World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(REVIEW ARTICLE)

CONTEXT-AWARE DIGITAL TWIN ARCHITECTURES FOR REAL-TIME TRANSPORTATION AND WAREHOUSE OPTIMIZATION IN CLOUD-NATIVE SUPPLY CHAIN PLATFORMS

Mahir Anwar *

University of Southern California, Los Angeles, California, United States.
* Corresponding Author

ORCID Details
Mahir Anwar: https://orcid.org/0009-0002-6274-1560

World Journal of Advanced Engineering Technology and Sciences, 2026, 21(01), 176–185

Publication history: Received on 06 September 2026; revised on 12 October 2026; accepted on 14 October 2026

Article DOI: https://doi.org/10.30574/wjaets.2026.21.1.0430

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

Context-aware digital twins are emerging as enabling architectures for coordinating responses to disruptions across inventory, warehouse, and transportation operations in cloud-based supply-chain platforms. They are important because they can be used to link continually evolving operational representations with optimization services that are able to react to traffic conditions, order arrivals, equipment status, changes in inventory, and facility constraints. This article reviews peer-reviewed journal literature on digital supply-chain twins, warehouse intelligence, dynamic vehicle routing, Internet of Things-enabled logistics, microservice architectures, and computational modelling. Some studies indicate that digital-twin approaches can improve visibility, scenario evaluation, and decision coordination in specific settings, but there is very little evidence of fully integrated real-time optimization of transportation and warehouse operations. Closed-loop orchestration has not been a primary focus of existing implementations, which tend to focus on warehouse simulation or monitoring, route adjustment, or resilience analysis across logistics domains. Other limitations include insufficient semantic interoperability, inadequate model fidelity, inconsistent latency assessment, deployment evidence, and consideration of cybersecurity and human intervention. The field therefore needs architectures that integrates event-driven context management, federated twin models, scalable optimization, auditable decision services, and explicit uncertainty handling.

Keywords: Cloud-Native Logistics; Context Awareness; Digital Supply Chain Twin; Real-Time Optimization; Transportation Management; Warehouse Optimization

1 INTRODUCTION

Digital twins are used to complement the existing infrastructure of monitoring systems by providing computational representations whose states are updated using operational data, models and feedback from the physical processes. In logistics applications, the relevant state is vehicle location, travel-time variation, order priority, loading status, inventory availability, picking congestion, the health status of the equipment, and the disruption signal. The key architectural challenge is now not only to create virtual representation, but to ensure there is adequate contextual

correspondence between physical events, digital state, and optimization decisions. Key enabling capabilities identified in digital-twin research include connectivity, model integration, data management, and feedback, while unresolved issues include interoperability, validation, and computational scalability [1]. In contrast, industrial digital-twin models focus on bidirectional information sharing, model lifecycle integration and model-based decision support, rather than visualization alone [2].

The supply-chain setting adds network scale, organizational heterogeneity, and competing decision horizons. The decision to use a specific mode of transportation can have an impact on dock workload, picking release, labor allocation, inventory exposure, and customer-service results. A route plan that appears efficient in isolation may become infeasible when warehouse congestion, inventory unavailability, or loading delays are considered. Digital supply chain twin research has therefore been described as a data-driven approach to assess risks of disruption propagation, risk mitigation strategies, and coordinated operational responses [3]. Numerous studies in the literature on logistics 4.0 also suggest that cyber-physical connectivity, automation, decentralized control, and data analysis are all coming together, albeit in a differentiated form across the different technologies and logistics functions [4]. The significance of context-aware architecture emerges because the same event may trigger different responses depending on its location, time, service commitment, state of the resources, severity of the disruption and model confidence.

Cloud-native deployment adds an extra design dimension. Containerized services, event streaming, elastic computation and independently deployable optimization components enable quick scaling and functional separation. Decomposition, however, can lead to inconsistent states, communication overhead, weak transaction boundaries, and observability problems. Delayed or conflicting contextual information can lead to optimization based on an outdated operational state and drive decisions that may look mathematically correct but are actually infeasible. Real-time performance should therefore be evaluated end to end, from sensing and event transmission through context interpretation, state reconciliation, optimization, approval, and physical execution.

The main gap in the research is that these dimensions are only partially integrated in the existing literature. The literature available in journals features significant research on the principles of digital twins, dynamic vehicle routing, automated warehousing, Internet of Things (IoT) and distributed software architecture. Closed-loop optimization, realistic latency and uncertainty, cloud-native deployment, and synchronized transportation and warehouse twins are integrated in relatively few studies, and fewer still validate such an architecture. The aim of the review is to assess the current state of knowledge in literature with regard to such architecture, examine methodological patterns and reported findings, identify inconsistencies and research gaps, and propose specific research priorities for real-time cloud-based supply chain platforms.

