

Review

Design Methodology of Corporate Information Systems with Integrated Decision Support for Transport and Logistics Companies

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Abstract

The study addresses the design and development of a unified corporate information system for multimodal transport and logistics companies engaged in maritime and railway transportation. Analysis of the existing literature revealed the absence of a coherent methodological framework for the design of corporate information systems tailored to the specific operational characteristics of multimodal transport and logistics enterprises. To bridge this gap, a design methodology for corporate information system databases is proposed, intended for subsequent deployment in companies operating multimodal supply chains. The development of the unified corporate information system was guided by the principle of “total costs,” which requires that the decision-maker—when selecting transport modes, methods of transportation, carriers, routing, and auxiliary intermediaries (insurer, stevedore, bank, and customs broker)—address the problem as an integrated whole rather than optimizing individual components in isolation. The study encompasses information modeling of the business processes of multimodal transport and logistics companies, construction of an optimal model of the transport process for maritime and railway transportation using integrated computer automated manufacturing definition (IDEF) and structured analysis and design technique (SADT) modeling, and the design of a multilevel unified database structure for the coordination of different transport modes. A decision-making and support system has been developed for managing the operational activities of a multimodal transport and logistics company engaged in maritime and railway transportation. The proposed unified corporate information system enables the replacement of task resolution by local optimization criteria applied separately to each transport mode—such as freight cost and delivery time—with a single global optimization criterion for the multimodal supply chain.

Keywords: corporate information system; information model of transport process; decision support system; model bases; multimodal transportation; maritime transport; railway transport



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1. Introduction

Transport logistics—encompassing maritime and railway transportation—constitutes a key sector of the Ukrainian economy, playing a critical role in the development of international trade and the facilitation of efficient goods movement. The transport logistics industry faces a range of challenges, including intensifying competition, regulatory constraints on the application of information technologies, stringent safety and environmental sustainability requirements, and the necessity of coordinating heterogeneous transport modes within multimodal supply chains. One of the fundamental factors affecting the operational performance of transport and logistics companies is the effective functioning of systems for the operation and management of vehicles of various types. This article examines promising directions for the implementation and improvement of operational maintenance management systems for maritime and railway transport vehicles. The objective of corporate information system (CIS) deployment is to enhance fleet and rolling stock utilization efficiency, ensure transport safety, optimize intermodal logistics operations, and achieve sustainable competitiveness for transport and logistics companies.

Transport logistics—encompassing maritime and railway transportation—constitutes the backbone of global supply chains, accounting for over 75% of international freight transportation. Maritime transport plays a decisive role in international trade; however, recent years have been characterized by declining service reliability, rising costs, and disruptions to logistics chains [1]. Maritime transport remains the dominant mode of international freight transport. However, recent disruptions have reduced schedule reliability and increased transportation costs, highlighting the need for more efficient information management and coordination systems (Figure 1) [2].

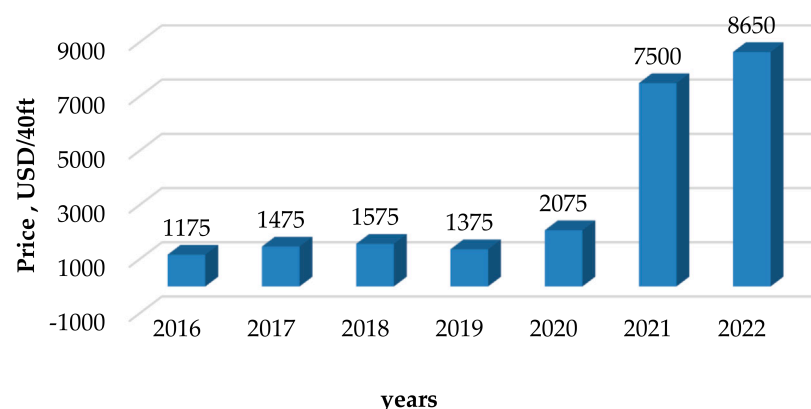


Figure 1. Changes in container shipping spot rates, 2016–2022.

According to [2], the schedule reliability of container carriers deteriorated significantly following the onset of the pandemic.

Railway transport is recognized as an environmentally sustainable and economically efficient mode of transportation [3,4]. According to [4], the rail freight market is expected to grow substantially over the coming years, reaching USD 377.49 billion by 2030 at a compound annual growth rate of 5.9% (Figure 2). Growth during the forecast period is projected to be driven by increased investment in the electrification of rail freight, the expansion of cross-border rail trade routes, and rising demand for cost-effective long-distance transportation. The sustained market growth and increasing investment in rail freight underline the importance of effective digital management solutions [3,4].

The integration of maritime and railway transport into multimodal logistics systems enhances transportation efficiency, reduces environmental impact, and improves the overall performance of supply chains. By combining the advantages of different transport

modes, integrated multimodal corridors strengthen the competitiveness of transport and logistics systems while contributing to the reduction of greenhouse gas emissions and more sustainable freight operations [5,6]. However, the absence of unified and interoperable information systems between maritime and railway segments remains a principal barrier to efficient multimodal operations, resulting in increased idle time, extended cargo processing periods, and inefficient resource utilization. The implementation of shared electronic platforms and automated information exchange among logistics stakeholders has been shown to substantially improve cargo handling efficiency and the coordination of transport processes [5,7,8].

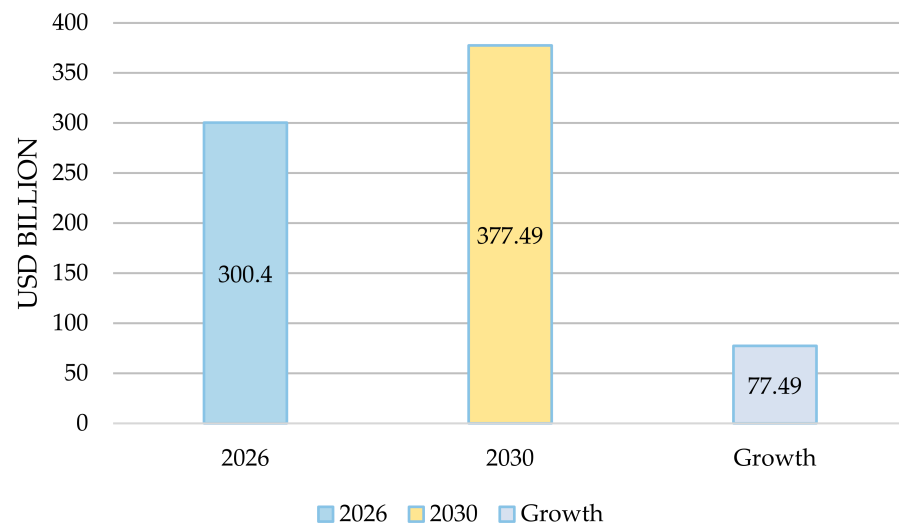


Figure 2. Rail freight market.

Contemporary transport and logistics companies face specific challenges related to the coordination of different transport modes. Railway transport is characterized by complex infrastructure dependencies, the need to synchronize the operations of multiple infrastructure operators, and capacity constraints at stations and transshipment terminals. Intermodal transportation requires precise coordination of vehicles, optimization of container transshipment times, and document management across multiple jurisdictions.

Simultaneously, international research documents a trend of profitability pressure on transport and logistics companies, driven by rising costs and the imperative to invest in digitalization and infrastructure. At the same time, the integration of railway transport into multimodal chains and the optimization of the maritime–railway interaction enable reductions in delivery times of approximately 20–30% and decreases in logistics costs, which are regarded as key reserves for maintaining and restoring industry profitability [9–11].

One of the most effective approaches to addressing these challenges is the utilization of CISs for managing the operational activities of transport and logistics enterprises.

At the current stage of development of Ukrainian transport and logistics companies, there is a demonstrated need for managing diverse aspects of maritime and railway transport operations, as well as for coordinating intermodal transportation. This task is addressed through the implementation of CISs incorporating the integrated decision support system (DSS).

The proposed methodology is independent of specific tariff values and freight market conditions. Changes in transportation tariffs, cargo flows, and regulatory requirements affect only the input parameters of the decision support system, while the overall methodological framework remains invariant. The proposed approach is, therefore, adaptable to various transport enterprises operating under different economic and regulatory conditions.

The deployment of CISs in transport and logistics companies, with DSSs as an integral component, leads to improvements in economic efficiency, management quality, and coordination among organizational units, as well as among different transport modes within multimodal supply chains. It also facilitates the identification and resolution of problems associated with low system responsiveness, while providing more reliable and systematic information processing for subsequent statistical analysis of transport processes [12–14].

Shipping companies are actively advancing digital transformation as a strategic direction for enhancing operational efficiency and competitiveness in the maritime sector [14,15]. Similarly, transport and logistics companies engaged in multimodal maritime and railway operations require integrated corporate information systems (CISs) with embedded decision support systems (DSSs) to facilitate effective information exchange, operational coordination, and managerial decision-making. Despite considerable research on digital transformation and information systems, existing studies are predominantly focused on individual transport modes, while the sector-specific requirements of integrated maritime–railway logistics remain insufficiently addressed. The development of a unified information environment capable of supporting multimodal transport processes and coordinating information flows among all logistics stakeholders, therefore, constitutes an important research objective [14]. Thus, the digital transformation of a company’s activities constitutes the basis of its competitiveness and the engine of its development, ensuring sustainable business growth in the face of dynamic environmental conditions. The necessity arises to implement a methodology for the design of a CIS as a unified management system for transport and logistics companies engaged in multimodal transportation. The DSS constitutes an effective instrument for operating such data. The outcome of the research is a unified transport–technological system for managing the process of passenger and freight transportation by various vehicle types using intermodal technologies. A transport–technological system is a form of organization of a multimodal transport process that ensures the unity of organizational, technical, technological, economic, and commercial–legal decisions for the transportation of goods by maritime and railway transport with maximum economic efficiency and optimal coordination between transport modes. Accordingly, the present research—devoted to the development of a unified information management system for multimodal transport and logistics companies and its DSS implementation tool—is relevant to enhancing the efficiency of maritime and railway transportation.

