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Advanced EWM-TM integration for seamless multi-modal transportation and yard logistics

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Abstract

As warehouse management and transportation management become increasingly consolidated, their integration has become a critical stage in digitally coordinated logistics, particularly where rail, road, port, terminal, and yard processes intersect. Purpose: This review examines scholarly literature relevant to the state-of-the-art EWM–TM integration to ensure seamless multi-modal transportation and yard logistics with EWM-TM integration viewed as the tightly integrated management of the warehouse operations, transport planning, appointment control, yard movements and event-based replanning. Scope: The article is a review of peer-reviewed literature on warehouse operations, intermodal planning, cross-docking, container terminal logistics, enterprise application integration, Internet of Things architectures, and Logistics 4.0. Findings: In the literature, it has been established that inventory visibility, door scheduling, yard staging, and mode-specific transport planning can be synchronized in a shared decision structure to yield significant performance improvement. Meanwhile, the reviewed literature shows incomplete connections between strategic network models and real-time implementation logic, limited consideration of yard uncertainty, and the limited capability to translate digital event streams into robust control rules. Implications: This area is important because fragmented execution is one of the key factors that lead to delays, congestion, underutilization of assets, and unreliable services in multi-modal logistics. A state-of-the-art EWM–TM research agenda should include interoperable data frameworks, event-driven optimization, and more empirical validation and an integrated set of warehouse, yard, and transport performance metrics.

Keywords*:* Digital Logistics; Intermodal Transport; Multi-Modal Transportation; Transportation Management Systems; Warehouse Management Systems; Yard Logistics

1. Introduction

The growing complexity of contemporary logistics systems has made the separation between warehouse operations and transportation planning an increasingly challenging aspect to maintain as separate operational domains. Traditional warehouse management research evolved with a view of storage assignment, picking, staging and internal flow control, whereas the transport research was based on routing, fleet utilization, schedule, and network design. That differentiation is no longer sufficient with the development of warehouses as high-frequency transfer nodes with inbound and outbound dynamic transport streams. This has caused a gradual transition to an integrated decision structure in which the condition of the warehouse, preparedness to ship, dock occupancy, and departure time must not only be synchronized with but also optimized along with each other. Initial studies of processes in a warehouse have already concluded that the receiving, storage, order processing and shipping operations influence performance, rather than functioning as isolated subproblems [1]. In practice, freight units, handling units, appointments, transport orders, and yard events are controlled via coupled information and control logic. This is no longer a limited software

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configuration problem, but a research problem in operations management, intermodal transport, information systems and industrial engineering.

This topic is becoming increasingly important because sustainability pressures and renewed interest in multimodal transport require tighter coordination across logistics nodes. Green logistics research has shown that any attempts to resolve the problem of environmental performance through cleaner vehicles or route compression alone may be insufficient because planning fragmentation tends to result in unnecessary buffer stocks, waiting time, empty moves and terminal congestion [2]. Simultaneously, intermodal freight literature has held the view that the effectiveness of integrating road and rail services, inland waterway and maritime services is in the quality of coordination at points of delivery rather than the effectiveness of line-haul services. An early, late, or inaccurately handled freight release at a warehouse or terminal disturbs the mode synchronization across the whole chain. This may be considered especially within multi-modal settings in which a rail departure, or terminal cut-off, spills over into yard overflow, rehandling and road substitution due to an emergency. It is based on this fact that the integration of EWM-TM should be viewed as an integrating mechanism which is employed to create time alignment, data integrity and visibility of execution between nodes and modes.

The relevance of this topic is also supported by the fact that the conditions of the current research are also making the topic more and more relevant. The e-commerce phase of warehousing is characterized by a shorter planning horizon, volatile order schedules, greater demands on service and lighter coupling among distribution, returns, and replenishment activities [4]. In the meantime, the yard and terminal environment is becoming more densely populated and technologically mediated incorporating automated handling equipment, gate systems, stack planning and truck appointment control. Container-terminal literature has repeatedly shown that major inefficiencies often arise from poor coordination between quayside or berth operations, yard activities, and landside transport, rather than from capacity constraints within any single resource class [5]. Similar coordination issues are found in manufacturing logistics parks, rail-road terminals and big distribution campuses where trailers, swap bodies, containers, and pallets are transported within narrow time constraints. A warehouse management tool that is aware of stock status and tasks but unaware of transport cannot be used to effectively dispatch in these environments. The transportation platform that optimizes tours and bookings but lacks real-time awareness of what is being loaded, congestion in the yard and exception events is also limited.