2 LITERATURE REVIEW

The first thematic cluster focuses on digital supply chain twins as platforms for visibility, simulation, and disruption management. A supply-chain case study illustrated the organization of distributed data and models around digital replicas of logistics assets and processes but focused more on representation and traceability than on continuous cross-domain optimization [5]. An analysis of food-retail disruption using a digital twin demonstrated that scenario modelling could provide insights into service deterioration, recovery paths and structural vulnerability in the face of severe demand and supply shocks [6]. Although both studies demonstrate the benefits of dynamic virtual representations, neither provides a generic control design for the joint rescheduling of transport, warehouse work and inventory decisions at the operational time scale, in the context of cloud-native networks. Literature provides stronger evidence for diagnostic and anticipatory value than for autonomous closed-loop control.

Another group is focused on digitalization in the warehouse. An Internet of Things (IoT)-based warehouse management system integrated identification, sensing, and operational information for better visibility and coordination of smart-logistics activities [7]. Studies on robotized and automated warehouse systems have shown that such systems can increase throughput and eliminate repetitive handling, but that performance is affected by fleet coordination, warehouse layout, storage policy selection, and congestion management, and by integration with order release [8]. Short response times, wide product assortments, dynamic order patterns and returns handling are also unique challenges for traditional batching, picking and sortation logic, as revealed by e-commerce warehousing studies [9]. Recent studies on integrated order-picking show that optimizing one or more order-picking aspects separately may result in poorer performance than optimizing several aspects together [10]. In this way, these findings directly support a warehouse twin that includes task dependencies and resource contention, but most warehouse studies treat inbound and outbound transportation as fixed boundary conditions rather than dynamically coupled decision processes.

The third cluster looks at transportation responsiveness. Dynamic and stochastic vehicle-routing research is characterized by the types of information obtained during execution and the probabilistic information available before execution [11]. The usefulness of dynamic routing has been shown to depend on updating frequency, request

characteristics, fleet constraints, the formulation of the objective, and the ability to modify plans without causing significant operational instability [12]. These studies provide well-developed algorithmic support for context-sensitive dispatching and route revision. However, the following variables are typically omitted from routing formulations: loading readiness, dock congestion, picker completion, inventory substitution, and warehouse automation status. Integrated network-level optimization remains difficult because transportation and warehouse contexts are represented at different levels of detail and are rarely modelled within a shared operational state.

The fourth cluster concerns integration across these domains. The reviewed literature consistently emphasizes the need for up-to-date state information, with the meaning of state, uncertainty and decision authority represented in a variety of ways. In digital-twin studies, model correspondence and scenario analysis are emphasized; in warehouse studies, resource coordination and throughput are emphasized; in routing studies, computational response to changes in requests and conditions of travel are emphasized. Among the studies reviewed in Table 1, none provides full validation of context-aware, cloud-native orchestration across transportation and warehouse operations. The central issue is not that there is no component technology, but that there is no proven architectural design that brings together the semantic context, twin state management, scalable optimization, and operational feedback.

Table 1: Summary of key findings

Ref	Focus	Key Findings
[5]	Digital-twin design for supply chains	Demonstrates distributed representation of assets and logistics processes; limited evidence of continuous transport–warehouse control.
[6]	Digital-twin disruption analysis in food retail	Reveals service and recovery consequences of pandemic-scale shocks through scenario modeling.
[7]	Internet of Things-enabled warehouse management	Connects sensing and identification data with warehouse visibility and coordination.
[8]	Robotized and automated warehouses	Shows performance dependence on coordinated fleet, layout, storage, and congestion decisions.
[9]	E-commerce warehousing	Identifies response-time, assortment, variability, and returns pressures that challenge static control.
[10]	Integrated order-picking planning	Finds strong interactions among assignment, batching, routing, zoning, and scheduling decisions.
[11]	Dynamic and stochastic vehicle routing	Classifies online information structures, uncertainty models, and algorithmic response approaches.
[12]	Dynamic vehicle-routing development	Shows that re-optimization value depends on information timing, operational constraints, and plan stability.

Table 1 shows complementary evidence, not evidence that is unified. Supply-chain twin studies focus on network representation and resilience, and warehouse and routing studies offer more detailed decision models for distinct operations within the supply chain. The challenge is to create a validated architecture from this complementary knowledge that shares context and state and coordinates execution.

