual reporting and comparable learning across all smart warehouse operations in Saudi Arabia.

IX. CONCLUSION

The best way to understand smart warehouse transformation is by looking at the combination of enterprise intent, execution intelligence, cyber-physical visibility and human capability. As the evidence examined shows, ERP offers enterprise governance, the WMS/WES turns commitments into controlled warehouse actions, and augmentation technologies improve performance provided they are incorporated into safe and understandable work systems. Saudi Vision 2030 provides the strategic context in which this merging can lead to logistics operations that are more visible, responsive and resilient.

The Saudi Smart Warehouse Integration Framework together with its five-stage maturity pathway sets out an approach for implementation: it calls for digitisation to come before integration, integration before orchestration, orchestration before augmentation, and the establishment of trusted measurement before aiming at adaptive autonomy. The framework does not suppose that all warehouses need to have maximum automation; rather, it stresses the importance of uniting technology, data and workforce capability in such a way as to ensure a reliable service while at the same time improving safety, resiliency and sustainable efficiency. The following step will be to carry out practical validation in the various warehouse sectors of Saudi Arabia in order to transform the framework from a proposition based on review into a measurable operating model.

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Source-model note: The two user-supplied review articles were used as structural and conceptual reference models. All manuscript prose, framework synthesis, tables and figures in this document are newly written for the stated topic.