Accordingly, the development of a design methodology for an integrated corporate information system capable of eliminating information exchange barriers among the participants of multimodal transportation constitutes a topical scientific and practical objective for the transport sector of Ukraine.

Although a substantial body of scholarly publications examines digital transformation, corporate information systems, ERP platforms, and decision support technologies for transportation, the majority address individual transport modes or isolated operational challenges. A unified methodological framework for the design of an integrated corporate information system with an embedded decision support system for multimodal transport and logistics companies combining maritime and railway operations has yet to be established. The present study addresses this research gap by proposing such a methodology.

The objective of this study is the development of a methodological framework for the design of an integrated corporate information system with decision support for multimodal transport and logistics companies engaged in maritime and railway transportation.

To achieve this objective, the following research contributions are made:

1. Information modeling of the business processes of multimodal transport and logistics companies has been conducted.

2. An optimal model of the transport process for maritime and railway transportation has been constructed using IDEF and SADT modeling.
3. A multilevel unified database structure for the coordination of different transport modes has been designed.
4. A decision-making and support system for managing the operational activities of a multimodal transport and logistics company engaged in maritime and railway transportation has been developed.

The paper is organized as follows: Section 2 reviews the existing literature on the subject and formulates the research problem, and the materials and methods are presented in Section 3. Section 4 is devoted to the construction of a unified information management system for the structural subdivisions of the transport and logistics company. The results obtained are discussed in Section 5, and the conclusions of the study are drawn in Section 6.

The implementation of the proposed methodology, software development, and experimental validation using real-world operational data fall outside the scope of the present study and constitute the next stage of the research.

2. Analysis of Literature Data and Problem Statement

Contemporary trends in the development of transport technologies are founded upon the digital transformation of company activities, which ensures sustainable business growth amid shifting external conditions. The primary prerequisites of technological transformation are new digital technologies: mobile Internet, social networks, artificial intelligence, Big Data, cloud technologies, next-generation robotics, virtual and augmented reality, the Internet of Things (IoT), and blockchain.

It is evident that these technologies emerged some time ago, yet the conditions for their widespread adoption materialized only during the past decade. Models of international road transportation demonstrate the potential for reducing transport costs by an average of 18% through digital solutions [12], while the automation of business processes and transition to cloud platforms yield cost savings of approximately 25–30% [13], ultimately reducing the share of transport costs in the final price of products.

The expanding scope of application and growing financial accessibility of technologies have led to the mass creation, presentation, and transmission of information in digital form. Today, virtually all information within the transport processes of maritime and railway companies exists in electronic form, creating the prerequisites for the integration of information flows in the execution of multimodal transportation.

As noted above, the foundation of the digital economy is the hyperconnectivity of subjects resulting from the deployment of information technologies. This constitutes an axiom of modern effective operational activity. Furthermore, the management of transport and logistics companies does not always recognize the necessity of continuous financial investment in the improvement of developed software complexes. The effective implementation of CISs requires a consolidation of efforts among Ukrainian transport and logistics companies operating across different transport modes. Existing studies address exclusively the technical operation of vehicles without interaction with other operational dimensions and without accounting for the specifics of multimodal transportation.

At the current stage of development of Ukrainian transport and logistics companies, the implementation of corporate information systems requires systems that incorporate multiple intelligent advisory modules for different operational dimensions: transport management by maritime and railway modes, vehicle maintenance, marketing, management, and coordination of intermodal operations. Such approaches are supported within the framework of studies [16], which demonstrate the effectiveness of applying Big Data, analytics, and predictive maintenance in railway transport [16]. The dependency of solutions to

certain tasks upon a unified database—itself generated in the course of solving other tasks that appear insufficiently related—leads, in practice, to the situation where the technical operation of vehicles is assessed and analyzed separately for each transport mode, with performance indicators formed accordingly, without accounting for the multimodal character of transportation. The implementation of corporate information systems in transport and logistics companies, with DSS as an integral component, can lead to improvements in efficiency, management quality, and coordination among different subdivisions, third-party organizations, and different transport modes within supply chains. Furthermore, it will help identify and resolve problems associated with the low responsiveness of the multimodal transport coordination system, as well as ensure more reliable and systematic information processing for statistical analysis of transport processes.

A significant aspect of corporate information systems for transport and logistics companies is their integration with global information networks. In maritime transport, systems such as the Global Analysis and Information Network (GAIN), implemented by leading shipping companies including Maersk Line, MSC, China COSCO Shipping, and CMA CGM, support information exchange and operational coordination. One of the principal barriers to improving multimodal transportation efficiency in Ukraine is the fragmentation of the information environment, where railway operators, seaports, freight forwarding companies, customs authorities, and other stakeholders employ heterogeneous information systems that do not provide standardized data exchange. This leads to information duplication, extended document processing times, and reduced interoperability between transport modes. The development of an integrated corporate information system is, therefore, essential for ensuring unified information exchange and coordinated management of multimodal transport processes [17].

The ERTMS is a unified European signaling and speed control system that ensures the interoperability of national railway systems, reduces the costs of acquiring and maintaining signaling systems, and enhances train speeds, infrastructure capacity, and railway safety. In [18], the author investigated the functionality of the ERTMS/ETCS (European Train Control System) as a unified railway traffic management system capable of increasing railway line capacity.

Moreover, numerous scholarly publications identify the primary objective of the ERTMS system as ensuring the safe operation of rolling stock while simultaneously increasing railway line capacity through the continuous digital transmission of information between trains and infrastructure [19].

Large and leading transport and logistics companies engaged in multimodal transportation already employ similar integration systems in their activities. Leading transport and logistics companies demonstrate that the successful integration of information systems across different transport modes requires more than the simple consolidation of individual platforms. It necessitates the development of a unified data architecture ensuring the semantic interoperability of information models for maritime and railway transport [12–14].

The primary focus of contemporary research on the digital transformation and automation of transport companies concerns the parameters used to measure digital maturity across various dimensions. The literature indicates that many studies conducted in this field are concentrated exclusively on the assessment of the digital maturity of the investigated objects. Insufficient attention has been devoted to the implementation of information data processing systems for multimodal transport and logistics companies engaged in maritime and railway transportation. This points to the need for further research directed at the development and implementation of comprehensive corporate information systems that account for the specific characteristics of maritime–railway transport interactions.

Attention in research is devoted to organizational culture and the degree to which it is reflected in enterprise operational models. The results of studies conducted in this field are oriented toward determining the level of digital maturity of the investigated objects and emphasize the necessity of automating company activities.

At the same time, notwithstanding the availability of digital maturity assessment methodologies and developed digital transformation models, the issues of practically integrating information systems into the management of transport and logistics companies engaged in maritime and railway transportation remain insufficiently developed. This refers specifically to the creation of unified or integrated information systems—including CISs—that would ensure the coordination of multimodal operations, data exchange among different transport modes, and real-time decision support [20–23]. It should also be noted that the level of deployment of technological innovations—IoT, artificial intelligence, and data exchange platforms—and the degree of information system integration across transport segments directly determine the competitiveness and operational efficiency of transport and logistics companies within multimodal supply chains [7,20,23–28].

Furthermore, and of considerable importance, researchers [29] have provided evidence that digital companies outperform their competitors in terms of financial and operational efficiency. One option for overcoming the corresponding difficulties may be the implementation of a unified corporate database for multimodal transportation. The issue cannot be resolved without the implementation of digital transformation and the construction of a unified management system for the transport and logistics enterprise engaged in maritime and railway transportation. All of this provides grounds for asserting that it is both appropriate and timely to conduct research devoted to the construction of a unified corporate information system for data processing in the management of the transport–technological system of multimodal transportation.

The transport and logistics industry lacks fundamental research in the field of digital transformation and enterprise resource planning (ERP) information technologies [30] for multimodal transportation. This creates difficulties in managing the present and shaping the future of the transport and logistics industry combining maritime and railway transport. For this reason, the concept of digital maturity remains topical. Works [30,31] emphasize that the existing transformations are fundamental in nature but do not provide pathways for the further development and analysis of multimodal transport processes [32,33].

Previous studies [34,35] show that digital transformation is anything but a comprehensive methodology for the operational management and forecasting of transport processes. The present research contends that digital transformation must concern itself with substantial changes in all parts of the transport business, creating a unified system—technological, technical, managerial, financial, and environmental. Innovations enable organizations to adapt more rapidly to the dynamics of changing operating conditions. As a result of the general analysis [36], it was found that the question of the formation of a mechanism for the effective implementation of the CIS and DSS [37] remained unresolved. One option for overcoming the corresponding difficulties may be the presentation of a methodology for the construction of a CIS in the management of maritime shipping companies. The implementation of the CIS and DSS, as an integral component thereof, ensures competitiveness and sustainable business development under volatile market conditions [35,36].

For example, the authors of [38] investigated the impact of information technologies on railway transportation—specifically the implementation of automatic control of locomotive and train movement on Ukrainian railways. The task of identifying moving objects on the railway and determining their precise location can be resolved through the deployment of satellite navigation systems and their integration into the information base of Ukrzaliznytsia. Through the classification and comparison of the characteristics and

functional capabilities of foreign and domestic systems in this domain, the most optimal variant for implementation on Ukrainian railways was identified [38].