3 METHODOLOGY

Several methodological approaches were identified in the reviewed literature, which can be classified into architectural modeling, simulation, mathematical optimization, data-driven state estimation and literature-based conceptual classification. The deployment portability, isolation, orchestration, and elastic scaling capabilities provided by container technology research have the potential to aid distributed digital-twin services; however, container technology does not solve consistency, latency, or governance issues. In microservice research, bounded functional components and independent deployment are also identified as features, but the architectural challenges that frequently arise are communication complexity, difficult testing, granularity of services, and data ownership [14]. When applied to a supply chain twin, these results suggest that transport optimization, warehouse control, context processing, state storage and simulation should not be monolithic, but remain semantically connected.

According to the direction and level of automation of data exchange, digital-twin classification studies distinguish digital models, digital shadows and more tightly coupled twins [15]. A wider digital-twin review points out the lack of

standardized terminology, validation rules, inconsistent model fidelity, and the lack of evidence of lifecycle maintenance [16]. Research on modeling further highlights the importance of calibration, uncertainty quantification, data assimilation, reduced order modeling, and computational efficiency [17]. Smart-logistics research shows that real-time tracking, intelligent identification, and Internet of Things connectivity are viable data foundations, whereas interoperability, security, and implementation costs remain ongoing challenges [18]. All of these approaches suggest that context awareness is not limited to sensor ingestion. Context must be semantically interpreted, temporally aligned, assessed for confidence, and explicitly mapped between what is observed and what is allowed.

To combine the architectural needs mentioned in the literature surveyed, the proposed reference architecture for context-aware, digital-twin-driven transportation and warehouse optimization is illustrated in Figure 1. The architecture comprises eight integrated layers to support the operational decision loop. Event streams generated by IoT sensors, transportation and warehouse management systems, enterprise platforms, demand updates, external traffic and weather services are first connected to physical execution objects like shipments, vehicles, handling units, warehouse locations, business partners, and equipment states These events are then correlated, temporally aligned, and mapped to entities, evaluated for quality, annotated with uncertainty estimates, and mapped semantically by a context and semantic layer, before being placed in the digital-twin state.

The digital-twin layer keeps transportation, warehouse, network, and disruption states synchronized and serves as the operational state for optimization services. These optimization services may include dynamic vehicle routing, load consolidation, dock scheduling, inventory reallocation, labor and equipment assignment, disruption response, scenario analysis, and multi-objective optimization. The architecture explicitly includes an approval and governance workflow, where proposed decisions can be reviewed, validated, modified, rejected or authorized based on the operational risk and decision authority. Once the decisions are approved, they are forwarded to enterprise and operational execution systems such as transportation-management systems, warehouse-management systems, warehouse-control systems, carrier systems, and IoT actuation systems. Execution results, exceptions, changes in key performance indicators (KPIs), sensor observations, and user feedback are returned via a closed feedback loop which updates the context state and the digital twins continuously and allows that context to be used for subsequent decisions based on the most recent operational conditions.