Although the topic is urgent, the scholarly landscape remains fragmented. The optimization of warehouses is the focus of a significant amount of research, intermodal planning is explored by another corpus, and digital integration and event-enabled logistics are the focus of another stream of research. Explicitly vendor-specific EWM-TM integration requires relatively little peer-reviewed research, thus necessitating a wider analytical frame. The best academic course is then to go through related yet very relevant literature and establish the recurrent mechanisms that facilitate a smooth coordination. The current article is aimed at fulfilling the objective. Accordingly, this review conceptualizes the literature on integrated logistics control, identifies the dominant methodological approaches in the field, evaluates the empirical and operational findings reported in prior studies, clarifies the major empirical and theoretical knowledge gaps, and outlines the most promising directions for future research. The subsequent parts follow a thematic overview of the literature with a framework of methodological approaches, a critical discussion of reported findings and lastly, research needs to further integrate EWM-TM in multi-modal transportation and yard logistics.

2. Literature Review

The earliest foundation for conceptualizing advanced EWM–TM integration as a coordination problem, rather than a software interface problem, can be identified in the literature on intermodal planning. The existing literature on the topic of container terminals emphasized the centrality of integrated planning in seaside, yard and landside decisions and intermodal freight reviews showed that most of the planning problems are related to terminal assignment, mode choice, departure synchronization, and service reliability [6], [7]. This view was enhanced by a subsequent decision-support agenda on intermodal transport which argued that future development would be based on the need to tie the strategic and operational layers of decision making at a higher level [8]. This argument is directly applicable to the EWM-TM integration as warehouse release decisions, loading priorities, and appointment management are precisely the operational layer that lies between the network plans as well as the physical implementation. However, the intermodal literature often treats the terminal or warehouse as a simplistic transfer node, even when the local execution regulations in the terminal node have a strong influence on the time of departure that is permitted, as well as the use of assets. A typical weakness is the tendency to model transfer points using deterministic buffers, rather than congested operational systems with queues, rehandling and information latency.

A second key stream is about yard and terminal operations particularly in a containerized environment. The initial descriptions of transshipment and terminal operations emphasized the interrelation between the crane scheduling, yard storage, truck arrivals, and rehandling effort [9]. Studies on cross-docking subsequently applied the same rationale to door assignment and coordinated truck scheduling and revealed that when service time, staging capacity and departure commitments are collectively taken into account inbound and outbound flows cannot be separated [10]. The literature on storage yards also contributed to the analysis by showing the stack-based structure and priorities in retrieval of loading, unloading and premarshalling decisions [11]. A wider overview of transport activities in container terminals categorized the industry into transport modes, scope of operations and planning horizons, which validated the observation that the efficiency of transfers relies on coherent decisions in various set-ups of equipment and control [12]. Subsequent study of sea container terminals added the impact of new technologies, including automation and advanced analytics of operations, and, nonetheless, found that computational sophistication alone does not eliminate the coordination burden [13]. The key lesson from this stream is: yard logistics is not merely a supportive operation and is not merely an indirect contributor to transport reliability, but the factor that determines the reliability of transport and warehouse throughput.

A third literature stream is on the topic of digital integration, information architecture and event-driven logistics. The literature on Logistics 4.0 talks about the shift away from separate planning systems to cyber-physical logistics environments where sensors, middleware, analytics, and execution environments are interconnected on continuous streams of event data [14]. The research on Internet of Things in supply chain management supports the importance of real-time visibility towards the condition of the assets, their location, confirmation of the process, and exception management [15]. Other related studies regarding the digital technologies and their effects have indicated that digitally connected supply networks can boost risk detection and response as long as the quality of the control rationale to the information decides the added value [16]. The research on enterprise application integration introduces a significant layer in the organization and architecture: There is more than just a technical issue of data exchange between the large applications but also a question of process ownership, semantic alignment, and transaction consistency across systems [17]. Finally, the research on the use of big data analytics in the supply chains reveals that the digital information is of no use until analytical models convert the heterogeneous streams of data into an operationally exploitable decision support that could be interpreted and occurs in time [18]. This literature is extremely applicable in EWM-TM integration as the activities of a warehouse activities, transport plans, gate events, and yard states all generate data whose value depends on coordinated interpretation.

