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Digital Twin-Driven Logistics Coordination for High-Stakes Institutional Operations: A Framework for Real-Time Planning and Contingency Management

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Abstract- The growing complexity and dependency of institutional operations are leading to the need for logistics systems which are able to provide real-time planning, resource allocation coordination, risk prediction, and contingency planning. Traditional logistics frameworks are heavily based on static plans, fragmentary data analysis, and reactive decision-making. Such approaches limit the capacity of institutions to react efficiently to dynamic changes in operational situations. This study explores the possibilities of digital twin technology as a mechanism for integration and coordination of logistics operations in high-risk situations. The conceptual model for this study was developed based on the connection of real-time operational data, digital twin, prediction intelligence, scenario simulation, logistics coordination, and contingency management. Relying on the recent literature in the field of digital twins, logistics systems, supply chain resilience, and intelligent decision support, this model outlines the continuous cycle of institution operations in which institutions will be able to detect changes in operational conditions, synchronize the operational data, make predictions about possible risks, test different scenarios, coordinate resources, intervene in case of emergencies, and learn from operations. The research further identifies critical implementation considerations, including data quality, interoperability, cybersecurity, model reliability, governance, scalability, and human oversight. The presented framework sees the digital twin not just as a monitoring or visualization tool, but as an intelligent infrastructure that is capable of providing support in making decisions during the logistics coordination process. According to the research findings, logistics based on digital twins have great potential for improving institutional resilience by allowing the early identification of disruptions, planning in response to them, allocation of resources, contingency planning, and learning from organizational experiences.

Keywords: digital twins; logistics coordination; institutional operations; real-time planning; contingency management; supply-chain resilience; predictive analytics; digital transformation; operational resilience.

I. INTRODUCTION

The increasing complexity and interdependence of institutional operations have created significant challenges for logistics coordination, particularly in environments where interruptions to resources, transportation, facilities, information, or service delivery can have serious consequences. High-stakes institutions such as healthcare organizations, emergency-response agencies, humanitarian organizations, critical infrastructure operators, public institutions, and large service organizations depend on the continuous coordination of multiple logistics activities. In such environments, conventional planning approaches based on static schedules, historical information, periodic reporting, and reactive intervention may be insufficient when operating conditions change rapidly. The growing availability of real-time data and advanced digital technologies has consequently created opportunities to transform institutional logistics from a predominantly reactive function into a more predictive, adaptive, and resilient capability.

Digital twin technology is among the most innovative developments in this revolution. The digital twin refers to the digital reflection of a physical entity, process, system, or network that sustains a continual connection with its physical counterpart via data. In the logistics and supply chain context, the digital twin can bring together operational data from such sources as systems, sensors, transport, inventories, facilities, suppliers, and other resources in order to create an evolving picture of operations. According to Le and Fan (2024), digital twins can become critical instruments for enhancing decision-making within the logistics and supply chain environment through integration of physical operations, data, models, and decision support.

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In addition to enhancing visibility in operations, the capability of the digital twin to integrate real-time data with simulation and analysis provides organizations with an opportunity to assess alternative decisions prior to implementation of the chosen strategy. For example, a logistics manager may use the digital twin to assess the impact of a transport disturbance, inventory deficiency, failure of the supplier, or sudden increase in demand and evaluate different courses of action. This transforms the digital environment into a decision-support space where potential interventions can be evaluated against operational constraints and objectives.

Recent literature demonstrates growing interest in the relationship between digital twins and supply-chain resilience. Liu et al. (2026), in a systematic review of 89 peer-reviewed studies, found that digital twins can contribute to multiple stages of resilience, including preparedness, resistance to disruption, recovery, and adaptive reconfiguration. Their findings indicate that digital twins can support risk sensing, real-time monitoring, scenario testing, disruption response, recovery planning, and longer-term adaptation. This provides a strong basis for considering digital twins not merely as monitoring technologies but as components of broader resilience-management systems.

Technologies that are emerging, including Internet of Things, RFID, cloud computing, cyber-physical systems, simulation, and analytics, continue to amplify the possibilities in this regard. According to Zaidi et al. (2024), in a systematic review of digital twins in supply chain contexts, such technologies can help to ensure connectivity, synchronization in real time, modeling and decision-making within supply-chain processes. However, the use of such technologies is associated with certain challenges, including data quality, interoperability, cybersecurity, governance, complexity of systems and technology, and organizational adaptation.

It is especially true for high-stakes institutional contexts. While in ordinary commercial logistic operations, logistics planning is guided by the usual parameters such as cost and efficiency, in institutional logistic operations, the importance of logistics resilience, responsiveness, critical resources, interdependencies in the process of operation, and contingency capacity should also be considered, since there is no way to quantify the costs of service interruption exclusively in financial terms. Indeed, in the institutional context, failure to deliver an important resource, failure to provide transportation capacity and coordinate operational activities might prevent the organization from performing its basic functions.

The central argument of this research is that digital twins can provide a framework for integrating these requirements. By connecting real-time operational data with dynamic system representation, predictive intelligence, scenario simulation, resource coordination, and contingency management, institutions can develop a more responsive approach to logistics planning. The proposed framework views logistics coordination as a continuous cycle of observing operational conditions, synchronizing information, predicting potential disruptions, simulating alternative responses, coordinating resources, executing decisions, monitoring outcomes, and learning from operational experience.

For that reason, the research addresses digital twin-based logistics coordination in the context of critical operations for institutional entities. The research looks at digital twins' capacity to enhance operational transparency, manage resources flexibly, detect new threats, plan based on scenarios, and respond to disruptions adaptively. It also takes into consideration the necessary prerequisites for the successful application of digital twins, which are interoperability, data management, cybersecurity, models' reliability, scalability, and human oversight.

The offered viewpoint contributes to digital twins literature by combining two concepts – logistics coordination and contingency management – within the same framework. Unlike in the current researches, where these activities are treated as separate entities, planning, monitoring, detecting disruptions, and reacting to them are viewed from the angle of an interconnected and integrated process. This can assist institutions in transforming static contingency plans into adaptable systems.

Ultimately, the research proposes that the strategic value of digital twins in institutional logistics lies not simply in their ability to replicate physical operations digitally, but in their capacity to connect real-time awareness, predictive intelligence, scenario evaluation, coordinated decision-making, and operational learning. This capability provides a foundation for developing institutional logistics systems that are more resilient, responsive, and capable of maintaining continuity under uncertain and high-pressure conditions.

- INTRODUCTION TO DIGITAL TWIN-DRIVEN LOGISTICS COORDINATION

The increasing complexity of institutional operations has created a growing need for logistics systems capable of coordinating resources, personnel, transportation, facilities, information, and operational activities in real time. Institutions operating in high-stakes environments cannot rely exclusively on static plans or conventional logistics information systems because their operating conditions may change rapidly in response to demand fluctuations, infrastructure failures, transportation disruptions, emergencies, resource shortages, or other unexpected events. In such environments, the ability to understand the current state of operations and anticipate how alternative decisions may affect future conditions becomes a critical component of operational resilience.

This problem can be addressed using digital twin technology, which appears to provide a potential solution. A digital twin refers to a dynamic digital replica of an actual thing, process, system, or network, which connects with data from its physical replica. Contrary to a simulation model that operates independently of the physical system, a digital twin is designed in such a way that it maintains an ongoing connection with the physical system. As a result, it captures, processes, and visualizes operational information and enables decision-making based on the information. Thus, in logistics, the use of digital twins opens up new possibilities to shift from reporting to monitoring, predicting, evaluating scenarios, and managing operations (Le & Fan, 2024).

It becomes easier to understand the importance of digital twins in the context of logistics when the latter is viewed as an interrelated system and not as separate steps. There are numerous activities involved, including procurement, inventory, warehousing, transportation, distribution, facilities management, suppliers, service providers, and end-users. A transportation delay, for example, can affect inventory availability, workforce scheduling, service delivery, and subsequent distribution activities. A digital twin can provide an integrated representation of these relationships and allow decision-makers to examine the potential consequences of alternative interventions before implementing them in the physical environment.

According to new studies, there are ongoing investigations about digital twins in terms of their use to enhance visibility, modeling, monitoring and decision making in supply chains. Le and Fan (2024) suggest that logistics and supply chain digital twins must be able to facilitate effective, efficient, transparent and timely decision making while considering the necessity for trustworthy and resilient system operation. Such a conceptual framework is especially applicable to institutional logistics since it requires not only more data, but also an instrument that could transform data into coordinated decisions.

The function of the digital twin thus goes beyond visualization. The importance of the digital twin is to serve as a bridge between the physical operational world and the digital decision making world. The data collected from vehicles, warehouses, inventory management systems, facilities, sensors, enterprise systems, personnel activities and other external data sources can be incorporated in the digital twin. Further analysis and simulations can be performed in order to assess the impacts of changes on the operations.