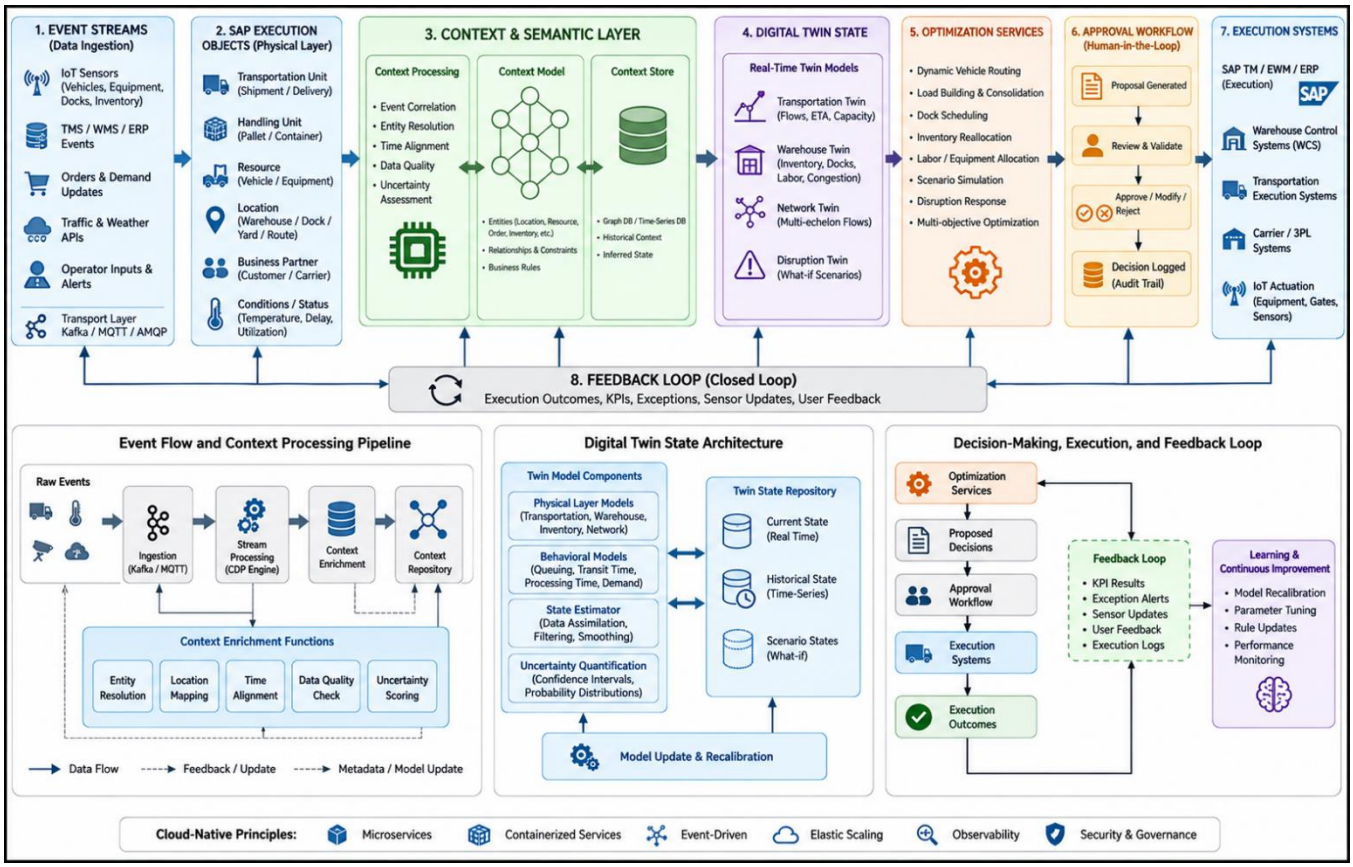


Figure 1: Reference architecture for context-aware, digital-twin-driven real-time transportation and warehouse optimization, illustrating event ingestion, SAP/physical execution objects, semantic context processing, synchronized digital-twin state, optimization services, human-governed approval, operational execution, and closed-loop feedback within a cloud-native platform

Figure 1 is therefore not merely a digital-twin model; rather, it represents a governed decision infrastructure that links operational events with context interpretation, state estimation, optimization, human oversight, execution, and learning. The separation of event ingestion, contextualization, and twin-state management and optimization is especially significant because only under ideal conditions, in which sufficient, reliable, and semantically consistent state information is available, is an optimization result operationally valid. Finally, the closed-loop feedback path distinguishes the proposed architecture from previous monitoring or digital-shadow architectures where decisions taken and actions observed are not fed back into the twin for state reconciliation, model updating, and subsequent re-optimization.

Table 2: Method comparison

Ref	Method	Strengths	Limitations
[3]	Digital supply chain twin with disruption and resilience modeling	Links network visibility, simulation, and recovery analysis.	Limited operational validation of second-by-second control.
[5]	Case-based digital-twin architecture	Demonstrates asset and process representation across supply-chain entities.	Generalizability and optimization coupling remain limited.
[6]	Scenario simulation of retail disruption	Captures time-dependent service degradation and recovery effects.	Results depend on scenario assumptions and model calibration.
[7]	Internet of Things warehouse architecture	Improves event capture, identification, and operational visibility.	Does not establish integrated transport optimization or twin fidelity.
[11]	Dynamic and stochastic routing models	Formalizes online information, uncertainty, and route revision.	Warehouse readiness and dock state are commonly abstracted.
[13]	Container-technology analysis	Supports deployment portability, isolation, and elastic service operation.	Container orchestration does not guarantee consistent twin state.
[14]	Microservice architecture mapping	Supports bounded services and independent deployment.	Introduces distributed data, testing, and communication complexity.
[17]	Mathematical modeling perspective for digital twins	Clarifies calibration, data assimilation, uncertainty, and reduced-order modeling.	High-fidelity models can remain computationally prohibitive.

Table 2 compares the main methodological approaches. When calibration is infrequent, simulation may diverge from real-world operations, although it can still offer a controlled way to analyze disruptions and alternative policies. Optimization provides explicit decision recommendations but is sensitive to the level of accuracy in the state and computational constraints. Internet of Things architectures improve operational observability, but they are not sufficient evidence of causal or operational validity. Cloud-native decomposition enhances deployability and elasticity but demands thoughtful design of state, interface and failure management.