Table 1 provides a summary of the technical focus of core studies of the literature base on which the review is based. According to the table, the discipline has transitioned from problem-oriented optimization to more broad-based decision-support and digital-integration problems, although the interface between the two domains is under-theorized. Operational research provides certain knowledge on door timing, stack scheduling and terminal transportation and digital logistics research provides insight to visibility, interoperability and event-processing insights. The only thing missing is a combined scholarly coverage of the functioning of warehouse implementation reasoning, transport coordination and yard control to be assembled in a common control framework in multi-modal environments. This is the main focus of the current topic since both the quality of the algorithms used and the coherence of the processes across the enterprise are the keys to seamless EWM-TM integration.

Table 1 Summary of key findings

Ref	Focus	Key Findings
[6]	Container-terminal operations research update	Demonstrates that terminal performance depends on coordinated berth, yard, and landside planning; highlights growing model complexity but limited real-time integration.
[7]	Intermodal freight planning problems	Identifies network design, terminal selection, service scheduling, and mode coordination as recurring planning challenges shaped by transfer-node performance.
[8]	Intermodal decision support	Argues for multi-level decision support linking strategic configuration with operational control; notes insufficient integration of execution data.
[9]	Container transshipment operations	Shows that stacking, internal transport, and truck interaction jointly determine terminal responsiveness and rehandling exposure.
[10]	Cross-docking truck scheduling	Establishes that integrated inbound–outbound scheduling reduces waiting and coordination losses relative to decoupled dock planning.

[11]	Stack loading, unloading, premarshalling	Classifies yard-stack control problems and shows that local storage rules materially affect later retrieval effort and time reliability.
[12]	Container-terminal transport operations	Provides a classification of terminal transport decisions and reveals strong dependence between equipment coordination and yard layout assumptions.
[13]	New terminal technologies and OR models	Reviews automation and advanced models, concluding that technology improves control only when linked to robust operational decision rules.
[14]	Logistics 4.0 architectures	Describes the shift toward connected logistics systems with cyber-physical visibility, decentralized data capture, and digitally supported decision making.
[15]	IoT in supply chain management	Shows that sensor-enabled tracking enhances event visibility and exception detection, while interoperability and data quality remain key obstacles.
[16]	Digital technology and ripple effects	Indicates that digital connectivity improves disruption sensing and response, but benefits depend on the responsiveness of planning and execution layers.
[17]	ERP and application integration	Finds that enterprise integration success depends on semantic consistency, process alignment, and architectural governance rather than interface count alone.
[18]	Big data analytics in supply chains	Concludes that analytics can enhance operational decisions, yet data heterogeneity and organizational readiness often constrain implementation impact.

The reviewed literature therefore indicates a cumulative yet incomplete research path. Previously, the research was analytical in nature to solve tightly constrained operational problems, but recent research broadened the perspective to digitally interconnected logistics systems. The only problem that could not be resolved is in the middle layer where execution events should modify planning priorities in near real time in order to affect the vehicle dispatch, yard moves, and release of work in the warehouse. Multi-modal transportation exacerbates that problem since an incomplete handoff may spread through multiple modes and facilities. The further integration of EWM-TM, which can be considered in light of this literature, can be best explained as a gap in meso-level research between enterprise applications, operational optimization, and real-time logistics control.

3. Methodology

The literature has four general methodological families applicable to advanced EWM-TM integration. The first is optimization that prevails in the intermodal planning, cross-docking and terminal operations. The network model, assignment model, scheduling formulations, and stack-control algorithms are designed to enhance the utilization of resources, minimize delay and control transfer dependencies [7], [10], [11]. Their primary benefits are formal strength: the constraints are formulated in a formal manner, and the performance trade-offs can be quantified, and alternative policies can be compared directly. However, these models tend to assume fixed data and discrete time events. Shipment readiness, the arrivals at the gate, equipment availability and disruption conditions are changing dynamically, in real-world warehouse-yard-transport environments and can undermine the practical applicability of deterministic formulations. The second is review research based on classification and framework, such as typical of the intermodal and terminal literature, where the types of problems along with the levels of planning are mapped, although no immediate control rules are given [6], [12]. This approach assists in defining the problem outline and gaps in the research, but the complexity of implementation as such is hardly ever covered.