However, contemporary works lack a unified methodological approach to the design of corporate information systems for multimodal transport and logistics companies. In the practical domain, there is an absence of a methodology for implementing the technology for constructing ERP systems and creating, on this basis, data management systems for different user conditions among companies engaged in maritime and railway transportation. The question arises of the necessity to implement a methodology for designing corporate information system databases for subsequent deployment in transport and logistics companies engaged in multimodal transportation [37,39]. This facilitates effective company management. Maritime and railway transportation constitute parts of a unified supply chain system, and digital integration between different transport modes determines the organizations that remain competitive in the marketplace.

The principal characteristic in the organization of freight and passenger transportation is a system-wide approach to the activity of moving goods and passengers. This refers to the principle of “total costs.” This principle prescribes that the decision-maker—when selecting transport modes, methods of transportation, carriers, routes, and auxiliary intermediaries (insurer, stevedore, bank, and customs broker)—must address the problem comprehensively. The CIS enables the resolution of this task by replacing multiple local optimization criteria (freight cost and delivery time) with a single global criterion [12–14].

The foregoing analysis demonstrates that it is expedient to conduct research on the construction of a corporate information system for multimodal transport enterprises engaged in maritime and railway transportation—research that confirms the digital maturity status of the company and its competitiveness in the field of intermodal logistics.

3. Materials and Methods

The purpose of this section is to describe the methodological framework developed for the design of an integrated corporate information system (CIS) with an embedded decision support system (DSS) for multimodal transport and logistics companies engaged in maritime and railway transportation. The proposed methodology focuses on the organization of information flows, business process modeling, database design, and the integration of decision support mechanisms into a unified information environment.

The object of study is the operational activities of multimodal transport and logistics companies engaged in maritime and railway transportation. The subject of study is the methodological framework for the design of an integrated corporate information system with an embedded decision support system supporting operational management [40–42].

The research methodology combines systems analysis, business process modeling, functional decomposition based on IDEF0 and SADT methodologies, information modeling, database design, and decision support system modeling. These methods were selected as they enable the formal representation of operational processes, information flows, and interactions among the structural units participating in multimodal transport operations [42].

The specific character of the business processes of railway transportation lies in the necessity of coordinating the activities of the rolling stock operator, the infrastructure operator, and the carrier, forming a complex tripartite interaction model. This is confirmed by contemporary studies on the digitalization of traffic management systems, based on the implementation of automated signaling and control systems, such as ERTMS, which ensure the integration of transportation management processes [43].

Railway transportation is characterized by rigid timetables, infrastructure capacity constraints, and the necessity of reserving track resources, requiring the application of com-

plex planning algorithms. Contemporary research emphasizes that the use of digital twins and analytical models enables enhanced infrastructure utilization efficiency, optimized movement schedules, and reduced transportation delays [41,44,45].

Multimodal transportation adds an additional layer of complexity, requiring the synchronization of different transport modes, management of transport nodes, and maintenance of unified digital document flow. Scholarly works emphasize that digital platforms and corporate information systems ensure the effective coordination of such processes, while also enhancing the reliability and safety of transportation [46].

Differences in information flows between maritime and railway transport are determined by the specific characteristics of the managed objects. Maritime transportation operates with data on vessels, ports, and containers, whereas railway transportation involves the processing of detailed information concerning wagons, locomotives, stations, infrastructure, and movement schedules. As noted in contemporary research on the digitalization of railway transport, the high complexity of infrastructure and operational processes necessitates the use of integrated information systems capable of processing large volumes of data in real time and supporting managerial decision-making [47,48].

The research examines methods for constructing an effective management system in transport and logistics companies for managing the multimodal transport process and information flows between different transport modes. A methodology is presented for constructing a target and typical functional model of the information decision support system for transport and logistics businesses engaged in maritime and railway transportation.

For this purpose, the study examined the laws and means of operation of the environment and objects constituting the functional system of the transport and logistics company engaged in maritime and railway transportation. This conceptual framework leads to the creation of a corporate technical, technological, economic, and financial DSS for multimodal transportation—specifically, a corporate system of databases for different transport modes and a model base for the coordination of intermodal operations.

Prior studies have established that integrated corporate information systems and decision support technologies can enhance operational efficiency by up to 20% under certain conditions [5,9]. These figures are presented as literature-derived data and do not reflect experimental results obtained within the present study.

It is, therefore, expedient to concentrate on the improvement of the controlling system, enabling the concentration of intellectual, financial, and time resources, as well as ensuring timely and precise managerial decision-making.

The principal characteristics of the approach to CIS construction are as follows:

1. Comprehensive analysis of multimodal transportation business processes, based on which the information system design project is developed and the solutions embedded therein—concerning the coordination of different transport modes—are substantiated.
2. Application of a broad palette of contemporary methodologies and instrumental tools for system modeling and design for intermodal logistics, and detailed elaboration and agreement with the client on all stages of project development, control points, and required resources [37].

The optimization of multimodal transportation business processes in modeling enhances the precision and responsiveness to external influences and changes in supply chains. The improvement of business process implementation efficiency enables the organization to obtain the following competitive advantages: increased company dynamism in coordinating different transport modes, enhanced economic efficiency of intermodal operations and business security, reduced investment costs, and the formation of a basis for creating an integrated information technology system within the organization.

The theoretical basis for the relevant work consists of a set of standards collectively designated as IDEF, and the SADT model [49].

The functional modeling methodology, constituting a component of SADT, enables the description of a business process in the form of a hierarchical system of interrelated functions. The functional model of an organization represents a system of functions (business processes) executed within the framework of that organization. The relationships between functions (processes) are reflected through the movement of objects between them, that is, through data models. This approach ensures the development of integrated solutions built on objective data concerning enterprise operations, with timely agreement on all substantive matters.

The SADT model is a precise, complete, and adequate textual and graphical description of a system with a specific purpose, presented as a hierarchically organized collection of diagrams constructed based on a standard data representation. It is a description of a system with a single subject, objective, and viewpoint, developed using the SADT methodology. The model represents a collection of hierarchically ordered and interrelated diagrams organized in a tree-like structure, where the uppermost diagram is the most general and the lowest-level diagrams are the most detailed. The methodology is grounded in the concept of systems modeling. It enables the examination of a system through the description of its functions or through the description of its objects (data). Two types of models are, therefore, distinguished within the SADT methodology:

- Functional SADT models, oriented toward the functions of the described system.
- SADT data models, oriented toward the objects of the described system.

The SADT methodology underlies the IDEF group of methodologies, which consists of three foundational methodologies for the graphical description of systems: Function Modeling Method (IDEF0), Information Modeling Method (IDEF1), Dynamic Modeling Method (IDEF2) [49]:

- IDEF0 is used to create a functional model reflecting the structure and functions of the system, as well as the information flows and material objects transformed by those functions.
- IDEF1 is applied to construct an information model reflecting the structure and content of the information flows required to support the system's functions.
- IDEF2 enables the construction of a dynamic model of the time-varying functions, information, and resources of the system.

IDEF0 is a functional modeling methodology and graphical notation designed for the formalization and description of business processes. The distinguishing feature of IDEF0 is its emphasis on the subordination of objects. IDEF0 examines the logical relationships among operations rather than their temporal sequence (workflow) [1].

The study employs predicate algebra constructs for describing the subject domain as a modeling tool within the corresponding subject area. Each language includes an alphabet, vocabulary, and rules for constructing the data description language (DDL). The term “predicate” has been applied in language theory for a considerable time [32,36].

The set of sufficient database states is termed a schema, described by means of DDL. Changes in the state of the database, and the extraction of data from it for subsequent analysis, are achieved through data manipulation language (DML) and the implementation of data manipulation models. The combination of DML and DDL constitutes the data model supported by the database. The model is also understood as a collection of methods and tools for defining the logical structure of the database and for dynamically modeling different states of the database subject domain. The data model may thus be interpreted not

only as a means of forming abstractions for the design database, but also as a communicative intermediary between the subject domain and the database.

4. Research Results and Construction of a Unified Information Management System for the Structural Subdivisions of a Transport and Logistics Company

4.1. Corporate Information System Architecture

Information modeling of the business processes of multimodal transport and logistics companies has been conducted. An optimal model of the transport process for the coordination of maritime and railway transportation has been constructed.

The transport process model was constructed using IDEF and SADT modeling [49,50]. The principal characteristics of the approach to constructing a corporate information system for transport logistics enterprises engaged in maritime and railway transportation are a comprehensive analysis of multimodal transportation business processes, on the basis of which the information system design project is developed, and the decisions embedded therein—concerning the coordination of different transport modes—are substantiated.

The database organization is presented as a unified environment for storing corporate data in structures optimized for the execution of analytical operations. Analytical tools enable the end user, who possesses no specialized knowledge in the field of information technologies, to navigate and present data in the terms of the subject domain.

The diagram (Figure 3) presents the sequence of actions describing the information model of elements and their relationships within the design domain for multimodal transport and logistics companies.

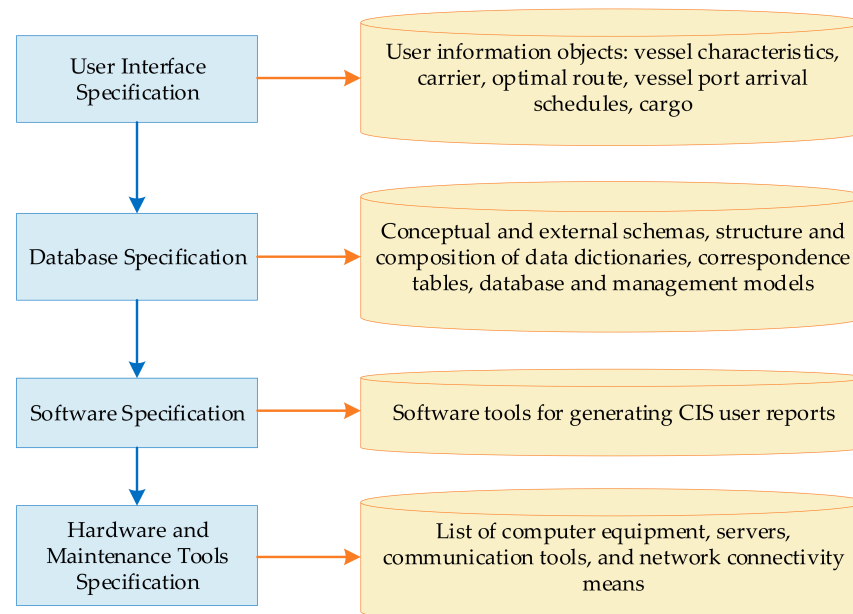


Figure 3. Multilevel system architecture.