This capability is particularly important for high-stakes institutional operations, where the consequences of poor logistics coordination can extend beyond financial inefficiency. Hospitals, emergency-response organizations, humanitarian agencies, public-sector institutions, critical infrastructure operators, universities, large financial institutions, and other complex organizations may depend on continuous availability of people, equipment, supplies, transportation, facilities, and information. In these settings, logistics failures may compromise service continuity and institutional performance. A coordination architecture capable of detecting emerging problems and testing alternative responses can consequently become an important component of institutional resilience.

Digital twin-based coordination may be perceived as an ongoing cycle of operations. First, data are generated by the physical environment; second, these data are transmitted into the digital model; third, the digital twin interprets and contextualizes the data; fourth, the patterns in the data are identified by means of analytics or deviations from normal operations are recognized; fifth, different scenarios are simulated; sixth, decisions about interventions are made; seventh, the consequences of the decision appear in the physical system and enter the digital twin as well.

The current empirical literature proves the importance of this capability for supply-chain resilience. As Liu et al. (2026) point out in their systematic review of 89 articles, digital twins may assist in different stages of supply-chain resilience. Specifically, during the stage of preparedness, they may help to provide visibility, to sense risks, and to test different scenarios. At the stage of resistance to disruptions, they may help with monitoring in real time, providing early warnings, and assessing different mitigation options.

Such an approach to logistics is crucial for the current model, as institutional logistics with its high stakes cannot be designed merely to ensure optimal performance under normal conditions. It needs to be ready for the abnormal ones. Hence, the focus should not be on finding out the optimal logistics setup under normal conditions, but rather on what will happen once the assumptions are challenged.

The suggested study, thus, views digital twin technology as a coordination platform for institutional logistics instead of just another means of digital observation. The main emphasis in the suggested framework will be on the combination of real-time data, operational modeling, intelligent forecasting, scenario simulation, resource coordination, and contingency management. The core hypothesis behind the model is that institutions increase their operational resilience when their logistics system allows creating a constantly updated digital picture of physical operations and making decisions based on that picture.

A further reason for this approach is the increasing availability of technologies that can supply the digital twin with operational data. The literature identifies technologies including the Internet of Things (IoT), radio-frequency identification (RFID), cloud computing, cyber-physical systems, cybersecurity technologies, and simulation modelling as important components of contemporary supply-chain digital-twin development (Zaidi et al., 2024). A systematic review of 129 studies found that these technologies create opportunities for connecting internal and external supply-chain actors and for improving real-time synchronization, although significant technical and organizational challenges remain.

The research therefore addresses a fundamental operational question: How can a digital twin be structured to coordinate institutional logistics continuously, anticipate emerging disruptions, support real-time planning, and enable rapid contingency management? Addressing this question requires attention not only to technology but also to the architecture through which information, models, decision processes, and operational actors are connected.

II. DIGITAL TWINS AND THE TRANSFORMATION OF INSTITUTIONAL LOGISTICS OPERATIONS

Classical institutional logistics typically has used a mixture of enterprise information systems, spreadsheets, periodic reports, manual communication, inventory tracking, transport management systems, and managers' experience. All these means are helpful; however, they usually offer fragmented information about operations. Various units may have their own version of information regarding operations, and decision-makers may be unaware of the connection between changes in various areas of operations.

The digital twin provides the potential for building an integrated model of operations. In contrast to inventory, transportation, facilities, suppliers, and services requirements being separate sources of information, a logistics digital twin will allow you to connect all these parts into a single digital space. It is not necessary to get rid of all other systems of information; instead, you should build an integrated layer allowing synthesizing information from these systems and representing the state of the whole logistics network.

Le and Fan (2024) stress the necessity of building digital twins which are transparent, reliable, and resilient. For institutional operations, it is especially important. A high-stakes organization cannot base an important operational decision on a digital model whose underlying data are unreliable or whose assumptions cannot be understood by decision-makers. Trust therefore depends on data quality, model validity, system transparency, interoperability, and appropriate governance.

The transformation created by digital twins can be understood across several dimensions.

2.1 From Static Planning to Dynamic Planning

Traditional logistics planning usually starts with predictions and plans. While predictions are needed, it is impossible for predictions to capture all the changes in operations. With digital twins, planning will become dynamic since up-to-date data can constantly alter the simulation of the system.

For instance, when there are changes in transportation, the digital twin can incorporate the new state and consider what effect it may have on the schedule and resources. Likewise, when there are unexpected increases in demand, the digital twin can help to consider the amount of inventory, delivery capacity, labor, and other sources.

This does not mean that digital twins make decisions by themselves. What they do is provide an environment that helps to make better decisions faster.

2.2 From Fragmented Information to Operational Visibility

Institutional logistics frequently involves information generated by multiple departments and external partners. Procurement may monitor suppliers, warehouse teams may track inventory, transportation teams may monitor vehicle movements, and managers may monitor service requirements. Without integration, these data streams can produce fragmented situational awareness.

A digital twin can function as an integration mechanism by combining relevant information into a shared operational representation. Zaidi et al. (2024) emphasize the importance of connecting external actors such as suppliers and distributors with internal processes such as procurement, production, and logistics when developing supply-chain digital twins. This integrated approach allows disruptions to be examined as network-level events rather than isolated departmental problems.

2.3 From Reactive Management to Predictive Coordination

A significant shift includes shifting from responding to problems after they emerge to spotting possible problems before they turn into operational failures. Constant streams of data enable a digital twin to detect deviations from normal conditions.

Predictive coordination may consist of observing deviations from delivery time, abnormal usage of inventory, limitations of capacity, transportation delays, supplier performance, facility conditions, or anything else. With this information included in the analysis model, the system creates early warning signs and allows decision makers to act.

According to Liu et al. (2026), risk sensing, scenario testing, real-time disruptions identification, and option assessment for mitigation are some of the key digital twin capabilities linked to resilience. It means that the digital twins have the potential to assist institutional logistics not only by reporting on current events but also by spotting future problems and suggesting possible actions.

2.4 From Isolated Optimization to Network Coordination

Other critical transformation pertains to the decision-making level of logistics activities. Optimal planning of an activity in isolation will result in adverse effects elsewhere. For example, the least cost of transportation might imply high delivery times, and low inventory levels might make an organization vulnerable to demand fluctuations.

A digital twin provides the means of evaluating these effects in the context of the whole system. Decision-

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makers get an opportunity to assess how adjustments of one subsystem impact other subsystems, which becomes the basis for the simultaneous consideration of such variables as service reliability, resource availability, cost, time, capacity and resilience.

The 2024 systematic review by Zaidi et al. reflects the increased focus on integration of digital-twin systems across various supply-chain activities and data-driven modeling of these systems with real-time synchronization of data. The authors highlight the complexity of implementation of integrated systems as a critical issue.

2.5 From Disruption Response to Resilience Engineering

Perhaps the most important transformation for high-stakes institutions is the shift from emergency response toward resilience engineering. Conventional contingency planning often establishes predefined responses to anticipated disruptions. Such plans remain valuable, but they may become inadequate when actual events differ from expected scenarios.

A digital twin can complement predefined contingency plans by enabling organizations to test alternative scenarios against current operational conditions. Instead of asking only, "What is our contingency plan?" decision-makers can ask, "Given the current state of our system, which response is likely to preserve the highest level of operational continuity?"

Liu et al. (2026) describe this progression through preparedness, resistance, rebound, and growth. Digital twins can support preparedness through scenario testing, resistance through monitoring and mitigation, rebound through recovery planning and adaptive reconfiguration, and longer-term growth through organizational learning and network redesign.

This perspective is especially valuable for institutional operations because resilience is not simply the ability to return to a previous operating state. A resilient institution should be able to learn from disruption and improve its future configuration. Information generated during a disruption can therefore become part of the digital twin's historical knowledge base, allowing subsequent planning cycles to incorporate lessons from previous events.

2.6 Institutional Logistics as a Cyber-Physical Coordination System

The transformation can ultimately be understood as the emergence of a cyber-physical logistics environment. Physical assets and processes generate operational data; digital systems interpret those data; analytical models simulate possible futures; and managers use the resulting intelligence to coordinate physical operations.

As a result, a constant connection will be established between the physical logistics infrastructure of the institution and its digital depiction. Consequently, the value of the digital twin will depend on the quality of this connection. In case the data is not timely, accurate, complete, or effectively integrated into the system, the digital depiction might not correspond to operational realities. However, if the model is timely updated and properly governed, it can serve as an effective decision-making tool.