The third family entails information-focused and architecture-based solutions. The literature on enterprise integration addresses the process harmonization, shared data definitions, middleware and consistency of transactions across important systems [17]. The Logistics 4.0 and IoT research also expands on this, since it takes into consideration event capture, connectivity of devices, exception ownership, timestamp quality of the processes [14], [15]. These solutions are even more essential in the case of the integration of EWM and TM as the communication between a transport platform and a warehouse platform is not limited to the exchange of the master data. It comprises event semantics, ownership of exception, and the time stamp quality, object identity and decision rights in loading, departure, gate and receipt milestones. Architectural research designs are appropriate in displaying the limitations of interoperability, and governance requirements. The weakness is that it is not commonly conceptually defined in its operational consequences as it is the norm to quantify them using well-defined logistics performance models.

The fourth methodology of research is the analytics and digitally enabled resilience research. The capabilities of heterogeneous streams of events to increase the quality of anticipation, replanning, and control in the presence of volatility are studied in digital-risk studies and big data [16], [18]. The significance of these solutions lies in the fact that multi-modal yard logistics does not tend to have delays that are independent of each other. A late inbound trailer can affect slot allocation, labor assignment, train loading plan and downstream customer commitments in a constrained time frame. Techniques of analysis that facilitate quick reprioritization are thus very valuable. However, there is a uniform absence of descriptive visibility and decision logic that can be applied in the literature. Real-time data cannot be used to generate a coordinated action unless it is augmented with optimization, rules or dispatch heuristics to the visibility layer. It is this that has led to poor-quality handoff even in the digital-based logistics setups between the warehouse, yard, and transportation processes.

Figure 1 presents a layered conceptual model of high-level EWM-TM integration and sums up these methodological observations. The figure is pivoted around shared master and transactional objects since an integrated control is defined by shared representations of freight, resources, locations, appointments and events. It also indicates that the execution visibility should support local control and cross-node replanning or multi-modal coordination would be reactive and fragmented.

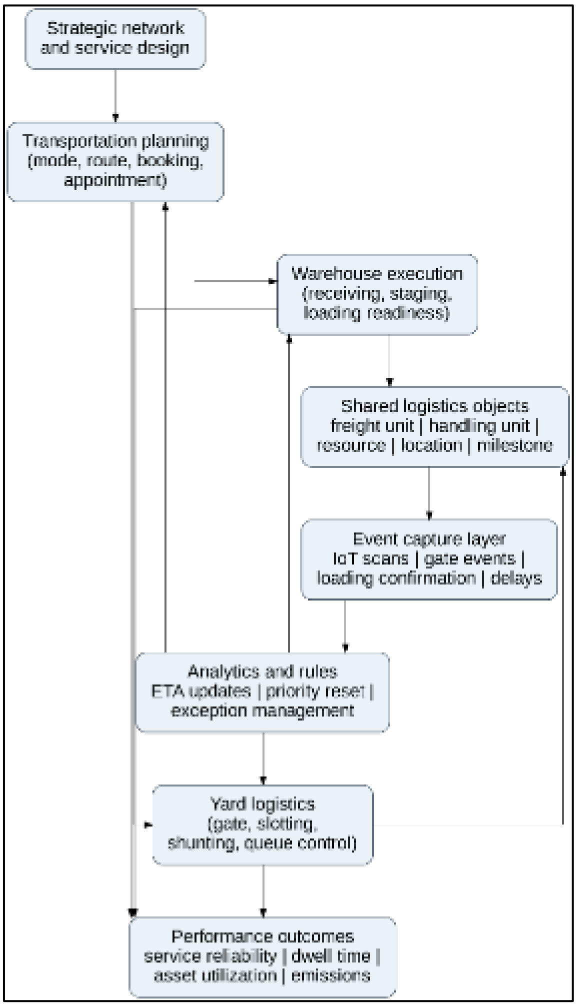

Figure 1 Layered conceptual framework for advanced EWM-TM integration in multi-modal yard logistics

This paradigm can be used to understand why a limited interface view cannot be adequate. The high-level integration demands a methodological amalgamation: optimization to make quality decisions, enterprise architecture to maintain semantic consistency and event-driven analytics to retain control in case of uncertainty. Each of the elements has not been developed equally in the literature. One key avenue of future research would be to take these approaches even more explicitly together around common objects of logistics and performance measures across domains.