4 DISCUSSION

The most common direction of evolution is from a static view of visibility to a model-driven view for decision support, but end-to-end operational closure remains insufficiently established. Digital-twin studies in supply chains demonstrate that adapted network representations can assess disruption propagation and can compare recovery policies [3], [6]. Research in the warehouse reveals that resource interaction, rather than the individual task, is the key to performance in high-density warehouse automation with fluctuating demand [8]–[10]. Research on dynamic-routing has shown that new information has operational value only when algorithms can revise plans in relevant decision windows [11, 12]. The overall architectural idea that emerges from these findings is that the optimization of transportation and warehouse functions should be done with a common and coherent state over time. A route should not be released solely because travel time is favorable if the load is incomplete, the dock is occupied, inventory is insufficient, or the picking robot is

unavailable. Similarly, the logic of releasing the vehicle at the warehouse must take into account the uncertainty of vehicle arrival and the capacity of the downstream system, not just the capacity of the warehouse.

Reported benefits remain difficult to compare, due to the various levels of analysis, validation conditions and objectives of the different studies. Typical parameters chosen for the digital-twin disruption studies are service level, recovery time, inventory exposure, and network resilience [3], [6]. Throughput, travel distance, utilization, waiting time, congestion, and order cycle time are key metrics in warehouse studies [8] – [10]. Some studies on routing focus on distance, cost, lateness, accepted requests, utilization of the fleet and computational response [11, 12]. Cloud-architecture studies consider factors besides logistics performance such as portability, scalability, modularity, deployment independence, and operational complexity [13] and [14]. It is therefore unclear whether a cloud-native digital twin delivers positive end-to-end performance after taking into account sensing delay, messaging delay, state reconciliation, solver time, human approval and actuation. Table 3 therefore compares reported outcomes using the evaluation criteria applied in each literature stream, as incompatible values are not given as one performance measure.

Table 3: Comparison of Reported Outcomes Across Literature Streams

Ref	System / Context	Metric / Basis of Comparison	Outcome
[3]	Multi-tier supply network twin	Disruption propagation, recovery, resilience policy	Supports anticipatory comparison of mitigation and recovery choices.
[5]	Supply-chain digital-twin case	Asset visibility, process representation, information integration	Establishes a workable digital representation but provides limited closed-loop control evidence.
[6]	Food-retail network under pandemic disruption	Service deterioration and recovery trajectory	Shows that structural and operational interventions produce different recovery patterns.
[7]	Internet of Things-enabled warehouse	Identification accuracy, event visibility, coordination basis	Improves availability of operational data for warehouse decisions.
[8]	Automated and robotized warehouse	Throughput, congestion, fleet and layout interactions	Indicates that automation gains depend on coordinated control and system design.
[9]	E-commerce fulfilment	Response time, demand variability, assortment complexity	Shows that static warehouse policies become less suitable under rapid order volatility.
[10]	Order-picking system	Combined planning decisions versus isolated decisions	Demonstrates material interaction among assignment, batching, routing, and scheduling.
[11]	Dynamic and stochastic vehicle routing	Online information structure and algorithmic responsiveness	Identifies conditions under which route revision can exploit newly available information.
[12]	Dynamic vehicle-routing operations	Cost, service, stability, and update timing	Shows that frequent re-optimization can conflict with plan stability and execution practicality.
[13], [14]	Containerized microservice platform	Scalability, deployment independence, communication complexity	Supports elastic services but creates distributed-state and observability burdens.

The tension between local and system-level optimization is evident across the reviewed literature and is summarized in Table 3. Implementing warehouse automation can increase local processing capacity, but aggressive release policies can result in dock queues or load production before transport capacity is available. Although dynamic routing can reduce travel costs, frequent route changes may cause disruption among loading sequences, driver instructions, customer expectations, and warehouse staging. Digital-twin simulation can uncover the network-level effects, but the accuracy of the simulation can diminish if the operational context evolves at a faster rate than the model can be calibrated. Scaling optimization services can reduce computational queuing, but additional service boundaries can increase message latency and inconsistent reads. Architecture evaluation should, therefore, be based on a multi-metric approach and consider service, cost, stability, computational delay, “state freshness”, and operational feasibility.

Figure 2 presents the distribution of the article set whose reviews were conducted, by domain and by evidence type. The predominance of review and conceptual studies, and the limited number of integrated empirical examples, are important because the claims made in architecture are progressing at a much faster rate than end-to-end operational testing. The bars are stacked and the 18 journal articles reviewed are classified by primary domain and dominant type of evidence. The distribution shows substantial conceptual and review coverage but more limited empirical or case-based validation for integrated logistics twins.