At present, there is no recognized leader in the software production domain for constructing the CIS and the DSS integrated therein. No company produces a ready-made solution directly applicable to the client's production process. The creation of the CIS and DSS invariably includes stages of data and business process analysis, the design of repository structures accounting for the client's needs, and technological processes [35]. The problem is a pressing one, given the scale of the financial and other resources involved,

the complexity and multi-stage character of DSS construction projects, and the evidently high cost of design errors.

Figure 3 presents the proposed multilevel architecture of the corporate information system for multimodal transport and logistics companies. The architecture integrates databases, model bases, a decision support system, and management subsystems into a unified information environment. It illustrates the interaction between the data layer, analytical models, and decision-making components, providing the foundation for coordinated management of maritime and railway transport processes.

From an implementation perspective, the proposed architecture is independent of specific software technologies. Accordingly, the corporate information system may be implemented using Java, C#, or Python, while the data layer may rely on PostgreSQL, Microsoft SQL Server, or Oracle Database. Integration with external transport information systems can be achieved through standard middleware technologies and REST-based interfaces.

The proposed methodology is intended for subsequent software implementation and validation using operational data from multimodal transport and logistics enterprises. The present study focuses on the methodological aspects of corporate information system and decision support system design. The practical verification of the proposed architecture—including the quantitative assessment of operational efficiency, transportation costs, and decision-making effectiveness using real enterprise data—constitutes the next stage of this research.

The sequence of steps for resolving the task of developing logistics procedures in organizing a multimodal transportation route and its evaluation is presented in Figure 4.

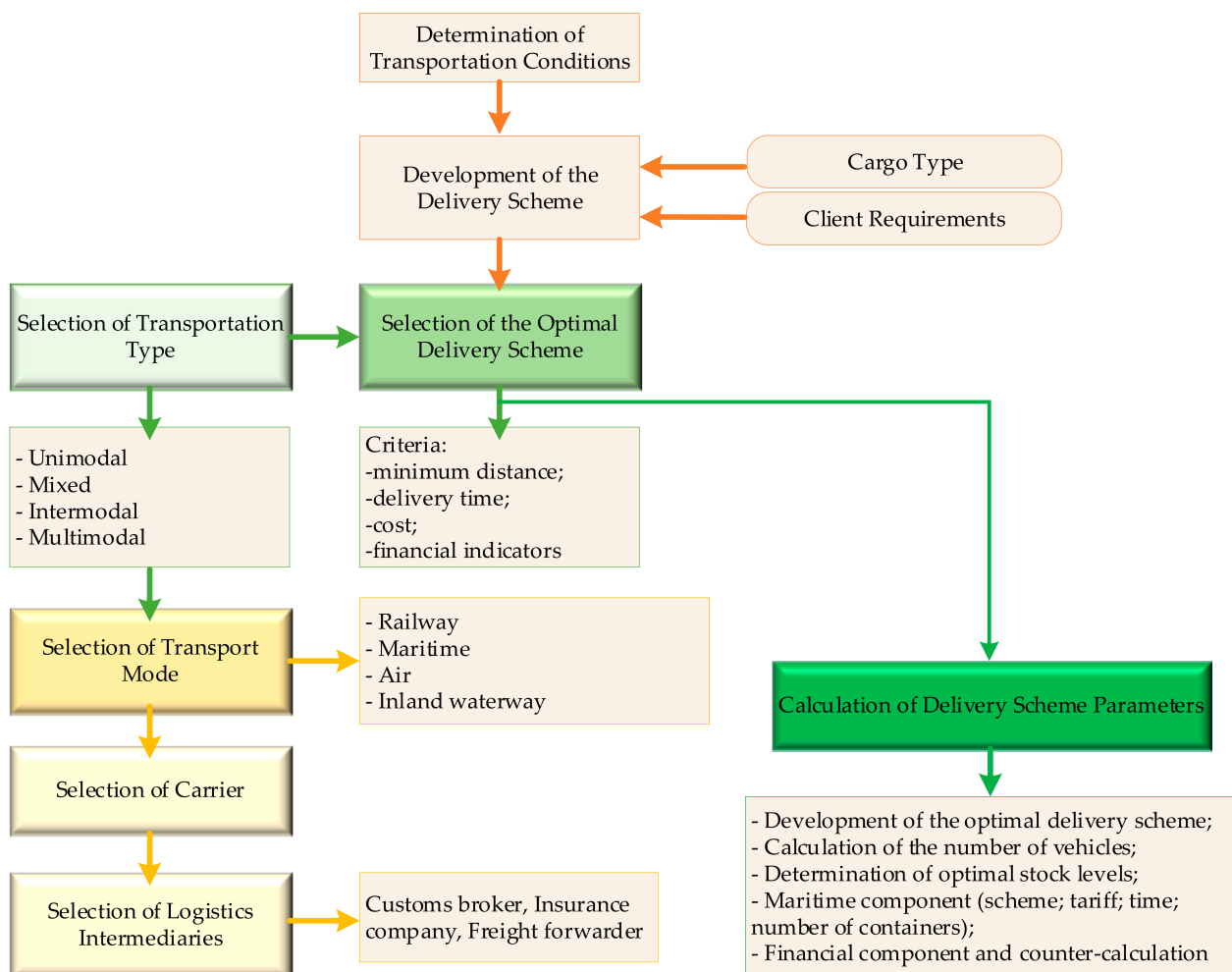


Figure 4. Logistics procedures in organizing a multimodal transportation route.

Figure 4 presents the sequence of logistics procedures performed during the organization of a multimodal transport route. The logical order of decision-making actions is illustrated, from the initial client request through to route evaluation and operational control. The figure also demonstrates how the proposed DSS supports coordination between maritime and railway transport, accounting for operational constraints and optimization criteria.

The flowchart illustrates the information processing sequence within the proposed corporate information system. The principal elements comprise the client, transport operator, carrier, transport terminals, and corporate database, which interact during the planning and execution of multimodal transportation.

Unlike existing industrial digital platforms, such as those implemented by Maersk and MSC, which are primarily designed for the operational management of logistics services within their own digital ecosystems, the proposed approach focuses on the development of a methodological framework for the design of a corporate information system and integrated decision support system for multimodal transport and logistics companies.

The proposed methodology combines IDEF0-based business process modeling, conceptual database design, functional decomposition of transport and logistics processes, and decision support principles within a unified framework. This enables its adaptation to the operational requirements of transport enterprises regardless of their organizational structure or software environment. ERTMS is regarded in this study as an example of an internationally recognized interoperability standard for railway transport, rather than as a direct analog of the proposed corporate information system.

As shown in Table 1, existing industrial solutions are designed to support specific operational tasks in the maritime or railway transport domain. The present study, by contrast, does not introduce yet another operational platform, but rather proposes a comprehensive methodology for the design of a corporate information system integrated with a decision support system. The proposed approach combines functional business process modeling, conceptual database design, and decision support principles within a unified framework that can be adapted to multimodal transport and logistics enterprises.

Table 1. Comparison of the proposed methodology with existing transport information systems.

Criterion	Maersk Digital	MSC GAIN	ERTMS	Proposed Methodology
Railway and maritime transport integration	Limited	Limited	Railway only	Integration within multimodal transportation is provided
Business process modeling	Not provided	Not provided	Not provided	IDEF0 methodology is applied
Conceptual database model	Not described	Not described	Standardized	Conceptual database design is provided
Decision support methodology	Limited	Limited	Oriented toward traffic management	Integrated DSS methodology

All specified procedures are executed in accordance with a system of criteria subject to a defined system of constraints for different transport modes. These constraints are determined by factors of the external macro- and micro-economic environment and by the specific characteristics of maritime and railway transportation (Figure 5).

Stage 1: Identification of external objects and information interactions with them, identification of the company's main business processes, and identification of information linkages among these processes.

Stage 2: Construction of the current model based on the results of the survey of the transport and logistics company's activities using the structured approach and the notation of the foundational methodologies for graphical system description: IDEF0, IDEF1, and IDEF2 [49] (Figure 3).

The context diagram for a multimodal transport and logistics company is provided in Figure 5.