4. Discussion

The reviewed studies consistently report performance improvements when transfer-node decisions are coordinated across warehouse, yard, and transport layers rather than handled through sequential, cascading decisions. The study of intermodal planning demonstrates that the transport outcomes are highly related to the assumptions of the terminal, in particular, the synchronization of the services, the time of departure, and the quality of transshipment [7], [8]. The studies in cross-docking enrich this aspect by showing that inbound and outbound truck decisions, are structurally connected via the capacity of doors, staging limits, as well as temporal compatibility [10]. Practically, this literature implication is that the integration of EWM and TM is value-creating when transport reservations and departure schedules are sensitive to the actual loading availability rather than fixed planned availability. At the same time, various formal models still view the completion times of warehouses, along with yard states, as exogenous inputs. The modeling decisions produce analytically tractable results, although they compromise scalability of the results to live multi-modal execution where the variables of interest are shipment readiness, gate arrivals and equipment contention, which are the delay-causing variables. Table 2 juxtaposes the key methodological strategies prevalent in the literature, and explains why none of the methods has so far addressed the entire coordination issue.

Table 2 Method comparison

Ref	Method	Strengths	Limitations
[7]	Intermodal network and service planning models	Captures mode choice, terminal selection, and service structure in a formal optimization setting.	Simplifies terminal execution and often assumes deterministic transfer performance.
[8]	Decision-support framework for intermodal transport	Connects planning levels and highlights managerial decision dependencies.	Remains more conceptual than operational at event-handling level.
[10]	Truck-to-door scheduling models for cross-docking	Represents temporal coupling between receiving and shipping with clear objective functions.	Usually bounded to a single facility and limited uncertainty treatment.
[11]	Yard-stack classification and algorithmic control models	Reveals how local stack rules affect future retrieval effort and rehandling exposure.	Focuses on storage logic more than end-to-end transport coordination.
[12]	Terminal transport classification and planning taxonomy	Organizes equipment and planning interactions across terminal transport systems.	Offers broad structure but limited executable integration design.
[15]	IoT-enabled visibility and event-capture architectures	Improves milestone accuracy, exception detection, and object traceability.	Data availability does not automatically translate into dispatch quality.
[17]	Enterprise application integration architecture	Addresses semantic consistency, transaction control, and cross-system process alignment.	Technical integration may proceed without proving logistics performance gains.
[18]	Big data analytics for supply chain decision support	Supports dynamic prioritization and pattern detection across heterogeneous data streams.	Governance, explainability, and operational adoption remain significant obstacles.

A broader longitudinal view of the literature reviewed shows that there is a significant shift in research focus. Previous studies focused on optimization of operations at transfer nodes, and recent studies are focusing more on visibility, interoperability and digital responsiveness [6], [14]. Figure 2 visualizes that change based on the reviewed studies categorized in terms of period and prevailing focus. The trend reinforces one of the main theses of this review: the discipline is shifting away from problem decomposition toward integrated logistics control but operational integration of these strands is not yet fully achieved.

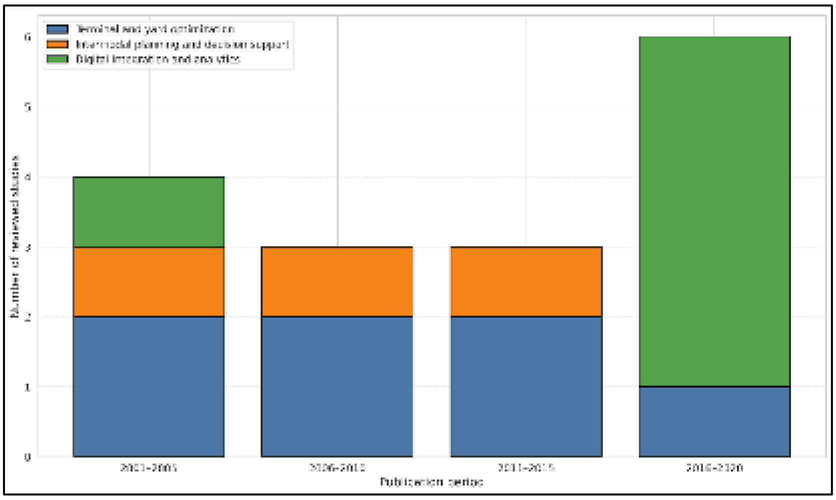

Figure 2 Shift in reviewed literature from node-level optimization toward digital integration

Figure 2 does not indicate the replacement of the operational research with the digitalization research. It should be interpreted more accurately that digital visibility has become necessary but not sufficient to make the implementation smooth. The terminal, warehouse, and intermodal studies have shown that to have an integrated performance, there must be an architecture in which the visibility can change decisions in time to affect outcomes. In the absence of such a connection, EWM-TM integration will be more of a reporting layer, and not an active control mechanism.