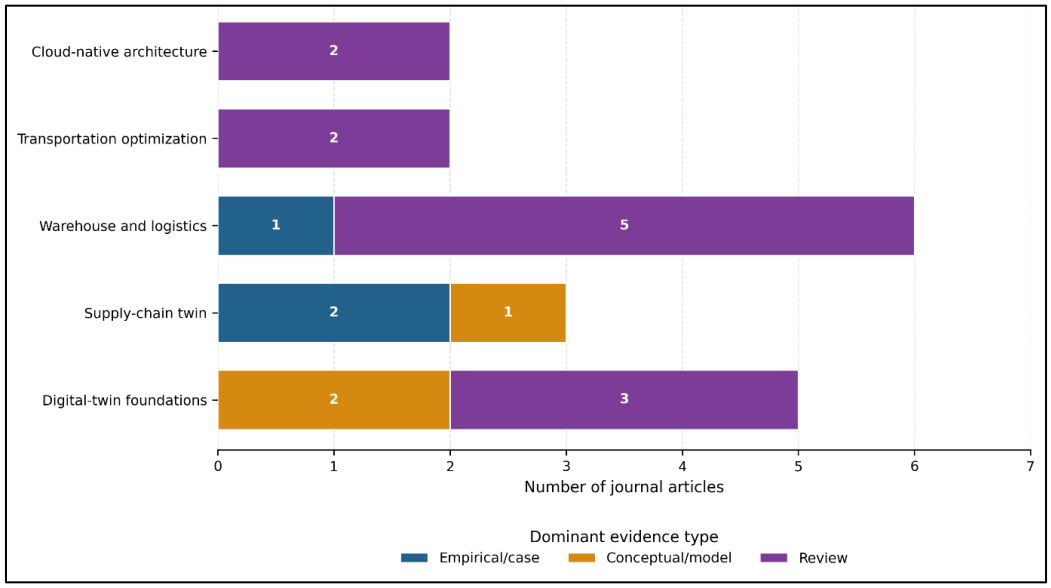


Figure 2: Distribution of reviewed evidence by domain and study type

Distribution of evidence also reveals an architectural blind spot. The digital-twin foundation papers address data linkage and model fidelity, and less commonly, report on the latency of logistics control under production workloads [1], [2], [15]–[17]. Cloud-architecture papers describe what containers and microservices are and typically do not test stale-state effects on routing or warehouse decisions [13, 14]. Warehouse and routing research usually takes the form of detailed models of the operations and typically assumes existing and reliable information on the state [8]–[12]. Context management is thus not considered as a measurable computational process, but as an implicit input. A valid context layer must answer questions of identity of entities, event time, place, units, confidence, precedence and causal relevance. If these functions are not performed, duplicate scans may occur, delayed traffic messages, conflicting inventory events or incomplete equipment telemetry in the twin state.

There is a second contradiction for model fidelity. Queueing, congestion, equipment interaction and the influence of policies can be modeled using high-fidelity discrete-event or agent-based models, but their execution time may be too slow to perform repeated operational optimizations. Reduced-order models can be used for rapid evaluation but can neglect rare constraints that make the problem feasible or not. Recent literature in the field of modelling recommends data assimilation (DA) and uncertainty handling (UH) [17] which are not always distinguished in logistics studies, with deterministic results reported instead. Cloud-native architecture should, therefore, cater for tiered architectures: fast surrogate models should be used for immediate screening, detailed simulations for high-impact decisions, and post-execution comparisons for recalibration. The twin should also store the model provenance, including which state version, prediction model, and constraint set were used in the generation of the recommendation, so that optimization services can access this information.

Figure 3 combines the contextual relationships that were most often implicit in the studies reviewed. This is important because it indicates that routing, dispatch, picking, slotting, replenishment, and recovery are part of overlapping context classes and isolated twin services are open to conflicting decisions. The bipartite network provides links between six operational context categories and six decision categories, and edge width represents the frequency with which each relationship was identified in the reviewed literature. Individually managed optimization pipelines for transport and warehouse twins are shown to be suboptimal because of shared context nodes.