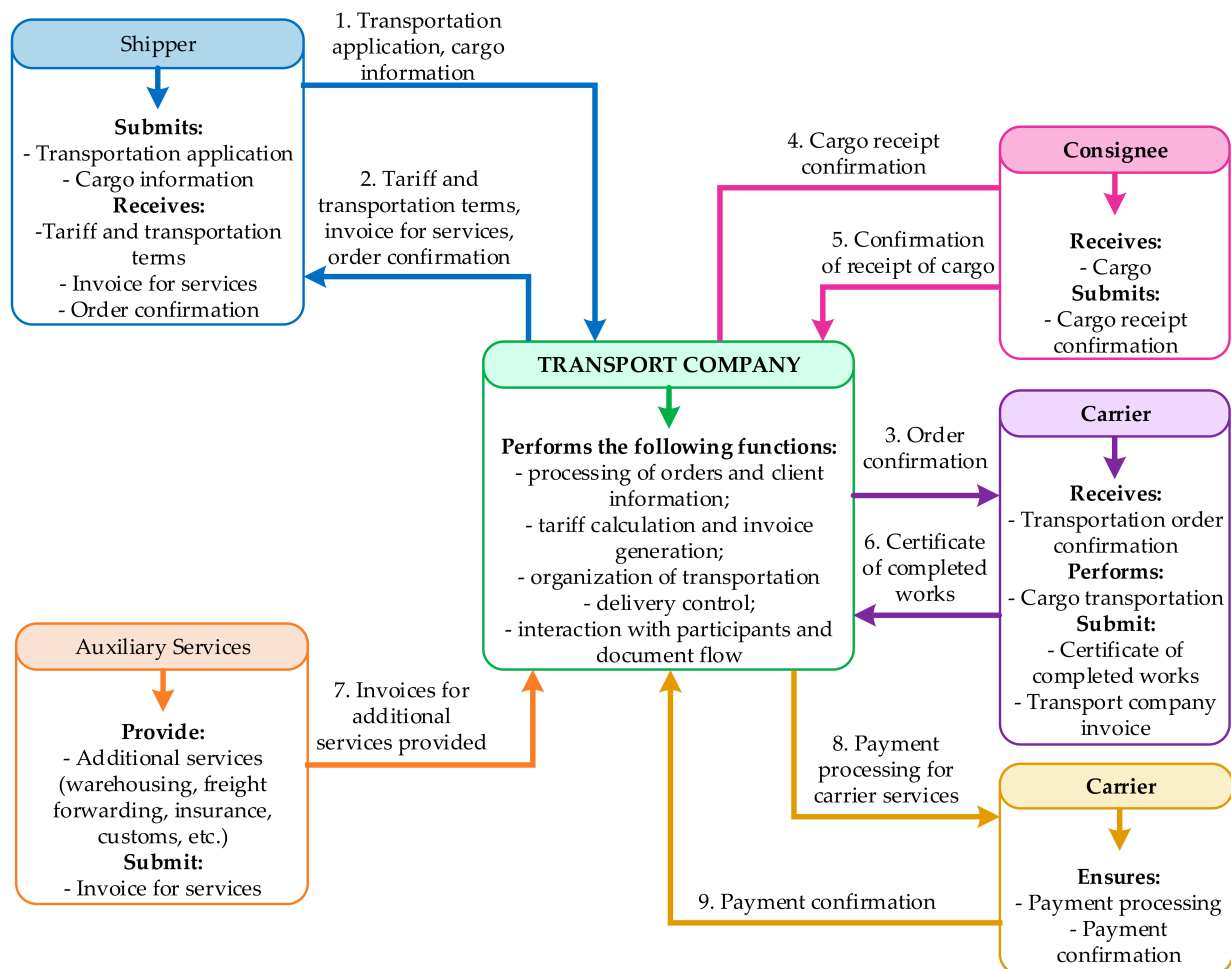


Figure 5. Information model of the general conditions scheme for multimodal transportation.

Figure 5 presents the IDEF0 context model of the multimodal transportation process. It defines the principal inputs, outputs, control mechanisms, and resources required for the organization of multimodal transportation. The model establishes the functional boundaries of the proposed corporate information system and serves as the foundation for the subsequent decomposition of business processes.

The context diagram (A-0) defines the overall activity of managing multimodal transport and logistics operations. At the first level of decomposition (A0), this activity is divided into the following principal business functions:

- customer order management,
- multimodal route planning,
- carrier selection,
- transportation execution monitoring,
- financial management and document flow.

Each function is further decomposed into lower-level processes in accordance with the IDEF0 methodology until the required level of detail is achieved.

A stage-by-stage modeling of the typical transport and logistics operations of a multimodal company engaged in maritime and railway transportation is provided. A systematic approach to modeling the information diagram of a transport company's operations has been developed, accounting for the coordination of different transport modes (Figure 6).

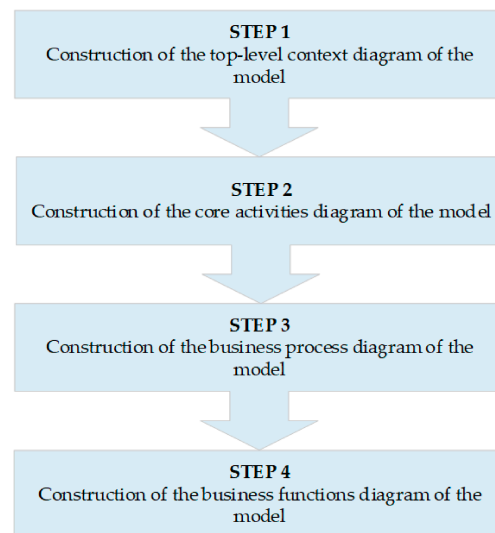


Figure 6. Sequence of constructing the current operational model of a multimodal transport and logistics company.

Figure 6 illustrates the hierarchical decomposition of the current operational model in accordance with the IDEF methodology. The proposed sequence ensures a structured transition from high-level business objectives to detailed operational processes, maintaining consistency between functional modeling, database design, and decision support system development.

The approach to structuring typical transport and logistics operations for intermodal transportation has been formalized.

The levels of transport process design in multimodal transport and logistics companies are provided.

Structuring is to be carried out in accordance with the company's operational directions and transport processes—accounting for the coordination of maritime and railway transportation—rather than in accordance with its organizational structure. It is precisely the business processes of multimodal transportation that constitute value for the client, and it is precisely the business processes that reflect information flows in the activities of a transport and logistics company.

Stage 1: The upper level of the model reflects the system context—the company's interaction with the external environment. The context diagram contains a single top-level process representing the operational activities of the multimodal operator (Figure 7).

Figure 7 illustrates the information interactions between the multimodal transport operator and external stakeholders, including clients, carriers, customs authorities, financial institutions, and infrastructure operators. The diagram represents the information, documentary, and financial flows coordinated by the proposed corporate information system and demonstrates its role as an integration platform for multimodal transport management.

The entity relationship (ER) model of the proposed corporate information system is presented in Figure 8.

The model defines the principal business entities required to support multimodal transport and logistics operations, including Client, Order, Shipment, Route, Carrier, Terminal, Document, and Invoice. The relationships between these entities ensure the integrity of operational, logistics, and financial information, and establish the data foundation for the proposed decision support system.

The information conceptual scheme of the transport processes of a multimodal transport and logistics company is presented in general form (Figure 7). Under the contemporary conditions of globalization and economic digitalization, the operational efficiency of lo-

gistics systems is directly dependent on the promptness and transparency of information exchange. In its activities, the transport company acts as a coordination hub: it consolidates information flows, document flows, and financial flows among all participants in the delivery chain. Specifically, it collects orders from clients, distributes them among actual carriers, controls the legal (customs) integrity of the process, coordinates the activities of agents, and conducts financial settlements through the banking system. All flows in the diagram are of a closed-loop character (request–response, invoice–payment, information–customs clearance), which minimizes the risks of information vacuum and ensures the continuity of the logistics chain. Such process architecture enables enhancement of the overall client-oriented quality of service.

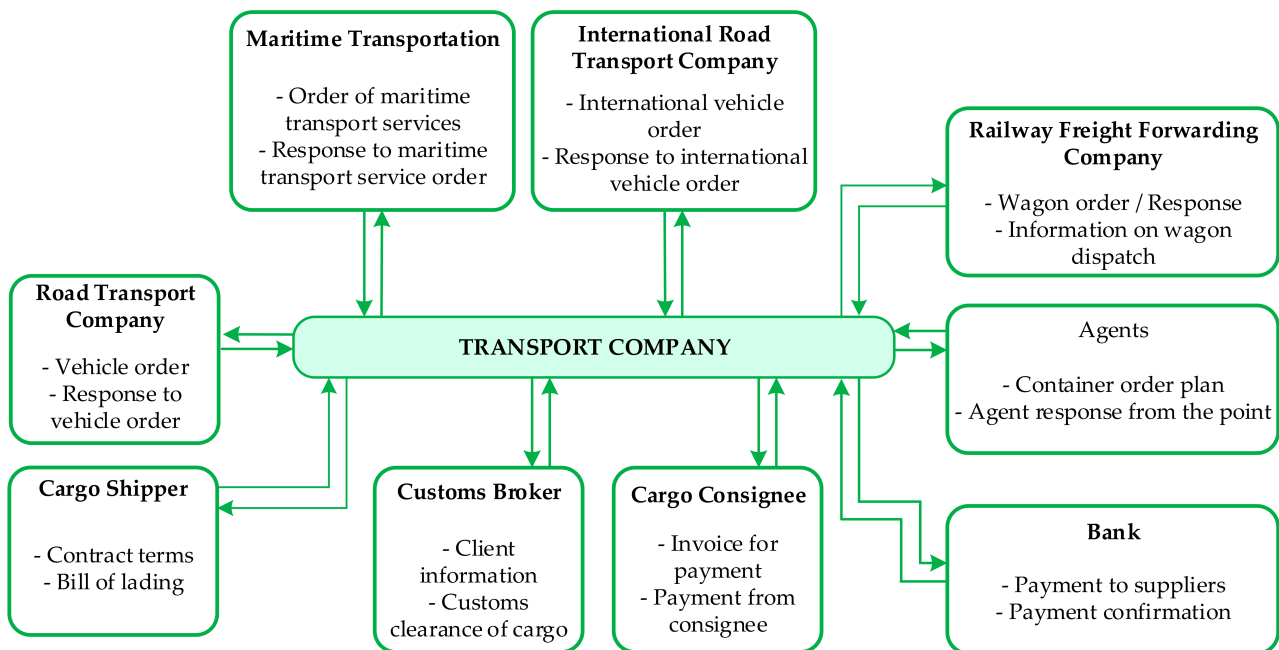


Figure 7. Information diagram of the activities of a multimodal transport and logistics company.