Thus, digital transformation of institutional logistics should not be assessed based on the number of sensors, platforms, dashboards, or applications used. Instead, it should be assessed based on an institution's ability to gain better situational awareness, conduct quick planning, allocate resources, detect disruptions, make contingency decisions, and ensure operational continuity.

In other words, the transformation suggested in this research should go from the logistics system that records and exchanges operational information to the system that continually depicts, predicts, simulates, coordinates, and learns from operational environments. It will serve as the basis for further development of the other components of the suggested digital twin-based framework.

III. REAL-TIME DATA INTEGRATION, VISIBILITY, AND OPERATIONAL SYNCHRONIZATION

The effectiveness of a digital twin-driven logistics system depends fundamentally on its ability to maintain an accurate and timely representation of the physical operating environment. A digital twin that is not adequately synchronized with its physical counterpart can quickly become an outdated digital model rather than a useful decision-support instrument. For high-stakes institutional operations, where decisions may need to be made under rapidly changing conditions, real-time or near-real-time data integration is therefore a central requirement.

The data used in institutional logistics originate from a variety of sources, ranging from inventory management systems, enterprise resource planning systems, warehouse management systems, transportation management systems, GPS-equipped vehicles, RFID tags, IoT devices, procurement systems, facilities management systems, supplier management systems, and manual operational reporting. The aforementioned sources vary in terms of structure, frequency, accuracy, and ownership. However, the problem lies not only in gathering information but rather in integrating the data to form a coherent operational picture.

According to Zaidi et al. (2024), the enabling technologies used in digital twins include IoT, RFID, cloud computing, cyber-physical systems, and simulation tools. Moreover, the systematic review by the authors shows that digital twins are increasingly applied in order to enhance connectivity of various supply chain processes. Thus, it can be concluded that the digital twin technology in institutional logistics must be capable of serving as an integration tool to create an integrated logistics operational picture. (Zaidi et al., 2024)

3.1 Data Integration as the Foundation of the Digital Twin

The first requirement is establishing a reliable data architecture. Each physical component represented within the digital twin should have identifiable data attributes that describe its current condition and operational status. For example, a transportation asset may be associated with location, estimated arrival time, route, capacity, fuel status, maintenance condition, and assigned delivery. An inventory item may be associated with quantity, location, consumption rate, reorder threshold, supplier, lead time, and demand forecast.

By combining these data elements, the digital twin is able to find associations between resources and actions. For example, delays of one vehicle could be analyzed in regard to its cargo, destination locations, workers awaiting the delivery, and subsequent tasks that depend on the delivery.

Le and Fan (2024) point out that effective connections between physical process, data, modeling, and decision-making are crucial to digital twins in logistics and supply chain systems. Connections make it a true digital twin and not just a visualization tool. (Le & Fan, 2024)

For this reason, data integration must be an ongoing activity, not sporadic synchronization. How often it needs to be done depends on the situation. Some activities within institutions require ongoing updates, while some may work well enough with periodic synchronization. High-risk logistics that involve emergency delivery of goods or fast-changing demand would need much shorter update cycles than routine administrative logistics.

3.2 Operational Visibility and Situational Awareness

The capability of data integration in real time forms the basis of operational visibility. Visibility is defined as the ability of managers to comprehend the current situation in relation to logistics activities and resource allocation.

If there is a lack of sufficient visibility, managers might learn about disruptions only when their impact on operations becomes evident. The use of a digital twin could eliminate information lag by consolidating representations of current conditions. Managers could assess at the same time the situation concerning inventories, transportations, suppliers, facilities capacities, deliveries, and demand situation.

It is critical if operational problems happen simultaneously. Disruptions on their own might be manageable, while several concurrent disruptions may overload standard coordination practices. Digital twins can reveal the interconnections between the occurring disruptions and prioritize the ones that would have the highest impact on operations.

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In Liu et al.'s (2026) review, digital twins and real-time visibility and monitoring are presented as key capabilities for achieving supply-chain resilience. The review proves that the value of visibility becomes particularly high in case of disruptions since it is needed to evaluate whether a disturbance is local or systemic. (Liu et al., 2026)

3.3 Synchronization between Physical and Digital Environments

Synchronization is the continual updating of the digital twin to maintain consistency with the changing physical environment. Synchronization is a key element in having a useful digital twin.

The synchronization process can take place via data streams. Equipment conditions can be reported by sensors, location of transport can be reported by GPS systems, inventory movement can be reported by RFID systems, and transactions can be reported by the enterprise systems. The streams of data can then be processed and integrated into the digital twin.

However, synchronization is more than a technical issue. The organization has to decide which data sources are authoritative, which competing data sources can be reconciled, how missing data is managed, and how often various variables should be updated.

Thus, a logistics digital twin should have built-in data quality measures. They could be validation, anomaly detection, timestamp management, source checking, duplicate data handling, and resolution of conflicting records. The poor quality of data can defeat even the best analysis and simulation.

3.4 Interoperability across Institutional Systems

Institutional logistics rarely operates through a single information system. Different units may use different software platforms, databases, communication protocols, and data formats. Consequently, interoperability is essential.

Interoperability allows the digital twin to communicate with existing institutional systems rather than requiring the organization to replace all legacy systems. Application programming interfaces, standardized data structures, integration middleware, cloud platforms, and event-driven architectures can support this connection.

The literature identifies interoperability as one of the significant challenges associated with digital-twin implementation. Zaidi et al. (2024) highlight the complexity created by integrating multiple technologies, systems, and supply-chain actors. This problem becomes more pronounced when institutions operate across organizational boundaries and depend on external suppliers, logistics providers, regulators, or emergency-response organizations. (Zaidi et al., 2024)

3.5 From Data Visibility to Operational Synchronization

Visibility, by itself, does not ensure coordination. An organization might have plenty of information but still deliver poor logistics performance when all departments are not reacting to the same operational image.

Therefore, the suggested concept differentiates between the concepts of data visibility and operational synchronization. The former defines the answer to the question, "What is going on?" The latter expands it into the question, "Do the people and resources involved react to the same operational reality?"

For instance, if the shipment is delayed, the activities of procurement, warehouse staff, transportation coordinator, and delivery manager could need adjustment. And a digital twin can offer the common picture of the situation and its probable outcome for all parties to synchronize their actions.

Such a common operational view is especially important in critical settings since delayed decisions can magnify the effects of disruption. Without consistent information, the institution could respond to the situation ambiguously or inefficiently.

3.6 Data Integration and Institutional Decision Latency

One of the main advantages associated with real-time synchronization can be seen in the form of a reduction in decision latency. Decision latency refers to the period between when the operational condition occurs and when action is taken to address this condition.

The conventional approach can entail collecting data, manually preparing reports, reviewing by management, communicating within the department, developing options, and making decisions. A digital twin can save on time by automatically collecting data, identifying any deviations, updating the model of the system, and offering decision-makers relevant scenarios.

The point is not to eliminate human decision-making altogether. Instead, the goal is for decision-makers to receive the relevant information at the right time in order to make the right decisions.

This is critical because high-stake institutional logistics often requires decisions that cannot be left entirely to automated systems. Issues of ethics, organizational needs, regulations, safety, and exceptional circumstances may require managerial decision-making. The digital twin must then serve as a decision-support environment, and not an autonomous decision-maker.

IV. DIGITAL TWIN-ENABLED PLANNING AND RESOURCE COORDINATION

Real-time visibility becomes operationally valuable when it can be translated into better planning and resource coordination. Institutional logistics involves continuous decisions concerning what resources are required, where they should be located, when they should be available, and how they should be allocated under changing conditions.

Traditional planning approaches often depend on forecasts, historical data, predetermined schedules, and managerial experience. These remain important, but digital twin technology can supplement them by allowing planners to evaluate proposed decisions against a continuously updated representation of the operating environment.

4.1 Dynamic Logistics Planning

Dynamic planning is the capability to adapt logistics planning based on changing circumstances. As opposed to making a plan and sticking to it until the next planning period comes up, the organization will always have the opportunity to review its operational setup.

For instance, it may adjust its transportation schedule after an occurrence such as the breakdown of a road, adjust its inventory setup in response to unexpected demand, or even revise its supplier setup based on decreased capacity.

The digital twin makes it possible for these kinds of changes to be made within the context of the digital world where the changes may be simulated prior to their implementation in the physical world.

According to Le and Fan (2024), simulation and decision-support are two important elements in logistics and supply chain digital twins. (Le & Fan, 2024)

4.2 Resource Allocation

Resource coordination is central to institutional logistics. Resources may include vehicles, warehouses, inventory, personnel, equipment, facilities, financial resources, and supplier capacity.

Under normal conditions, resource allocation may focus on efficiency. Under high-stakes conditions, however, allocation must also consider availability, urgency, redundancy, vulnerability, and continuity of service.