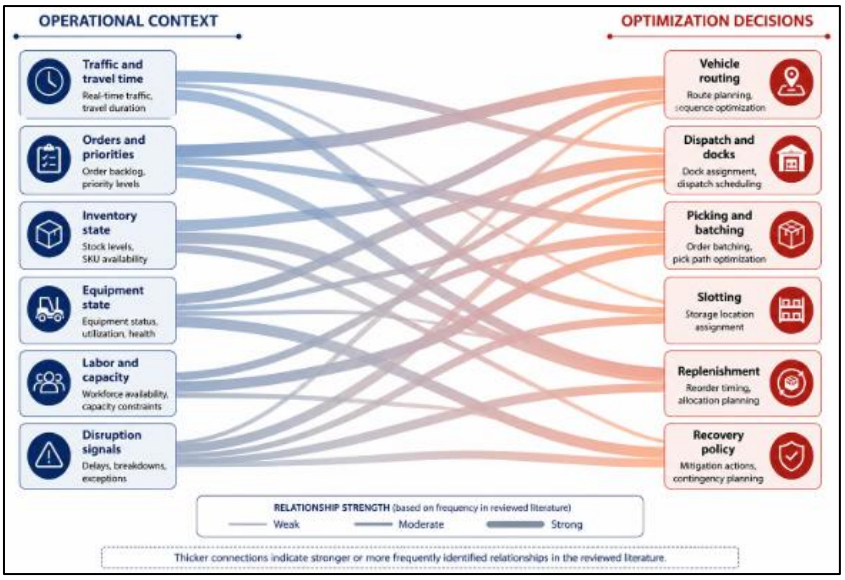


Figure 3: Context-to-decision relationship network for transportation and warehouse optimization

The relationship network indicates that there is no direct correspondence between architectural modularity and decision independence. Although microservices can separate service ownership and deployment, they still require an operational contract for cross-service decisions. The service that determines the order priority should publish the updated priority and its effective time, while the transport service should expose the commitments made with the vehicles and the docks, and the warehouse service should expose the distributions of task completion times, rather than just planned times. Eventually consistency may be acceptable for some descriptive applications, but stronger consistency or explicit state-version controls may be required for decisions involving scarce inventory, hazardous loading, or time-critical dispatch. Additional coordination mechanisms are therefore needed for critical state transitions, such as commands that can be versioned, reservation services, idempotent events, compensating actions and decision expiration.

There is also a lack of focus on security and governance aspects in the reported evidence. Digital-twin connectivity increases the attack surface because falsified contextual information can influence physical actions. Inventory can be incorrectly updated, causing unnecessary reordering; traffic data can be mis-entered, causing rerouting of vehicles; equipment status can be changed, releasing tasks into unsafe situations. Service identities, application programming interfaces, image registries, orchestration control planes, and distributed logs are examples of other items being added to cloud-native architectures that need to be protected. However, logistics-twin studies rarely test adversarial context manipulation, degraded communication, or compromised services; cybersecurity is generally treated as an implementation concern rather than an experimental condition. Operational governance must include authentication, authorization, message integrity, anomaly detection, model approval, audit trails, and safe fallback policies.

Human involvement nevertheless remains essential. Dynamic optimization can produce mathematically superior plans that may clash with tacit operational knowledge, labor agreements, driver limitations, customer commitments, or safety practices. repeated automated changes can also cause decision fatigue and loss of trust. Not only physical and digital states but also intervention thresholds, approval thresholds, explanation requirements, and decision reversibility should be represented. Thus, the best architecture to achieve the near-term objective is likely to be selectively autonomous, meaning that routine adjustments that pose little risk to operations can be performed automatically, while more significant actions are ranked, explained, and sent to the appropriate decision makers for approval. This approach balances computational speed and selective autonomy while retaining institutional accountability.

Future Directions

Benchmark architectures and experiments for evaluating the full decision loop should be developed for future research. An appropriate benchmark needs to include streaming traffic data, vehicle telemetry, order arrivals, inventory uncertainty, picker or robot deployment, dock capacity and disruption events in a repeatable transportation-warehouse scenario. Event age, twin-state divergence, context-processing latency, solver latency, actuation latency, service level, cost, energy consumption, plan instability, and recovery time should be reported in the evaluation. That would allow for a comparison of monolithic, microservice, edge-assisted, and federated twin architectures instead of comparing individual algorithms. Failure scenarios such as delayed messages, duplicate events, missing sensors, network partitions, stale forecasts, solver timeout, and conflicting commands [13, 14, 17] should also be tested in research.

Uncertainty-aware, semantically interoperable twins should be considered a priority in methodological development. There should be a separation of observed, inferred, predicted and assumed context in a probabilistic state estimate. Shared ontologies and versioned event contracts should be used to connect entities across transportation, warehousing, orders, and inventory without being restricted to a single centralized database. Multi-fidelity optimization should integrate fast heuristics, mathematical programming, simulation and learned surrogate models according to decision urgency and potential consequences. Rules for state authority, reconciliation and privacy also have to be developed for federated architectures where logistics partners are still responsible for local data [3, 5, 15].

Longitudinal deployment studies should be a priority over short demonstrations. Model drift, maintenance effort, computing cost, operator acceptance, cybersecurity exposure, and economic value should be measured after the initial implementation. Comparative tests should be used to establish that under some conditions, integrated optimization outperforms coordinated local optimization, whereas under other conditions, information overhead or modeling uncertainty makes the case for the latter stronger. Other work should explore carbon-aware routing and warehouse control, edge processing for low-latency sites and explainable recommendations for dispatchers, as well as resilient degradation when cloud services are unavailable [6], [8], [11], [18].