Yard and terminal studies reported also indicate that local material-flow rules have transport implications on a system-wide basis. The initial research on transshipment revealed that the internal transport policies, stack positions and equipment routing determine cycle times as well as flexibility [9]. The later loading, unloading and premarshalling studies showed that the costs of poor local decisions are likely to be recovered later in the form of rehandling, slowness in retrieval or even reduced responsiveness to changes in departure schedules [11]. Terminal transport reviews, on a greater scale, then pointed out the same pattern: the subproblems in the operations are analytically independent but physically coupled to each other [12]. The reviews of the new technology also reported that performance may be improved by automation and high-level decision support, but once again such improvements will depend on the level of alignment of the local control rules to the upstream and downstream commitments of logistics [13]. To have an advanced EWM-TM integration, this implies that yard logistics cannot be a loosely-linked side module. Slotting, queue control, and trailer location and shunting priority have significant impacts on the reliability of the shipment release, cut-off compliance and mode synchronization.

Table 3 provides a more precise comparative summary of the key results that have been reported in representative studies. As indicated in the table, most positive results are obtained as a result of improved coordination logic as opposed to mere expansion of resources. This is one of the main points in multi-modal logistics, where delays often arise not from lack of capacity but from mismatches between information timing and physical readiness but not their inaccessibility.

Table 3 Results comparison

Ref	System	Metric	Outcome
[7]	Intermodal freight network	Generalized transport cost; service coordination	Improved visibility of cost–service trade-offs, but sensitive to terminal-time assumptions.
[8]	Intermodal decision-support environment	Planning coherence across strategic and operational levels	Better alignment of decisions, with limited direct treatment of real-time execution events.
[10]	Cross-docking terminal	Truck waiting time; dock makespan	Joint scheduling lowered coordination losses relative to decoupled truck-door planning.
[11]	Storage-yard stack system	Rehandling effort; retrieval feasibility	Structured premarshalling policies reduced downstream retrieval disruption.

[12]	Container-terminal transport system	Equipment interaction; transfer efficiency	Integrated treatment of transport subsystems clarified bottlenecks hidden by isolated planning.
[13]	Sea container terminal	Technology-enabled operational performance	Automation and OR support improved control potential, but benefits depended on process integration quality.
[15]	IoT-enabled supply logistics	Event visibility; exception detection	Better milestone accuracy and anomaly identification, with interoperability as a main constraint.
[16]	Digitally connected supply structure	Disruption response; risk propagation control	Faster disturbance detection and response potential, contingent on actionable planning rules.

Among the main conclusions of the discussed results, the possibility of the seamless integration of EWM-TM can be viewed as an order-handling-loading-transport-commitment-yard-resource relationship system. Figure 3 illustrates this relationship structure. The figure stresses the fact that the gate-control events do not occur independently of the yard placement, staging completion and departure confirmation; all of them affect the decision space that can be achieved in the following control action. This confirms the common occurrence in the literature that execution milestones are to be used to make coordinated attempts to update as opposed to standalone status messages.