A digital twin can represent resource availability and demand simultaneously. This allows planners to identify potential shortages before they become operational failures.

For example, if the digital twin indicates that projected demand for a critical resource will exceed available inventory, planners can evaluate different responses: increasing procurement, redistributing inventory, identifying alternative suppliers, adjusting delivery schedules, or prioritizing critical users.

The value lies in evaluating these alternatives in relation to the wider system rather than making isolated decisions.

4.3 Scenario-Based Planning

Scenario analysis is one of the strongest applications of digital twins in logistics. A scenario represents a hypothetical change in operating conditions and allows planners to examine potential consequences.

Possible institutional logistics scenarios could include:

- A major supplier becoming temporarily unavailable;
- A transportation route becoming inaccessible;
- An unexpected increase in demand;
- A warehouse experiencing capacity constraints;
- A critical vehicle becoming unavailable;
- A facility experiencing an operational outage;
- Simultaneous disruptions affecting several suppliers or routes.

The digital twin can simulate these conditions and estimate their effects on inventory, transportation, service levels, resource utilization, and operational continuity.

Ivanov (2023) particularly emphasizes the potential of intelligent digital twins for supply-chain stress testing, resilience, and viability. This perspective is directly applicable to institutional logistics because it shifts the purpose of the digital twin from merely observing current operations toward testing how the system behaves under stress. (Ivanov, 2023)

4.4 Multi-Objective Logistics Coordination

Institutional logistics decisions rarely involve a single objective. A decision that minimizes cost may increase delivery time; a decision that maximizes speed may increase resource consumption; a decision that reduces inventory may increase vulnerability to disruption.

Digital twin-enabled planning can therefore support multi-objective decision-making. Relevant objectives may include:

- Service continuity;
- Delivery speed;
- Resource utilization;
- Logistics cost;
- Inventory availability;
- Operational risk;
- Resilience;
- Safety; and
- Stakeholder requirements.

The relative importance of these objectives can change according to the operational context. During normal operations, cost efficiency may receive greater weight. During a critical disruption, continuity and response speed may become more important.

A high-stakes institutional digital twin should therefore be capable of supporting different decision priorities depending on the operational state of the organization.

4.5 Coordinating Internal and External Resources

Institutional logistics often extends beyond organizational boundaries. Suppliers, third-party logistics providers, contractors, transportation companies, emergency agencies, and other external actors may form part of the operational network.

A digital twin can help represent these external dependencies and evaluate their influence on institutional operations. Zaidi et al. (2024) emphasize the importance of extending digital-twin perspectives across supply-chain actors rather than limiting them to individual organizational processes.

This is particularly important for contingency management. If an institution depends heavily on one supplier or transportation provider, the digital twin can identify this dependency and simulate the consequences of its failure. Alternative providers or resource configurations can then be evaluated before an actual disruption occurs.

4.6 Predictive Capacity Planning

Planning should also consider future resource requirements. Historical consumption patterns, current demand, external conditions, and operational trends can be incorporated into predictive models.

For example, a digital twin may identify a projected increase in demand for a particular resource and calculate whether current procurement, storage, and transportation capacity will be sufficient. If a projected shortage is identified, managers can intervene before the shortage materializes.

This creates an important transition from reactive resource allocation to predictive capacity management.

4.7 Digital Twin as a Decision Sandbox

The digital twin can ultimately function as a decision sandbox. Decision-makers can test alternative plans digitally before committing physical resources.

Suppose an institution must determine how to respond to a major logistics disruption. Instead of selecting a response based solely on experience, managers can compare several options within the digital environment. One scenario may involve rerouting transportation; another may involve redistributing inventory; a third may involve activating an alternative supplier.

Each scenario can be evaluated against operational objectives and constraints. The preferred response can then be implemented with greater confidence.

This capability is consistent with the resilience-oriented perspective identified by Liu et al. (2026), in which digital twins support scenario testing, disruption response, recovery, and adaptive reconfiguration.

4.8 Toward Continuous Planning

The combination of real-time synchronization, predictive intelligence, scenario modelling, and resource coordination ultimately creates the possibility of continuous planning.

Continuous planning does not mean that managers constantly change operational plans without discipline. Instead, it means that plans remain responsive to meaningful changes in operational conditions.

The digital twin continuously compares the current state of the system with expected or desired conditions. When deviations are detected, decision-makers can determine whether intervention is necessary. If intervention is required, alternative responses can be evaluated and incorporated into the operational plan.

This creates a planning cycle that can be represented conceptually as:

Observe → Synchronize → Predict → Simulate → Coordinate → Execute → Monitor → Reconfigure.

This cycle provides the foundation for the next component of the proposed framework: using predictive intelligence to identify emerging disruptions and determine how they may propagate through institutional logistics networks.

V. PREDICTIVE INTELLIGENCE FOR DISRUPTION DETECTION AND RISK MANAGEMENT

The ability to detect operational disruptions before they develop into major failures represents one of the most important opportunities offered by digital twin-driven logistics coordination. In conventional logistics environments, disruption management is frequently initiated after an adverse event has already affected transportation, inventory, facilities, suppliers, or service delivery. This reactive orientation can increase the time required to restore operations and may allow relatively small disturbances to propagate across interconnected activities. A digital twin provides an opportunity to move toward predictive risk management by continuously comparing the current operational state with expected conditions and identifying signals that may indicate emerging problems.

Digital twin technology is particularly suited to this purpose because it combines real-world operational data with digital representations, analytical models, and simulation capabilities. Rather than examining disruption risk only through periodic assessments, the institution can continuously evaluate the condition of its logistics network. This creates a foundation for early warning, scenario testing, and proactive intervention.

Liu et al, identify risk sensing, real-time monitoring, disruption detection, scenario testing, and mitigation evaluation among the resilience-related capabilities associated with digital twins. Their systematic review demonstrates that the technology can support multiple stages of resilience rather than being limited to post-disruption recovery. (Liu et al., 2026)

5.1 From Risk Identification to Continuous Risk Sensing

Typically, conventional risk assessments take place periodically. Managers evaluate possible risks and

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threats and calculate their probability and impact. Also, managers devise solutions. Despite its usefulness, the risk situation for a sophisticated logistics operation may evolve constantly.

For instance, a previously reliable supplier may start lagging on deliveries. A traditionally safe transportation route can become congested. Inventories may start being consumed beyond forecast expectations. A site may display unusual behavior of machinery. None of them individually means much, but collectively, these signs may suggest rising vulnerability of the operation.

A digital twin, however, can continuously track these signs. Past experiences may be compared to the current state, and a prediction model will detect any anomalies.

This makes it possible to shift from periodic risk assessment to constant risk sensing.

The difference is significant in terms of institutional high-stakes operations due to the possibility of early detection. It allows managers to use a number of options when there is still time to do something. If the same problem is detected only after operational failure occurs, the institution may be forced into emergency action.

5.2 Anomaly Detection and Early Warning

Anomaly detection is an important component of predictive risk management. An anomaly occurs when observed operational behavior differs significantly from an established baseline or expected pattern.

Examples may include:

- unusually long delivery times;
- abnormal inventory consumption;
- unexpected transportation delays;
- sudden reductions in supplier capacity;
- unusual facility conditions;
- abnormal equipment behavior;
- unexpected demand increases; or
- significant divergence between planned and actual resource utilization.

The digital twin can establish a baseline representation of normal operating conditions and compare incoming information against that baseline. Statistical techniques, machine-learning models, and rule-based systems can then be used to identify potentially significant deviations.

However, an anomaly should not automatically be treated as a disruption. A sophisticated system must distinguish between harmless variation and conditions requiring intervention. This requires contextual interpretation.

For example, a temporary increase in demand may be normal during a predictable institutional event but problematic if it occurs unexpectedly and coincides with declining inventory availability. The digital twin should therefore evaluate relationships among variables rather than examining individual indicators in isolation.

5.3 Predicting Disruption Propagation

The most prominent feature of logistics systems is the characteristic of interdependence. Disruptions seldom remain limited to the starting point of a disruption.

In the case of a supplier delay, the first effect could be decreased inventory. If there is a continuation in the delay, there could be a drop in the inventory in the warehouses. Low inventory levels can have an impact on service provision. If other sourcing is needed, there could be increased transportation needs.

There will be a cascade of effects.

The digital twin could map these effects and even simulate the propagation channels. Thus, the institution can determine not just the possibility of a disruption but also its likely propagation through the operational network.

As Ivanov (2023) notes, intelligent digital twins offer immense value in the stress-testing and viability of supply chains. The most important application is stress testing, which helps to analyze the impacts of an adverse event before its occurrence in the actual system. (Ivanov, 2023)

5.4 Predictive Risk Scoring

A further development is the creation of dynamic risk scores for operational components.