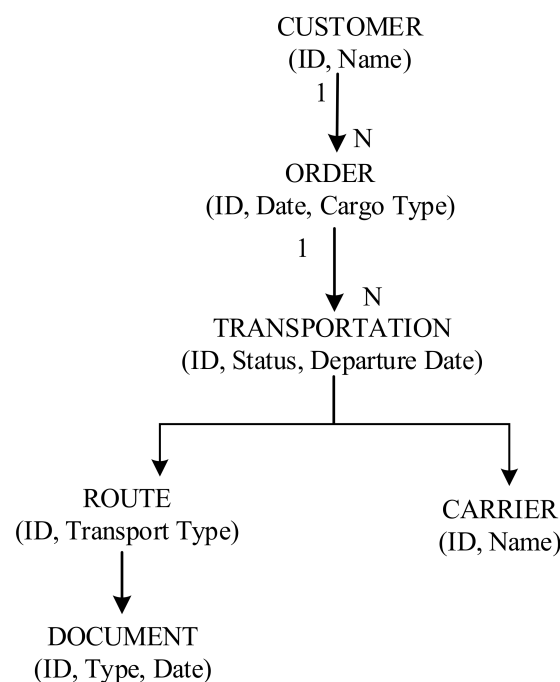


Figure 8. Entity relationship diagram of the corporate information system database.

Where many operational directions exist, some may be transferred to the third level of the model. For example, the process of organizing freight transportation includes the following:

- Maritime transportation management.
- Railway transportation management.
- Coordination of intermodal operations.
- Management of transshipment between transport modes.
- Control of transportation and cargo transfer to clients.

In each instance, no more than two model levels are to be allocated per operational direction.

Stage 3: Each operational direction, in turn, is to be detailed into business processes at a unified level of abstraction. For example, the operational direction of control of transportation and cargo transfer to clients is to include the following business processes:

- Control of maritime transportation.
- Control of railway transportation.
- Control of transshipment between transport modes.
- Organization of cargo transfer to clients.

The planning of intermodal routes constitutes a multifactorial task requiring the simultaneous optimization of vehicle selection, transshipment points, and movement schedules, accounting for cargo characteristics, time constraints, and economic criteria for each route segment.

Contemporary research in the field of multimodal transportation emphasizes that effective planning of such routes is based on the application of mathematical optimization models and digital decision support platforms, enabling the accounting of uncertainty and dynamism in transport processes [51].

Attention is required for the coordination of transshipment operations. The effectiveness of the multimodal chain critically depends on the synchronization of the arrival and departure of vehicles of different types. This requires equipment reservation, precise planning of the sequence of operations, and buffer stock management at transport nodes. As noted in contemporary scholarly work, the digitalization of logistics processes and the use of real-time technologies enable a significant enhancement of operational coordination and a reduction of idle time at transshipment nodes [52,53].

The management of transport nodes—such as seaports with railway terminals or intermodal logistics centers—encompasses the optimization of transshipment capacity utilization, vehicle queue management, infrastructure load monitoring, and the coordination of different operators within a single transport node. Research demonstrates that the implementation of integrated information systems and digital twins of transport nodes contributes to enhanced throughput and resource utilization efficiency [54].

Rolling stock monitoring in a multimodal system involves the real-time tracking of the location and condition of vessels, railway trains, containers, and cargo. This ensures the transparency of logistics processes, client notification regarding delivery status, early detection of schedule deviations, and prompt decision-making on cargo re-routing. Contemporary research emphasizes that the use of IoT, Big Data, and analytical platforms enables significant improvements in forecasting precision and transportation reliability [5,53].

Stage 4: Further detailing of transport processes is carried out by means of business functions. For example, the business process of organizing cargo transfer to clients includes the following business functions:

- Receipt of the client's application for transportation by different transport modes.

- Querying the data accumulator for information on multimodal transportation contract variants.
- Contract variants with the client for intermodal transportation.

Thus, the principal stages for creating the current information model of a multimodal transport and logistics company engaged in maritime and railway transportation have been developed.

Stage 4 (target): Construction of the target model. The primary task of this stage consists of the modification of the model based on the results of business process analysis (Figure 9).

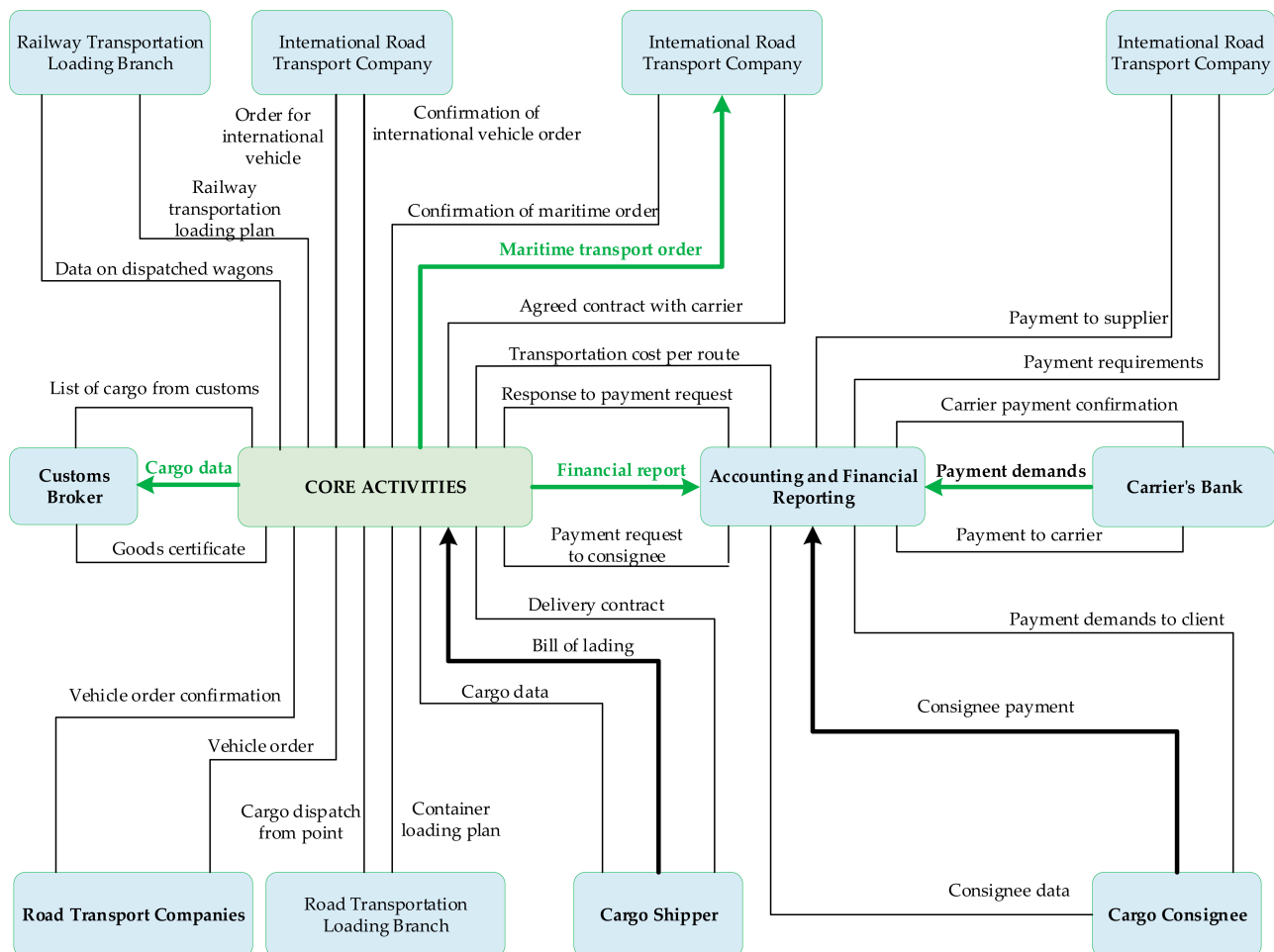


Figure 9. Conceptual scheme of the linkages between the principal activities of a multimodal transport and logistics company and other subsystems.

Figure 9 presents the conceptual structure of the corporate information system, illustrating the interrelationships between the operational, financial, administrative, and auxiliary subsystems. The diagram demonstrates how integrated information exchange enables coordinated decision-making and supports the implementation of the proposed multimodal transport management methodology.

Stage 5: Assessment of the quality of the target model. From the perspective of the systems approach, for a business process to be of high quality it must satisfy the following criteria: the criterion of cohesion and coupling—each function must perform a single subtask that is connected to the general objective. The application of cohesion and coupling criteria enables the quality assessment of each subsystem individually, as well as of the linkages between them, and consequently of the complete system.

The quality assessment outcome at this stage may be satisfactory or unsatisfactory. In the former case, a model is obtained that not only adequately reflects the company's strategies and business processes, but also improves the systems of planning, management, and control of company activities. If the result is unsatisfactory, the preceding stages must be reviewed.

Thus, five principal stages have been developed for constructing the target functional model of a multimodal transport and logistics company. The model is adapted to the DSS and CIS technology (Figure 8).

Subsequently, a method of digital transformation of multimodal transportation business processes was developed—a methodology for reflecting the conceptual model in the physical database structure and unifying them into the CIS for the coordination of maritime and railway transportation.