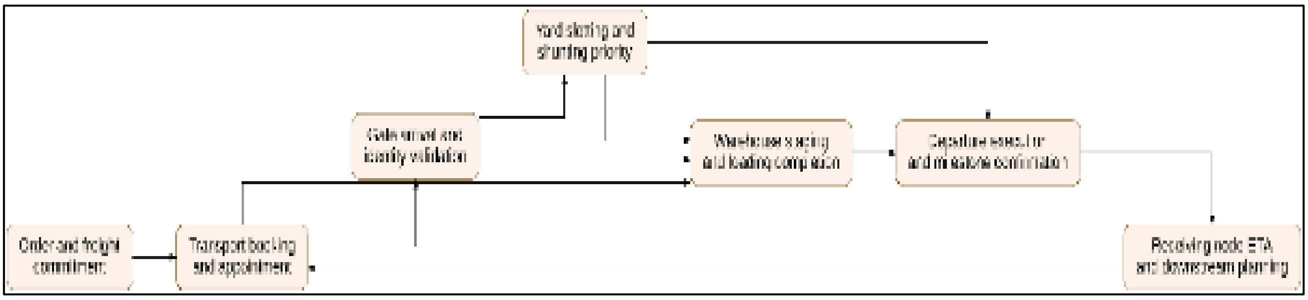

Figure 3 Relationship diagram for warehouse–yard–transport event dependencies

Alterations in the nature of logistics control brought about by digital connection are also demonstrated in the literature since it provides the ability to re-plan rather than execute against outdated plans. The IoT and analytics studies show that the control responsiveness can be significantly enhanced by using milestone confirmation, delay detection, and asset-state visibility [15], [18]. However, container terminal and cross-docking experiments warn that data latency is not the only obstacle in operations but that there are no built-in control policies that can take action on the information [10], [13]. This distinction is important since most practical integration projects do not go beyond the message exchange but do not dispatch, repair by appointment, load resequencing and yard reprioritization because they operate under separate rule sets. In research language, the gap is no longer visibility alone; the design of decision loops that cut across various domains of execution.

That understanding is translated into an overall operating model of advanced EWM-TM settings in figure 4. The model bridges the gap between planning, implementation, event capture and replanning and that is exactly what fragmented architectures do not do. It is also indicative of the repeated message throughout the studies reviewed: the reliability of transportation in multimodal settings is through continuous optimization in the nodes of transfer and not through optimization at the beginning of the process.

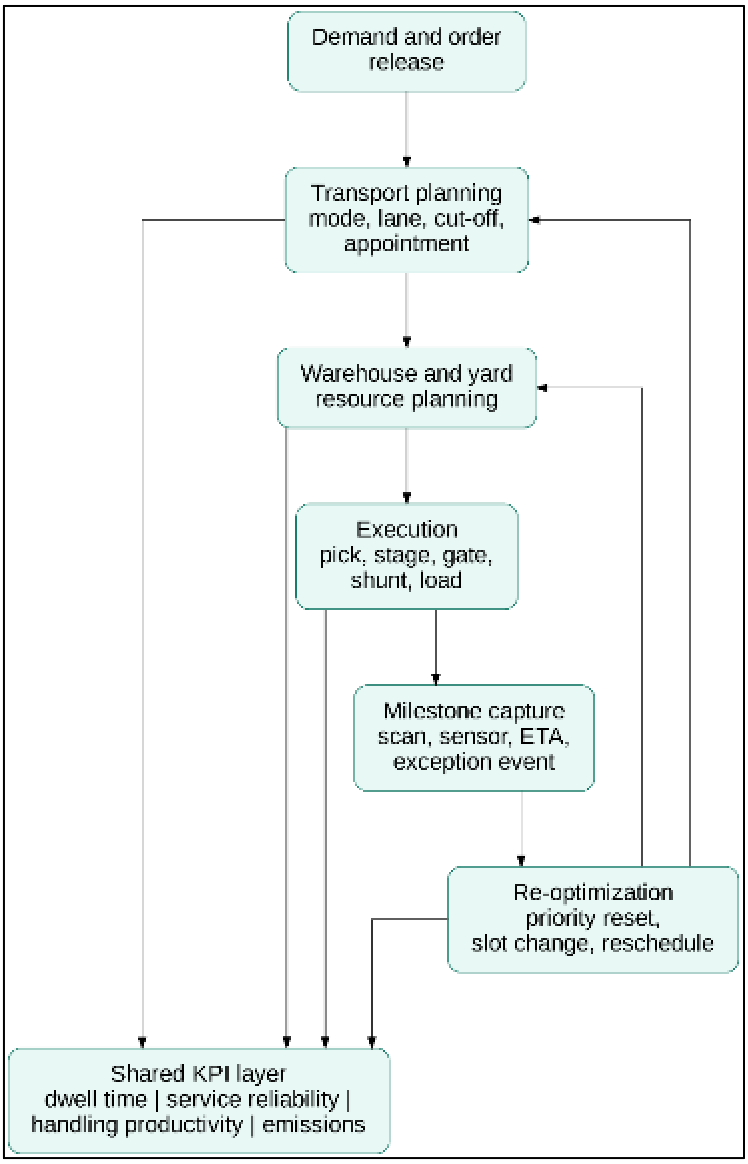

Figure 4 Integrated operating model for advanced EWM-TM coordination

Overall, the reported studies suggest that there is a coherent interpretation of advanced integration of EWM-TM. To begin with, the most significant performance improvements are at handoff points: release to dock, dock to yard, yard to departure and departure to downstream receipt. Second, yard logistics is a control lever, and not a space-management activity. Third, digitalization creates substantial value only when the execution events are able to refresh the priorities in the warehouse and transportation in a shared decision architecture. Their persistent limitations can still be observed in the literature. There is limited empirical research on cross-system transactional data. Numerous papers optimise one of the subsystems and approximate the rest. To date, uncertainty treatment is still weak particularly in scenarios where there are stochastic arrival processes, gate congestion, equipment interruptions and multi-actor governance conditions. These shortcomings justify why a fully developed academic account of a seamless EWM-TM integration has not been achieved regardless of the huge advancements in the related literature.