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For example, the digital twin could calculate risk levels for:

- suppliers;
- transportation routes;
- warehouses;
- inventory categories;
- facilities;
- vehicles;
- critical equipment;
- distribution nodes; and
- service dependencies.

A risk score could incorporate several variables, including probability of failure, potential impact, exposure, recovery time, redundancy, current operating condition, and dependency relationships.

The purpose would not be to reduce complex risk to a single number but to provide decision-makers with a structured mechanism for prioritizing attention.

A high-risk supplier, for instance, may require closer monitoring or activation of an alternative source. A high-risk transportation route may require contingency routing. A high-risk inventory category may require additional safety stock.

5.5 Predictive Maintenance and Logistics Continuity

Digital twins can also assist in predictive maintenance. Assets in the form of vehicles, machinery in warehouses, refrigeration systems, generators, material-handling equipment, and any other infrastructure can be replicated digitally and monitored using operational data.

Once there is deviation from the norm in terms of asset conditions, the digital twin can help determine where maintenance will be required.

This is due to the fact that any failure of an asset can cause indirect logistics disruptions. Vehicle failure causes delays in deliveries, while machinery failure at the warehouse causes lower throughput. Therefore, predictive maintenance can become part of logistics continuity planning.

The use of digital twins in production logistics has been extensively studied in the literature. Kaiblinger and Woschank (2022) have identified digital-twin applications in logistics and production settings and the benefits of the technology in modeling and improving operations. (Kaiblinger & Woschank, 2022)

5.6 Stress Testing Institutional Logistics

Stress testing involves deliberately exposing the digital representation of the institution to adverse conditions.

Potential stress scenarios may include:

- sudden supplier failure;
- transportation network disruption;
- substantial demand increase;
- inventory shortage;
- warehouse capacity reduction;
- equipment failure;
- simultaneous disruptions;
- communication-system failure; and
- prolonged service interruption.

The digital twin can estimate how the institution would perform under each scenario.

This provides two benefits. First, it identifies weaknesses before actual disruption occurs. Second, it enables managers to compare alternative resilience strategies.

For example, an institution may discover that a particular logistics route represents a critical dependency. Managers could then compare the cost of maintaining additional capacity against the potential consequences of route failure.

This approach changes contingency planning from a document-based exercise into a continuously testable operational capability.

5.7 Risk Interdependencies and Cascading Effects

High-stakes institutional operations are vulnerable to cascading risks because logistics functions are interconnected.

A single disruption may affect several operational dimensions simultaneously. A power failure, for example, may affect information systems, storage conditions, communications, facilities, and logistics processing. A cybersecurity incident may interrupt digital coordination and simultaneously affect procurement, inventory, and transportation information.

The digital twin should therefore incorporate dependencies rather than treating risks independently.

This is one of the reasons that supply-chain resilience literature increasingly emphasizes network-level modelling. Zaidi et al, show that digital-twin applications extend across multiple supply-chain processes and technologies, creating opportunities for integrated modelling of interconnected operations. (2024)

5.8 Predictive Intelligence and Decision Thresholds

Predictive intelligence becomes operationally useful only when it is connected to decision thresholds.

An institution should determine what happens when a predicted risk reaches a particular level. For example:

Low risk → continue monitoring;

Moderate risk → increase monitoring and prepare alternatives;

High risk → initiate contingency planning;

Critical risk → activate predefined response procedures.

These thresholds should be configurable because different institutional activities have different tolerance levels.

A high-stakes service may require intervention at a much lower risk threshold than a routine administrative activity. Consequently, the digital twin should incorporate operational priorities and institutional risk appetite into its decision-support logic.

VI. CONTINGENCY MANAGEMENT AND REAL-TIME OPERATIONAL RESPONSE

Predicting a disruption is only one part of resilience. The ultimate value of predictive intelligence depends on the institution's ability to respond effectively. Contingency management therefore represents the operational bridge between digital prediction and physical action.

A contingency-management system should answer four fundamental questions:

What has happened or is likely to happen?

What are the consequences for institutional operations?

What response options are available?

Which response provides the most appropriate balance between continuity, risk, cost, time, and available resources?

The digital twin can support each stage by maintaining an updated operational representation and providing a digital environment in which response options can be evaluated.

6.1 From Contingency Plans to Adaptive Contingency Management

Conventional contingency plans are generally prepared in advance for anticipated scenarios. They establish responsibilities, procedures, communication channels, and response actions.

The limitation is that actual disruptions rarely reproduce planned scenarios perfectly. The timing, severity, location, duration, and combination of disruptions may differ from assumptions made during planning.

Digital twin technology can complement predefined plans with adaptive contingency management. Instead of relying exclusively on a fixed response, managers can modify contingency actions according to the current operational state.

Liu et al. (2026) emphasize adaptive reconfiguration as an important aspect of digital-twin-enabled resilience. This supports the argument that digital twins should not merely preserve predefined response procedures but should enable organizations to adapt their responses as conditions evolve. (Liu et al., 2026)

6.2 Real-Time Scenario Evaluation

When a disruption occurs, the digital twin can generate alternative response scenarios.

For example, if a critical shipment is delayed, possible responses may include:

- rerouting an existing vehicle;
- using an alternative transportation provider;
- reallocating inventory from another location;
- activating an alternative supplier;
- changing delivery priorities;
- modifying service schedules; or
- combining several interventions.

Each option may have different costs and consequences.

The digital twin can evaluate these alternatives against current operational conditions. This is more powerful than selecting an intervention based solely on historical precedent because the simulation reflects the current state of the system.

Ivanov (2023) identifies stress testing and digital-twin-enabled resilience as important mechanisms for understanding supply-chain behavior under disruption. This concept can be extended to institutional logistics by using the digital twin as a real-time response-testing environment. (Ivanov, 2023)

6.3 Response Prioritization

Not every disruption requires the same response. High-stakes institutions need mechanisms for prioritizing disruptions according to their potential consequences.

A prioritization model can consider:

- operational criticality;
- affected population or stakeholders;
- expected duration;
- resource availability;
- cascading effects;
- safety implications;
- financial consequences;
- recovery time; and
- availability of alternatives.

For example, a disruption affecting a non-critical administrative supply may be tolerated for several days, whereas disruption involving an essential operational resource may require immediate intervention.

The digital twin can support this prioritization by linking disruptions to the processes and resources they affect.

6.4 Coordinated Contingency Execution

Once a response has been selected, execution requires coordination among multiple actors.

A logistics disruption may involve procurement officers, transportation managers, warehouse personnel, suppliers, facility managers, financial officers, information-technology teams, and senior management.

Without coordinated information, different departments may execute contradictory actions.

The digital twin can provide a shared operational picture that communicates the selected response, affected resources, expected consequences, and evolving conditions.

This supports what can be termed synchronized contingency execution: the alignment of different operational actors around a common representation of the disruption and response.

6.5 Dynamic Reconfiguration

One of the most important capabilities of a digital twin-driven system is dynamic reconfiguration.

Dynamic reconfiguration refers to changing the logistics network or operational plan in response to changing conditions.

For example, an institution may temporarily:

- change supplier allocations;
- reroute transportation;
- redistribute inventory;
- modify warehouse utilization;
- change workforce deployment;

- alter delivery priorities;
- increase safety stock; or
- activate reserve capacity.

These changes may remain in effect until the disruption is resolved or may become part of a longer-term redesign.

Liu et al. (2026) identify adaptive reconfiguration as an important resilience capability, particularly during recovery and post-disruption adaptation. (Liu et al., 2026)

6.6 Recovery and Return to Stable Operations

Contingency management should not end when the immediate disruption is controlled. Institutions must also manage recovery.

Recovery involves restoring disrupted resources, rebuilding inventory, returning transportation networks to normal schedules, repairing equipment, reassessing suppliers, and evaluating residual risks.

The digital twin can support recovery by tracking the institution's progress toward a stable operating state.

For example, the system can compare current inventory levels with required levels, monitor supplier recovery, track delayed deliveries, and determine whether temporary logistics arrangements can be withdrawn.

This creates a structured transition from emergency response to normal operations.

6.7 Learning From Disruptions

A major advantage of maintaining a digital representation over time is the ability to preserve operational history.

After a disruption, the institution can compare:

Predicted scenario → actual event → implemented response → actual outcome.

This comparison provides valuable organizational learning.

If a particular response performed better than expected, it can become part of future contingency planning. If a response failed to produce the expected outcome, its assumptions can be revised.

The digital twin therefore becomes not merely a representation of the present but an institutional memory of logistics behavior.

This creates a continuous improvement cycle in which each disruption improves future planning.