Figure 8 presents the scheme of information linkages and document flow of a multimodal transport and logistics company. The central nucleus of the model is constituted by the “Core Activities” (operational hub) and “Accounting and Financial Reporting” (economic support) blocks. The scheme reflects integrated information, documentary, and financial flows between the internal subsystems of the company and external counterparties. The central element of the model is the operational contour, incorporating the “Core Activities” and “Accounting and Financial Reporting” blocks.

The internal segment of the system ensures the coordination of specialized subdivisions: railway and road transport branches, as well as the customs broker, which transmit information on cargo loading, dispatch, documents, and certificates.

Interaction with external transport contractors is realized through the exchange of orders, confirmations, and contracts with maritime and road carriers. The client contour encompasses interaction with cargo shippers and consignees regarding cargo information, contracts, bills of lading, and payments.

The financial settlement contour ensures interaction with banking institutions, payment processing, and the formation of financial reporting. The internal data exchange between the operational and financial blocks supports the continuous flow of analytical and settlement information.

The proposed architecture ensures a closed-loop character of information and financial flows, minimizes risks of data loss at the interfaces between different transport modes, and creates the foundation for integrated logistics process management.

4.2. Business Process Modeling of the Transport and Logistics Company

A multilevel CIS structure has been designed for multimodal transport and logistics companies. It incorporates databases (DB) of typical operational data on maritime and railway transportation and model bases of typical operations of the transport and logistics company for the coordination of different transport modes.

Four principal functional components of the CIS for multimodal transportation can be identified: the DB of typical operational data on maritime and railway transportation, the model base of typical operations of the transport and logistics company, and the software system. The management system consists of three subsystems: the database management system (DBMS), the model base management system (MBMS), and the user–computer interface management system (Figure 3) [1,35].

1. The database contains data from various normative sources for maritime and railway transportation: the technical and economic characteristics of vessels and rolling stock, transportation tariffs for different transport modes, data on ports and railway stations, cargo characteristics, passenger class, parameters of transport nodes and transshipment points, etc., including internal organizational data, data generated by various applications, and

external data obtained from the Internet. The database constitutes a data bank supporting the information needs of the multimodal transport and logistics organization.

The maritime transport block includes the technical and economic characteristics of vessels, such as deadweight, speed, fuel efficiency, and propulsion system type. The structure incorporates maritime transportation tariffs differentiated by cargo type, passenger service class, and the characteristics of destination and departure ports, and information on port infrastructure, including fairway depths, number of berths, and transshipment capacities.

The railway transport block contains rolling stock characteristics, including the parameters of wagons of different types, locomotives, their technical condition, and maintenance schedules. The railway transportation tariff system is presented accounting for distance, cargo type, delivery speed, and service class. The database includes train movement schedules linked to specific stations and track slots, parameters of railway station throughput capacity, including the number of tracks, maximum train length, and simultaneous service capabilities, and characteristics of track infrastructure specifying track type, permissible axle load, and electrification availability.

The multimodal operations block contains information on the transshipment times of containers and other standardized cargo units between different transport modes, the technical capabilities of transport nodes, including types of transshipment equipment, its capacity, and operating schedule, customs clearance regulations at mode-change points, and temporary cargo storage standards at transport nodes.

2. CIS model base. The model base consists of various mathematical and analytical models used for the analysis of complex data, thereby producing the necessary information. A model yields output data based on various input data or conditions or determines the combination of conditions and input data required to obtain the desired result. The selection of models to be incorporated into the decision support system depends on user requirements and DSS objectives [22,27].

3. Management system (DBMS). A collection of general or special purpose software tools ensuring the management of production, manipulation, and utilization of databases (insert, delete, organize, and update). The system ensures data storage security, reliability, and integrity.

4. Model base management system (MBMS) for multimodal transportation. Data description language (DDL) and data manipulation language (DML).

The conceptual framework is presented: the DDL and DML for the database of multimodal transport and logistics companies.

Methodological tools for designing the database of a typical multimodal transport and logistics company engaged in maritime and railway transportation have been developed, along with a multilevel DSS structure for the coordination of different transport modes.

The database design methodology—or digital transformation methodology—consists of describing the sequence of implementing the digital transformation of typical transport and logistics procedures for maritime and railway transportation, the information modeling of these procedures, and their interrelationships in the execution of multimodal operations.

Constructs for describing the subject domain serve as modeling tools within the corresponding subject area. Each language includes an alphabet, vocabulary, and rules for constructing the DDL. The term “predicate” has been applied in language theory for a considerable time [32,36]. In mathematical logic, the concept of “predicate” is understood as a functional dependency:

$$P(x) : B \rightarrow \{0, 1\}, \quad (1)$$

where $x \in B$; B —values $\{0, 1\}$.

However, in this context the primary role is played not by information functions but by computation functions [36]. It should be clarified that the information functions of any information model are descriptive functions [32,36]. The term information language denotes a class of artificial formal languages that perform descriptive functions. The predicate language [30,31,37] belongs to the domain of informational formalization of process models (mathematical logic). Characteristic of mathematical logic is the use of formal languages with syntax and semantics that unambiguously determine the understanding of logical expressions and formulae. In mathematical logic, two languages exist, reflecting two variants of formal logic: propositional algebra and predicate calculus. Propositional variables, logical operators, and brackets constitute the alphabet of the propositional algebra language. The alphabet of the propositional algebra language may be regarded as zero-level information units, analogous to alphabet symbols in natural language. In the predicate language, information units include the universal quantifier and the existential quantifier. The syntax of the predicate language relative to the propositional language is extended by two axioms, namely, the generalization axiom and the existence axiom.

The generalization axiom:

$$\forall x A(x) \rightarrow A(t). \quad (2)$$

Its meaning: if a certain property A holds for all objects x , then it also holds for any particular object t from the subject domain.

The existence axiom:

$$A(t) \rightarrow \exists x A(x). \quad (3)$$

The meaning of the existence axiom is as follows: if property A holds for some particular object t , then there exists at least one object x for which this property is satisfied.

In expressions (2) and (3), x is a bound variable, and t is a free variable. By means of zero-level information units, various logical formulae can be constructed. The advantage of the predicate language over the propositional language is that it can express properties of an argument or relations between arguments.

Predicate formulae generalize the concept of propositional formulae. The concept of predicate languages is centered on the so-called “domain” [31,32], which includes collections of “objects,” their “properties,” and “relations.” The predicate language describes this domain and its content. This approach constitutes the basis for language definition and the basis for selecting axioms and inference rules.

For the informational integration of different data models, it is necessary to present the conceptual apparatus for describing the subject domain—which encompasses all integrated models—and to classify all types of functional dependencies between data. The DSS represents a collection of corporate databases, where each database is regarded as a collection of information models (schemas) required to support the operation of application programs.

For the conceptual representation of data, the integrated database (IDB) constitutes the general information model of the subject set. The levels of conceptualization are presented in Figure 3.

At the first level, multilevel object representation formalizes the process of defining and integrating information objects. There exists a process of integrating elements that may in turn constitute a hierarchical structure or a class. The concept of abstraction is introduced for the representation and formalization of modeling objects: aggregation, generalization, and identity. The result (Figure 9) is a diagram of integration across different levels.

Predicate constants constitute the most important information units of the language (sometimes termed predicate letters)—these are names or symbols denoting specific prop-

erties or relations between objects of the “domain.” Thus, the specification of the “predicate language” includes the following concepts:

$$P_j^{il,i} 2^{i \dots i} \{x_1^i, x_2^i, \dots, x_n^i\} \in N^j, \quad (4)$$

where P_j is a predicate variable with index j , which identifies a specific relation or property, il (intuitionistic logic) is an upper-register index indicating that the predicate is defined within an intuitionistic (constructive) logical system, and i is the type of the subject domain. The letter i as a superscript accompanying variable ($x_1^i, x_2^i, \dots$) indicates that all arguments belong to this type. Here, $2^{i \dots i}$ are unary arity indices indicating the arity of the predicate. In expression (4), the construction represents an n -ary predicate accepting n arguments. N^j is a membership marker denoting belonging to the syntactic class of formulae of Gentzen's natural deduction calculus for intuitionistic logic.

The formation of the structural scheme of the predicate is performed on the alphabet U :

$$U = \{U_1, U_2, U_3, U_4, U_5, U_6\}, \quad (5)$$

where:

$U_1 = \{x^i, y^i, z^i, \dots, x_1^i, y_1^i, z_1^i\}$ —subject variables of different sorts;

$U_2 = \{a^i, b^i, c^i, \dots, a_1^i, b_1^i, c_1^i\}$ —subject constants of different sorts;

$U_3 = \{P_j^{i_1, i_2, \dots, i_n}\}$ —predicate symbols with a fixed signature;

$U_4 = \{=, \neq, \geq, >, <, \leq\}$ —comparison symbols;

$U_5 = \{\forall, \exists, \vee, \wedge, \neg\}$ —quantifiers and logical connectives;

$U_6 = \{., (,), ;\}$ —auxiliary symbols.

Object variables: The first types of information units of the language are variable objects (also termed object variables or simply variables).

An unlimited number may be used: $x, y, z, \dots, x_p, y_p, z_p$.

The domain mentioned above represents the presumed range of all these information units.

Object constants: The next type of information unit consists of object constants (also termed individual constants, constant letters, or simply constants). These are names or symbols denoting specific objects of the domain.

Functional constants: Another type of information units consists of functional constants [31] (also termed function letters)—names or symbols denoting specific functions, i.e., mappings between domain objects or operations on these objects. They are referred to as logical operators or connectives.

The methodology for modeling the subject set (global conceptual schema) for multi-modal transport and logistics companies comprises two stages:

- Construction of the semantic model of the set by identifying vertices (classes for different transport modes) and reflecting their relations as binary and N -ary.
- Representation of classes and their linkages in the basic and characteristic constructs (DDL) of the database (Figure 7). The diagram (Figure 4) presents the sequence of actions describing the information model of elements and their relations within the design domain for the coordination of maritime and railway transportation.