5. Future Directions

Empirical validation should be a primary concern of research in the future. Quite a large part of the literature is model-based, review-based or architecture-based. This body of work is valuable, however, to move EWM-TM integration further, research based on event logs, appointment histories, yard-tracking records, handling verifications and transport milestone information logged on different systems is required. These data would allow experimenting with the impact of shared object models, and event-based control on dwell time, rehandling, and cut-off compliance and schedule predictability. It would also enable the disaggregation of the impact of digital visibility and the impact of changed decision rules and is something that is not studied in depth currently [14], [15].

The second direction is connected with the uncertainty-aware coordination. The concept of operational variability in intermodal and terminal studies is not new, but most formal models continue to be based on deterministic structures or stylized uncertainty treatments [7], [12]. The rolling-horizon control, robust appointment management, stochastic yard-state evolution, and adaptive release should be paid more attention in future work. In multimodal systems, uncertainty is cumulative, not isolated. A ripple effect of the delay of a gate transaction can be that the availability of the yard, labor placement, and viability of downstream departure will be altered in quick succession. Clear research designs that are utilized to model such propagation would make a huge contribution to the field [16].

The third one is the interoperability and semantic design. Experiments in enterprise integration indicate that the applications are not connected when the semantics of data, object identities and process ownership are out of sync [17]. This does not just happen with interface mapping but also in the high-level EWM-TM environments. Freight units, loading assignments, appointments and milestones need common semantics so that as an event is entered in one system, it does not cause an action in another system that lacks meaning and is ambiguous and needs human judgment. Reference data models, event taxonomies and governance structures, which are specific to multi-modal yards, would also be advantageous to future research. This could assist in closing the information-systems research and research in the operations research and logistics execution.

A final direction concerns broader performance framing. The literature available is inclined to compute individual values of waiting time, equipment usage or generic transport cost. Future research should come up with more holistic solutions, which would cut across service reliability, the ability to manage productivity, yard utilization, exposure to emissions, and capacity against disruption. This is especially applicable in multi-modal transportation where the cost and environmental impact can be redistributed due to the operational choices at a transfer node. A more comprehensive metric architecture would also make the field more relevant to the sustainability, resilience and the digitalization of industry discussions [2], [18] and a more realistic assessment of the state-of-the-art EWM-TM integration.

6. Conclusion

Advanced EWM–TM integration has become an important research topic since multi-modal transportation performance is more dependent on what occurs within transfer nodes, as opposed to just along transport corridors. The reviewed literature shows that warehouses, transportation planning, and yard logistics execution are very interdependent. Isolated control becomes structurally inefficient as soon as the interactions between appointments, cut-offs and stack conditions, loading readiness and departure events interact within a short planning horizon.

An interesting development is also evident in the literature. Earlier research provided strong analytical foundations on the operations within the warehouse, terminal control, cross-docking and intermodal planning. More recent research has added digital visibility, enterprise integration and event-driven analytics. The connection between high-quality data and high-quality optimization remains the most important unresolved issue: often, these aspects are located in different spheres of research and implementations.

One of the main research findings of this review is that yard logistics needs to be considered as a first-class part of integrated transport control. Delays, re-handling, congestion at the gates, and misalignment of the staging are not local inconveniences; these states determine modal synchronization, the reliability of service reliability and the resilience of the broader logistics network. In order to achieve smooth integration between EWM and TM, there must be a set of shared logistics objects, coordinated sets of decision rights and replanning loops between the warehouse, the yard and the execution of the transport.

The prospects are promising but challenging. The field is still in need of more robust empirical research, models that incorporate uncertainty, interoperability studies, as well as more comprehensive performance indicators to take the field beyond partial integration. Advancing these directions would help to ensure a more rigorous and operationally applicable theory of digitally coordinated multi-mode logistics, and direct implications for industrial practice, and future peer-reviewed studies.

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