6.8 Human Judgment and Digital Decision Support

Despite the sophistication of digital-twin technology, human judgment remains essential in high-stakes institutional operations.

A digital twin can estimate consequences and compare alternatives, but it may not fully understand ethical considerations, political priorities, organizational culture, stakeholder sensitivities, or exceptional circumstances.

The appropriate role of the digital twin is therefore to augment managerial decision-making.

Decision-makers should be able to inspect the assumptions behind recommendations, compare alternative scenarios, override automated recommendations when justified, and document the reasons for exceptional decisions.

This human-in-the-loop approach is particularly important where logistics decisions may have significant consequences for safety, service continuity, or vulnerable stakeholders.

6.9 An Integrated Contingency Cycle

The concepts discussed above can be combined into an integrated contingency cycle:

Detect → Diagnose → Predict → Simulate → Prioritize → Coordinate → Execute → Monitor → Recover → Learn.

The digital twin acts as the coordinating digital environment throughout this cycle.

Detection identifies emerging or actual disruptions.

Diagnosis establishes their operational implications.

Prediction estimates likely future consequences.

Simulation compares alternative responses.

Prioritization determines which intervention should receive attention.

Coordination aligns resources and actors.

Execution implements the selected response.

Monitoring evaluates the response as conditions evolve.

Recovery restores stable operations.

Learning incorporates the experience into future digital models and contingency plans.

This cycle represents a fundamental shift from static contingency planning toward continuous, data-driven, adaptive contingency management.

The significance of this model is that resilience becomes an ongoing operational capability rather than an emergency activity that begins only after failure. Digital twins can provide the infrastructure for maintaining this capability because they connect real-time data, operational models, predictive intelligence, scenario simulation, and decision-making within a common environment.

VII. FRAMEWORK FOR DIGITAL TWIN-DRIVEN HIGH-STAKES INSTITUTIONAL OPERATIONS

The preceding sections establish that digital twins can provide more than a digital representation of logistics assets and processes. When appropriately designed, they can function as an integrated coordination environment through which institutions monitor operations, anticipate disruptions, evaluate alternative plans, allocate resources, and manage contingencies. The central challenge is therefore to organize these capabilities into a coherent framework suitable for high-stakes institutional environments.

The proposed framework is based on the premise that institutional logistics should operate as a continuous feedback system connecting the physical environment, digital representation, analytical intelligence, managerial decision-making, and operational execution. The framework is consequently designed around six interconnected layers: the physical operations layer, data and connectivity layer, digital-twin representation layer, intelligence and simulation layer, coordination and decision layer, and execution and learning layer.

7.1 Physical Operations Layer

The physical operations layer represents the actual institutional environment. It includes logistics assets, facilities, vehicles, warehouses, inventory, personnel, suppliers, transportation networks, equipment, and service activities.

This layer is where operational events occur. Deliveries are made, inventory is consumed, vehicles move, facilities operate, equipment deteriorates, and demand changes. The digital twin cannot provide useful decision support unless it maintains an adequate representation of these physical conditions.

For high-stakes institutions, the physical layer should therefore be mapped according to operational criticality. Not every asset requires the same level of digital representation. Critical resources and processes should receive greater monitoring and modelling attention because their failure may generate significant consequences.

This principle is consistent with the resilience-oriented literature, which emphasizes the importance of identifying critical dependencies and understanding how disruptions can propagate through interconnected systems (Liu et al., 2026).

7.2 Data and Connectivity Layer

The second layer serves as a connector between physical processes and the digital world. This layer involves data from IoT devices, RFID, GPS, enterprise systems, warehouse management systems, transport systems, procurement systems, facility systems, and other data sources.

According to Zaidi et al. (2024), IoT, RFID, cloud computing, cyber-physical systems, and simulation can be listed among the technologies that make digital-twin-enabled supply chain systems possible. These technologies ensure the continuous flow of

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information that enables keeping the physical and digital worlds synchronized.

Nonetheless, connectivity does not mean the availability of huge amounts of data. This data needs to be timely, relevant, accurate, and structured properly. The digital twin based on irrelevant information may create a deceptive view of what is going on.

Thus, the concept involves such crucial issues as data validation, synchronization, data quality, interoperability, and secure information exchange.

7.3 Digital-Twin Representation Layer

The digital-twin representation layer translates the received operational data into a model of institutional logistics.

It models the relationships between resources, activities, locations, capacity, demand, transportation, suppliers, facilities, and other elements. It should reflect at all times the state of operations of the institution.

In their work, Le and Fan stress the significance of conceptualizing the digital twins for logistics and supply chain systems as frameworks integrating physical processes, data, modelling and decision support. They confirm the significance of using the digital twin as an operational representation tool and not just a visualization tool (Le & Fan, 2024).

In case of high-stakes institutional operations, it should reflect operational dependencies as well. For instance, if a specific supplier is responsible for a specific resource, it should reflect that relationship.

7.4 Intelligence and Simulation Layer

The intelligence and simulation layer transforms the digital twin into decision support technology.

The intelligence layer includes predictive analytics, anomaly detection, risk assessment, optimization, scenario building, and simulation. Its goal is to be able not only to understand the current state but also what might happen next and what could happen in different scenarios.

For instance, if the transportation data show growing delays, the predictions will help to find out whether the delays will have an impact on key deliveries, and the simulation will help to check different scenarios for dealing with the problem.

According to Ivanov (2023), intelligent digital twins have a great potential for the stress testing of the supply chain and evaluation of its resilience and viability. The idea is important for the institution because in high-stakes logistics it is necessary to analyze the performance of the system under both expected and unexpected conditions.

Therefore, the intelligence layer should include two important functions – prediction and experimentation.

7.5 Coordination and Decision Layer

Ultimately, the intelligence produced through the digital twin has to be converted into action. This is where the coordination and decision-making layer comes into play.

It links digital intelligence to the management and other stakeholders, such as logistical coordinators, operational units, and suppliers. Relevant information can be communicated through dashboards, alerts, scenario comparison, decision support systems, and communication channels.

However, it is essential that the framework preserves human decision-making power when making critical decisions. While the digital twin might generate the most appropriate response, the manager has to be able to compare the suggested action to the organizational needs and context.

This way, a human-in-the-loop digital twin framework emerges.

This particular approach is important since optimization doesn't always result in the most appropriate decision. An ideal solution might be inappropriate because of operational risks and failure to meet certain stakeholder demands.

7.6 Execution and Learning Layer

The final layer connects decisions to physical implementation and subsequent learning.

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Once a response is selected, relevant operational actors implement it. The digital twin continues to monitor the resulting conditions and determines whether the intervention is producing the expected outcome.

This feedback is important because a response that appears effective during simulation may produce different results in the physical environment. Actual performance data should therefore be returned to the digital twin.

The framework consequently incorporates a continuous learning loop:

Physical Operations → Data → Digital Twin → Prediction and Simulation → Decision → Physical Execution → New Data.

Over time, this loop can improve the institution's understanding of its logistics system and strengthen future contingency planning.

7.7 The Integrated Coordination Framework

The proposed framework can therefore be represented conceptually as follows:

PHYSICAL INSTITUTIONAL OPERATIONS
↓
REAL-TIME DATA AND CONNECTIVITY
↓
DYNAMIC DIGITAL TWIN
↓
PREDICTIVE INTELLIGENCE + SIMULATION
↓
MANAGERIAL DECISION AND LOGISTICS COORDINATION
↓
RESOURCE ALLOCATION + CONTINGENCY EXECUTION
↓
OPERATIONAL FEEDBACK AND LEARNING
↺ Continuous synchronization with the digital twin

The strength of this framework lies in its cyclical rather than linear structure. Logistics does not move from data collection to decision-making once. Instead, the system continuously updates itself as operating conditions change.

This is consistent with the resilience perspective advanced by Liu et al. (2026), in which digital twins can contribute across preparedness, resistance, recovery, and adaptive reconfiguration. It also reflects the broader digital-twin literature's emphasis on connecting real-world operations with digital models and decision-support capabilities (Le & Fan, 2024; Zaidi et al., 2024).

7.8 Application to High-Stakes Institutional Operations

The suggested framework could be used in a variety of institutions where logistics continuity plays an important role. Such institutions include healthcare institutions, emergency response organizations, humanitarian organizations, critical infrastructure organizations, public sector institutions, educational organizations, etc.

Suppose that an institution suffers from an unexpected disruption in its critical supply chain. Physical operations layer determines the disruption based on transportation and inventory information. Connectivity layer sends this information into the digital environment. Digital twin modifies the impacted logistics network and identifies dependent operations.

Intelligence layer analyzes possible impacts and develops various simulations for response options. Different scenarios could be compared in terms of such actions as rerouting, redistribution, alternative sourcing, priority allocation, etc. When a response option is chosen, the coordination layer informs all parties about the decision.