5 CONCLUSION

The scholarly literature provides credible component-level evidence for digital-twin modelling, transportation optimization, warehouse control, and cloud-native deployment, but limited evidence for their integration into a context-aware, real-time operational architecture. In these areas, state visibility, temporal consistency, uncertainty treatment, and feedback are more critical than virtual representation alone. A technically robust platform should integrate semantic context processing, federated twin state, scalable optimization, simulation, policy controls and auditable actuation.

The principal shortfall is the lack of validation of complete operational loops under realistic event rates, failure conditions, uncertainty, and organizational constraints. Previous studies demonstrate the feasibility of scenario analysis, local automation, route adaptation, and modular deployment, but fail to report on simultaneous improvement in service, cost, stability, latency, and resilience. Reproducible transport–warehouse benchmarks, explicit measures of state freshness and model fidelity, secure event-driven interfaces and longitudinal field evaluation are essential to future progress. the field is thus moving from isolated digital replicas toward governed decision infrastructures that coordinate transportation and warehouse actions through shared contextual state.

REFERENCES

[1] Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital twin: Enabling technologies, challenges and open research. *IEEE Access, 8*, 108952–108971.

[2] Tao, F., Zhang, H., Liu, A., & Nee, A. Y. C. (2019). Digital twin in industry: State-of-the-art. *IEEE Transactions on Industrial Informatics, 15*(4), 2405–2415.

[3] Ivanov, D., & Dolgui, A. (2021). A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0. *Production Planning & Control, 32*(9), 775–788.

[4] Winkelhaus, S., & Grosse, E. H. (2020). Logistics 4.0: A systematic review towards a new logistics system. *International Journal of Production Research, 58*(1), 18–43.

[5] Marmolejo-Saucedo, J. A. (2020). Design and development of digital twins: A case study in supply chains. *Mobile Networks and Applications, 25*(6), 2141–2160.

[6] Burgos, D., & Ivanov, D. (2021). Food retail supply chain resilience and the COVID-19 pandemic: A digital twin-based impact analysis and improvement directions. *Transportation Research Part E: Logistics and Transportation Review, 152*, 102412.

[7] Lee, C. K. M., Lv, Y., Ng, K. K. H., Ho, W., & Choy, K. L. (2018). Design and application of Internet of Things-based warehouse management system for smart logistics. *International Journal of Production Research, 56*(8), 2753–2768.

[8] Azadeh, K., De Koster, R., & Roy, D. (2019). Robotized and automated warehouse systems: Review and recent developments. *Transportation Science, 53*(4), 917–945.

[9] Boysen, N., De Koster, R., & Weidinger, F. (2019). Warehousing in the e-commerce era: A survey. *European Journal of Operational Research, 277*(2), 396–411.

[10] Van Gils, T., Ramaekers, K., Caris, A., & De Koster, R. B. M. (2018). Designing efficient order picking systems by combining planning problems: State-of-the-art classification and review. *European Journal of Operational Research, 267*(1), 1–15.

[11] Ritzinger, U., Puchinger, J., & Hartl, R. F. (2016). A survey on dynamic and stochastic vehicle routing problems. *International Journal of Production Research, 54*(1), 215–231.

[12] Psaraftis, H. N., Wen, M., & Kontovas, C. A. (2016). Dynamic vehicle routing problems: Three decades and counting. *Networks, 67*(1), 3–31.

[13] Pahl, C., Brogi, A., Soldani, J., & Jamshidi, P. (2019). Cloud container technologies: A state-of-the-art review. *IEEE Transactions on Cloud Computing, 7*(3), 677–692.

[14] Di Francesco, P., Lago, P., & Malavolta, I. (2019). Architecting with microservices: A systematic mapping study. *Journal of Systems and Software, 150*, 77–97.

[15] Jones, D., Snider, C., Nassehi, A., Yon, J., & Hicks, B. (2020). Characterising the digital twin: A systematic literature review. *CIRP Journal of Manufacturing Science and Technology, 29*, 36–52.

[16] Semeraro, C., Lezoche, M., Panetto, H., & Dassisti, M. (2021). Digital twin paradigm: A systematic literature review. *Computers in Industry, 130*, 103469.

[17] Rasheed, A., San, O., & Kvamsdal, T. (2020). Digital twin: Values, challenges and enablers from a modeling perspective. *IEEE Access, 8*, 21980–22012.

[18] Ding, Y., Jin, M., Li, S., & Feng, D. (2021). Smart logistics based on the internet of things technology: An overview. *International Journal of Logistics Research and Applications, 24*(4), 323–345.