The execution layer executes the response plan while digital twin monitors the performance. If some changes occur, another recommendation can be generated by the system. Once the disruption comes to an end, the real impact is recorded in the knowledge base of the institution.

This example demonstrates that the framework is not designed solely for emergency response. The same architecture can support normal planning, capacity management, resource allocation, performance monitoring, and continuous improvement.

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7.9 Performance Dimensions

The effectiveness of the framework should ultimately be evaluated through operational outcomes rather than technological deployment alone. Relevant performance dimensions include planning responsiveness, decision latency, logistics visibility, resource utilization, service continuity, disruption recovery time, contingency effectiveness, and resilience.

A successful implementation should enable institutions to detect operational problems earlier, understand their consequences more accurately, evaluate response alternatives more rapidly, and coordinate physical resources more effectively.

The ultimate objective is therefore not simply to create a sophisticated digital model. It is to improve the institution's capacity to sense, anticipate, decide, coordinate, respond, recover, and learn.

VIII. IMPLEMENTATION CHALLENGES, GOVERNANCE, SECURITY, AND SCALABILITY

Despite the potential of digital twins, implementation within high-stakes institutional environments involves significant technical, organizational, financial, and governance challenges. A digital twin is not simply a software product that can be deployed independently of existing institutional processes. It requires integration among data infrastructure, operational systems, analytical models, people, governance structures, and physical assets.

The literature consistently identifies interoperability, data quality, security, complexity, and organizational readiness as important challenges in digital-twin implementation (Le & Fan, 2024; Zaidi et al., 2024).

8.1 Data Quality and Reliability

The first challenge is data quality. Because the digital twin depends on operational data, inaccurate or incomplete information can lead to inaccurate representations and potentially inappropriate decisions.

Common problems include missing data, inconsistent records, delayed updates, duplicate information, sensor errors, and conflicting information from different systems.

For high-stakes operations, data-quality management must therefore be treated as part of operational risk management. Institutions should establish procedures for validating critical data, identifying anomalies, resolving conflicts, and determining which sources should be treated as authoritative.

The principle is straightforward: a highly sophisticated model cannot compensate for fundamentally unreliable operational data.

8.2 Interoperability and Legacy Systems

In many organizations, there are already complex legacy information systems being used. To completely replace all those systems just to enable the development of the digital twin can be too costly and complicated.

Integration of existing systems might therefore be the better way forward. This will require the use of common data formats, APIs, middleware, integration platforms, and interoperability standards.

According to Le and Fan (2024), interoperability is an important aspect in logistics digital twin development because of the multiplicity of technologies and organizations that participate in the supply chain (Le & Fan, 2024).

For institutional settings, interoperability should not only be internal, but should also include external entities such as suppliers and partners.

8.3 Cybersecurity and Data Protection

As such, the more connected the digital twin is, the higher the possibility of exposure to security risks associated with it.

Information on important assets, inventory status, transportation paths, physical facilities, suppliers, employees, and other operational risks might be contained within a digital twin. Consequently, any access and manipulation can prove to be very serious.

Security should be built into the architecture of a system from the start, and not after its deployment.

Access and authentication, encryption, segmentation of the network, monitoring, audit trails, backup measures, and incident response processes need to be implemented based on the sensitivity of the environment.

The security strategy needs to ensure confidentiality and integrity. It is not only important to restrict access but also ensure that information cannot be manipulated for incorrect decision-making.

8.4 Model Accuracy and Digital-Twin Fidelity

Another challenge concerns the accuracy of the digital representation.

A digital twin is an abstraction of reality. It cannot represent every physical condition with perfect accuracy. Institutions must therefore determine which variables are essential for decision-making and which can be simplified.

A model that is too simple may fail to capture important dependencies. Conversely, a model that attempts to represent every possible variable may become excessively complex, expensive, and difficult to maintain.

The appropriate objective is therefore not maximum complexity but decision-relevant fidelity.

The digital twin should be sufficiently accurate to support the decisions for which it is intended.

8.5 Organizational Adoption

Technology alone cannot transform institutional logistics. Employees and managers must understand how the system should be used and how its outputs should influence decisions.

Resistance may occur if employees perceive the digital twin as a surveillance mechanism, a threat to professional autonomy, or an additional administrative burden.

Successful adoption therefore requires clear governance, training, stakeholder involvement, and communication about the purpose of the system.

Managers should also understand the limitations of digital-twin outputs. Predictive recommendations are not infallible and should be interpreted within the context of operational knowledge.

8.6 Cost and Infrastructure Requirements

In any case, developing digital twins may be costly for many sensors, connectivity, computing infrastructure, software, integration, analysis, cybersecurity, and experts.

At places where there is not much money to invest, digitizing everything at once would be impossible.

It would be better to have a staged approach.

Institutions should start from a logistics process or an asset class where the increased visibility and contingency management would bring high value.

The next modules could be added after the first one starts working effectively.

8.7 Scalability

A digital twin designed for a small operational environment may become difficult to manage when expanded across an entire institution or network.

Scalability involves more than computational capacity. As the system expands, the number of data sources, users, assets, dependencies, security requirements, and external partners also increases.

The architecture should therefore support modular expansion.

Cloud-based infrastructure, distributed computing, standardized interfaces, and modular digital-twin components can facilitate growth. However, scalability should be balanced against cybersecurity, data governance, cost, and operational complexity.

8.8 Governance and Accountability

Because digital twins can influence important institutional decisions, governance is essential.

Institutions should establish clear responsibilities concerning who owns the data, who manages the digital model, who validates analytical outputs, who authorizes automated actions, and who is accountable when recommendations are incorrect.

Governance should also address model updates. A digital twin that accurately represents operations today may become less reliable as processes, suppliers, assets, or organizational structures change.

Consequently, model validation and periodic review should form part of the governance framework.

8.9 Human Oversight

High-stakes operational decisions should retain appropriate human oversight.

The proposed framework therefore does not advocate unrestricted automation. Instead, it supports intelligent augmentation in which the digital twin provides managers with timely information, predictions, simulations, and recommendations while preserving human responsibility for consequential decisions.

This approach provides a balance between computational speed and managerial judgment.

Human oversight is especially important where decisions involve competing institutional values. A system may identify the mathematically efficient allocation of a scarce resource, but managers may determine that operational criticality or stakeholder vulnerability should take precedence.

8.10 Scalability through Modular Development

From the foregoing, it appears that digital-twin technology needs to be implemented in a phased manner.

This may entail first deploying it in one high-value logistics function, ensuring that data quality and governance policies are in place, verifying the digital model, and gradually moving into predictive analytics, scenario simulations, and automation.

This strategy ensures minimal implementation risks and ensures value is realized from the deployment.

Ultimately, the structure may develop into an institutional logistics digital twin involving various departments, locations, suppliers, modes of transport, and functions.

It is thus critical that the objective be controlled scalability and not technological maximalism.

8.11 Balancing Innovation with Operational Reliability

Finally, the issue of innovation versus reliability should be addressed.

An organization working with high stakes can implement innovative solutions only when they possess not just technological excellence but also practical value, reliability, security, maintenance and compatibility with the needs of the institution.

Therefore, the digital twins should be introduced as operational capacities, not innovations of technology.

The most effective strategy is the one where each digital twin capability has its own operational problem. The real-time synchronization addresses visibility issues; the predictive analytics addresses emerging risk issues; the simulation addresses planning uncertainties, and the contingency management addresses resilience and continuity needs.

With such integration of technology and operational issues, the digital twin will become a part of logistics architecture of the institution, not an innovation project.

In general, the implementation literature shows that the success of digital twins is dependent on the quality of the surrounding ecosystem.

Interoperability, data governance, cybersecurity, organizational readiness, reliability of models and scalability are important aspects and not a secondary part of this ecosystem (Le & Fan, 2024; Zaidi et al., 2024).

IX. FUTURE DIRECTIONS FOR RESILIENT AND INTELLIGENT INSTITUTIONAL LOGISTICS

The development of digital twin-driven logistics coordination is likely to become increasingly important as institutions face greater operational complexity, interconnected supply networks, technological dependence, and uncertainty. The evolution of digital twins is moving beyond static visualization and monitoring toward predictive, adaptive, and increasingly intelligent systems capable of supporting continuous operational decision-making. For high-stakes institutional operations, this evolution presents an opportunity to create logistics systems that are not only more efficient but also more resilient, responsive, and capable of learning from changing conditions.

Future development should focus on strengthening the relationship between real-time operational data, predictive intelligence, simulation, human decision-making, and adaptive logistics execution. The objective should not simply be to make institutional logistics more automated. Rather, future digital-twin systems should help institutions understand complex operating environments, anticipate disruptions, evaluate alternatives, and respond to uncertainty while maintaining appropriate human oversight.

9.1 From Digital Representation to Intelligent Operational Ecosystems

The next step in digital twin development will most likely be moving from creating digital versions of individual assets or processes to creating interconnected digital ecosystems.

Rather than having separate digital twins for vehicles, warehouses, facilities, or inventory management, institutions can create interconnected versions that take into account the relationship between all the elements in the institution's operational environment. This will help to move from monitoring individual assets to coordinating a system as a whole.

According to Le and Fan (2024), the integration of logistics and supply chain processes is one of the directions for developing digital twins. The integration of logistics and supply chain processes will help to understand the impact that a change in one operational process has on other processes within the logistics chain.

For instance, a change in demand will affect inventory, warehousing, transport schedules, procurement activities, and staffing needs.

9.2 Integration of Artificial Intelligence and Predictive Analytics

It is projected that artificial intelligence will play an increasingly critical role in digital-twin-based logistics operations. Artificial intelligence systems can analyze operational data for trends, identify anomalies, forecast demand, determine probability of disruptions, and assist in predictive maintenance.

The use of digital twins together with artificial intelligence is particularly important since the digital twin acts as a context for understanding the results produced by the analysis. Instead of making predictions without taking into account the operation context, artificial intelligence models can operate within the context of institutional assets and constraints.

Using this approach, logistics prediction can be significantly enhanced, allowing institutions to ask not only what had already occurred but also what may happen and how one could decrease the related risks.

The relevance of intelligent digital twins to the stress testing and resilience of supply chains is explained by Ivanov (2023). The use of predictive intelligence along with simulations allows for designing a system for evaluating future potential states before their occurrence.

9.3 Autonomous and Semi-Autonomous Logistics Coordination

Future digital-twin systems may increasingly support semi-autonomous logistics decisions. Certain low-risk decisions could potentially be automated, while higher-impact decisions remain subject to human approval.

For example, an institution could establish rules allowing the system to recommend or automatically implement minor route adjustments, reorder routine supplies, or redistribute non-critical resources within predefined limits. More consequential decisions, such as changing strategic suppliers or reallocating critical resources, could require managerial authorization.

This creates a graduated model of automation rather than an unrestricted autonomous system.

Such an approach is particularly suitable for high-stakes environments because it combines computational speed with human accountability. The digital twin can handle repetitive monitoring and recommendation tasks while managers retain

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responsibility for decisions involving significant operational, ethical, or safety implications.

9.4 Digital Twins for Institutional Resilience and Stress Testing

One promising future direction is the use of digital twins for stress testing by institutions.

Instead of reacting to disruptions and identifying weak links, an institution can create various adverse scenarios and test its ability to cope with these scenarios. Various scenarios involving different combinations of supplier breakdowns, transport disruptions, surge in demand, equipment failure, facility disruption, or communication disruptions can be created within the digital domain.

These simulated scenarios will help identify potential risks that might not be apparent under regular circumstances.

According to Liu et al. (2026), digital twins have the potential to enhance several aspects of the resilience of supply chains, including preparedness, resistance, recovery, and adaptive reconfiguration. This highlights a broader use of digital twins as resilience management tools rather than operation monitoring tools.

Stress testing can become a routine part of strategic planning for institutions. Apart from the efficiency of logistics configurations, they can be evaluated in terms of their resilience to disruptions.

9.5 Greater Integration across Institutional Boundaries

It is not uncommon for institutional logistics to stand alone in nature. Digital twins of the future are bound to become more connected to the likes of suppliers, logistics providers, government bodies, contractors, emergency response teams, and others who might be outside of the institution.

This can help enhance visibility and offer a more holistic view of dependencies. But it must be noted that interorganizational integration can come with its own set of complications pertaining to data ownership, confidentiality, cybersecurity, and more.

According to Zaidi et al. (2024), digital-twin environments must consider the integration of multiple actors and technologies from the supply chain despite any potential complications therein.

9.6 Digital Twins and Sustainable Logistics

Future institutional logistics frameworks should also incorporate sustainability considerations.

Digital twins can potentially help institutions evaluate the environmental consequences of logistics decisions before implementation. Transportation routes, inventory strategies, warehouse configurations, vehicle utilization, and supplier choices can be assessed not only for cost and service performance but also for energy consumption, emissions, and resource utilization.

This creates the possibility of multi-objective logistics planning in which resilience and efficiency are balanced with sustainability.

The concept is particularly relevant because an operational strategy that maximizes short-term efficiency may not necessarily

X. CONCLUSION

It is necessary to take into account the growing complexity of institutional logistics and use approaches that will help go beyond static planning, isolated information and disruptive management. High-risk institutions function in interrelated environments where the elements such as transportation, inventory, suppliers, facilities, personnel, technology, and service requirements interact with each other all the time. Therefore, any disruption of one element may cause repercussions within the entire system of operations. The purpose of the present research is to explore whether digital twin technologies are able to offer an approach to cope with the issue.

The research proves that the main benefit of digital twins consists in establishing a dynamic link between the physical operations and digital environment of decision-making. It is possible to build a digital twin using information from operational processes involving IoT devices, enterprise systems, transportation systems, inventory systems, and many others. As a result, an institution will get a comprehensive picture of its logistical operations (Le & Fan, 2024; Zaidi et al., 2024).

In addition to visibility, the proposed conceptualization illustrates the value of digital twins in providing planners with dynamic planning and resource management abilities. Planners can utilize real-time digital twins rather than solely relying on static schedules and forecast models in order to evaluate resource allocations. Simulating scenarios helps planners to assess the impact of possible disturbances and operational changes on the actual system in advance. In such a way, a decision-making ability is developed.

Further, the proposed research reveals the significance of predictive intelligence in developing organizational resilience. Digital twins can be integrated with anomaly detection, predictive analytics, risk assessment, and stress testing in order to reveal vulnerabilities at an early stage before a system fails. Ivanov (2023) shows the relevance of intelligent digital twins for supply chain stress testing and resilience, whereas Liu et al. (2026) prove that digital twins can contribute to various stages of building organizational resilience, which include preparedness, disruption resistance, recovery, and adaptive reconfiguration.

The significant advantage of the suggested approach lies in the fact that contingency management in the framework is understood as a process rather than an event which takes place after the disruption occurs. The approach combines disruption identification with diagnosis, forecasting, scenario analysis, prioritization of responses, their implementation, recovery, and organizational learning. Such an approach allows creating a feedback loop where practical experience can help to make future plans and response to disruptions more efficient. Thus, for this organization, resilience is not merely the restoration of regular functioning following the disruptions; resilience is an ability of the organization to anticipate, absorb, adapt, and learn from changes.

Furthermore, the research acknowledges that the mere technological opportunity would not ensure successful implementation of the technology. Good-quality data, interoperability, cybersecurity, accurate modeling, scalability, governance, organizational adoption, and human supervision are crucial prerequisites. Poor data or interoperability will lead to the creation of inappropriate recommendations by the digital twin, while excessive automation without necessary managerial involvement could generate new risks for the company. Therefore, the implementation of digital twins should be governed by certain principles.

The proposed framework ultimately positions digital twins as coordination infrastructures for resilient institutional logistics. The framework connects physical operations, real-time data, digital representation, predictive intelligence, simulation, managerial decision-making, contingency execution, and organizational learning within a continuous cycle. Its conceptual logic can be summarized as:

Sense → Synchronize → Predict → Simulate → Decide → Coordinate → Execute → Monitor → Recover → Learn.

This cycle provides a practical foundation for institutions seeking to strengthen logistics continuity while maintaining flexibility in uncertain environments.

Future development of this framework should focus on deeper integration of artificial intelligence, advanced predictive analytics, autonomous and semi-autonomous decision support, inter-organizational digital-twin networks, sustainability metrics, and increasingly sophisticated stress-testing capabilities. As digital-twin technologies mature, their usefulness is likely to extend beyond individual logistics processes toward interconnected institutional ecosystems in which operational decisions can be evaluated across multiple resources, departments, and external dependencies.

In conclusion, digital twin-driven logistics coordination represents a significant opportunity to transform high-stakes institutional operations from predominantly reactive systems into continuously sensing, predictive, adaptive, and learning-oriented logistics environments. By integrating real-time operational visibility with simulation, predictive intelligence, coordinated decision-making, and contingency management, institutions can improve their ability to anticipate disruption, allocate resources

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effectively, maintain service continuity, and recover from unexpected events. The strategic importance of the digital twin therefore lies not merely in reproducing physical operations digitally, but in creating an intelligent bridge between what an institution is experiencing now, what it may experience next, and how it can respond most effectively.

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