The following concepts are introduced in the presented semantic model:

- Vertex concepts (domains).
- Phenomena.
- Characteristics.
- Values.
- Class vertices.

- Assertion arc—an arc (relation) between two concepts.
- Generation arc—an arc between a concept and a class.
- Binary arc—an N -ary relation (arc between two classes).

These relations are represented by predicates. The linkage between predicates and their arguments is reflected by role arcs.

For the corporate database of a multimodal transport and logistics company, the signature G (the set of operations, predicates, and relations accepted in the given model) varies as follows:

$$G = \langle U_1, U_2, U_3 \rangle. \quad (6)$$

The complete decoding and analytical description of each component of this signature is as follows:

1. U_1 is the set of base domains (DB). It defines the entity types (carriers of the logical model) for maritime and railway transport:

$$U_1 = \{D_{sea}, D_{rail}, D_{cargo}, D_{hub}, D_{time}, \dots\}, \quad (7)$$

where D_{sea} —names/identifiers of vessels, shipping lines, and container carriers; D_{rail} —train numbers, wagon types, and railway codes; D_{cargo} —cargo types (liquid bulk, dry bulk, and ISO containers); D_{hub} —multimodal terminals, ports, and railway marshalling stations; D_{time} —arrival/departure timestamps and time windows.

2. U_2 is the set of functions and inter-transport relations. It contains operations and mapping functions that link the domains of U_1 to one another (for example, the transfer of cargo from sea to rail):

$$U_2 = \{f_{transship}, f_{route}, \dots\}, \quad (8)$$

where $f_{transship}$ is a function for computing the transshipment time of cargo from vessel to train at a specific hub:

$$f_{transship} : D_{sea} \times D_{rail} \times D_{hub}. \quad (9)$$

f_{route} —computation of the distance or cost of an intermodal leg:

$$f_{route} : D_{hub} \times D_{hub} \rightarrow \mathbf{R}^+. \quad (10)$$

3. U_3 is the set of predicate symbols for multimodal operations. It defines predicates (logical conditions and constraints) that accept elements from the domains and return Boolean values $\{0, 1\}$ describing the state of the logistics chain:

$$U_3 = \{P_{compatible}, P_{available}, P_{connect}, \dots\}, \quad (11)$$

where $P_{compatible} \in D_{cargo} \times D_{rail}$ —a compatibility predicate: $P_{compatible}(c, r) = 1$, if cargo c can be loaded into wagon r without restriction; $P_{available} \in D_{hub} \times D_{time}$ —a terminal availability predicate: true if the hub is ready to receive a multimodal flow at the specified time; $P_{connect} \in D_{sea} \times D_{rail} \times D_{hub}$ —a coupling predicate: true if the rolling stock arrives in time for the unloading of the maritime vessel at the port.

The global optimization objective function based on the criterion of total cost (C_{total}) minimization takes the following form:

$$C_{total} = \sum_{i \in M} (C_{trans}^i \cdot x_i) + \sum_{i \in H} C_{hub}^j + C_{penalty} \cdot \Delta T \rightarrow \min, \quad (12)$$

where C_{trans}^i —transportation costs by transport mode;

C_{hub}^j —transshipment and storage costs at node j ;

$C_{penalty}$ —penalty for deviation from the delivery time window ΔT .

The principal system constraints are as follows:

- Time constraint: $\sum T_{trans}^i + \sum T_{hub}^j \leq T_{max}$ (maximum permissible delivery time).
- Cargo and rolling stock compatibility: $(P_{compatible}(c, r) = 1)$.
- Terminal throughput capacity: $(V_{flow} \leq V_{max}^{hub})$.

In the proposed methodology, the total costs principle is applied as a conceptual decision-making criterion for the design of the decision support system, rather than as a fully formalized mathematical optimization model.

Accounting for types (arities and sorts), the complete signature of the corporate multimodal database is expressed through the Cartesian products of domains:

$$G = \langle \{D_k\}_{k \in K}, \{f_m: D_{m1} \times \dots \times D_{mn} \rightarrow D_{mr}\}, \{P_j: D_{j1} \times \dots \times D_{jn}\} \rangle, \quad (13)$$

where $\{D_k\}$ —base domains from U_1 ; $\{f_m\}$ —transformation and mapping operations for transport flows from U_2 ; $\{P_j\}$ —multimodal logistics predicates for condition verification from U_3 .

The predicate language [28,30,37] belongs to the domain of mathematical logic. Characteristic of mathematical logic is the use of formal languages with syntax and semantics that unambiguously determine the understanding of logical expressions and formulae. In mathematical logic, two languages exist, reflecting two variants of formal logic: propositional algebra and predicate calculus.

Propositional variables, logical operators, and brackets constitute the alphabet of the propositional algebra language. The alphabet of the propositional algebra language may be regarded as zero-level information units, analogous to alphabet symbols in natural language. In the predicate language, information units include the universal quantifier and the existential quantifier. The syntax of the predicate language relative to the propositional language is extended by the two axioms, (2) and (3). In expressions (2) and (3), x is a bound variable, and t is a free variable. By means of zero-level information units, various logical formulae can be constructed. The advantage of the predicate language over the propositional language is that it can express properties of an argument or relations between arguments.

Predicate formulae generalize the concept of propositional formulae. The concept of predicate languages is centered on the so-called “domain” [31,32], which includes collections of “objects,” their “properties,” and “relations.” The predicate language describes this domain and its content. This approach constitutes the basis for language definition and the basis for selecting axioms and inference rules.

A predicate signature S includes at least one predicate constant and contains none of the following symbols:

- Object variables $x, y, z, x_1, y_1, z_1, \dots, x_n, y_n, z_n, \dots$
- Propositional connectives.
- The universal quantifier $\forall$ and the existential quantifier $\exists$.
- Brackets and comma.

The alphabet of predicate logic consists of elements of S and four groups of the additional symbols indicated above. A string is a finite sequence of symbols from this alphabet. In theory, basic information units as logical units link data to the constructed logical, info logical, or data logical structure of the database [33,35,49,50].

In graph theory, information units (arcs and vertices) are used to construct the structure of a graph, to search for solutions on a graph, and to verify the logic of actions on a

graph. Accordingly, the CIS (database integration model) may be regarded as a predicate signature G .

The study employs the definition of the conceptual database schema for multimodal transport and logistics companies as [49,50]:

$$\langle L_u, G, A, Inf \rangle, \quad (14)$$

where L_u —the formal language of the alphabet, based on many-sorted predicate calculus (calculus of variables on the domains of maritime and railway transportation); G —the signature of the language L_u , of the given database schema for different transport modes; A —formulae of the language L_u (axiom system); Inf —the collection of statement formation rules and the output format.

This approach represents the database as a model $B[D, R]$. A query to the database is represented as a formula A of the language L_u with the signature G and free variables from the set $i \dots j$ [35]:

$$A(x_1, x_2, \dots, x_n) \rightarrow L_u, G, \quad (15)$$

where $x_1, x_2, \dots, x_n$ are free variables from the set $i \dots j$ representing the query parameters of the multimodal transport and logistics database.

To demonstrate the practical interpretation of the predicate logic presented above, consider a multimodal transportation order involving railway and maritime transport. The client submits a transportation request (Order), whereupon the decision support system verifies carrier availability, terminal throughput capacity, transportation schedules, and route feasibility. On the basis of these predicates, the system identifies viable transportation alternatives and recommends the most suitable multimodal route in accordance with predefined operational criteria.

A step-by-step algorithm for the digital transformation of the subject set of multimodal transport and logistics companies into the conceptual, logical, and physical representation of database data has been formalized and provided (Figure 7). For the information integration of different data models on maritime and railway transportation, a conceptual apparatus for describing the subject set—which encompasses all integrated models and their classes—has been presented. The types of functional linkages between data classes of different transport modes have been identified.

The CIS has been constructed with the integration of a decision-making and support system for ensuring the operational activities of a multimodal transport and logistics company engaged in maritime and railway transportation. A new approach to the use of contemporary information technologies for the effective management of a transport and logistics company and the coordination of different transport modes has been presented. An information management and planning system for a multimodal transport company has been designed.

4.3. Integration of the Decision Support System into the Corporate Information System

The structure of the decision-making and support system for managing the operational activities of a multimodal transport and logistics company engaged in maritime and railway transportation has been constructed and developed.

A methodology is presented for the formation and application of specialized models for the resolution of business problems, and analytical tools for formalizing the operations of the fleet and rolling stock of a multimodal transport and logistics company (Figure 9). These models take tabular (matrix), mathematical, or graphical form. The use of a model base substantially distinguishes DSSs from reporting information systems. The model base for DSSs is a specially organized set of mathematical models (general-purpose and specific) [21,37].

Some of the presented models support computations, for example, single-factor and multi-factor models representing relationships among multiple variables, such as multiple regression models, the general linear programming problem, extrapolation, and cluster analysis. The database organization provides a unified environment for storing corporate data in structures optimized for the execution of analytical operations. Analytical tools enable the end user, who possesses no specialized knowledge in the field of information technologies, to navigate and present data in the terms of the subject domain.

Based on the results of this section of the research, the structure of the decision-making and support system for managing the operational activities of a multimodal transport and logistics company engaged in maritime and railway transportation has been constructed. The DSS is integrated into the unified corporate information management and planning system of the multimodal transport company ERP system. Based on contemporary computer technologies, a generation of management systems has been created, referred to as ERP. In Ukraine, its analog is the corporate information system (CIS). This is an IT-based integrated system for managing the internal and external resources of an enterprise. The application of the CIS and DSS enables the use of a single integrated program in place of several disparate systems (Figure 10).

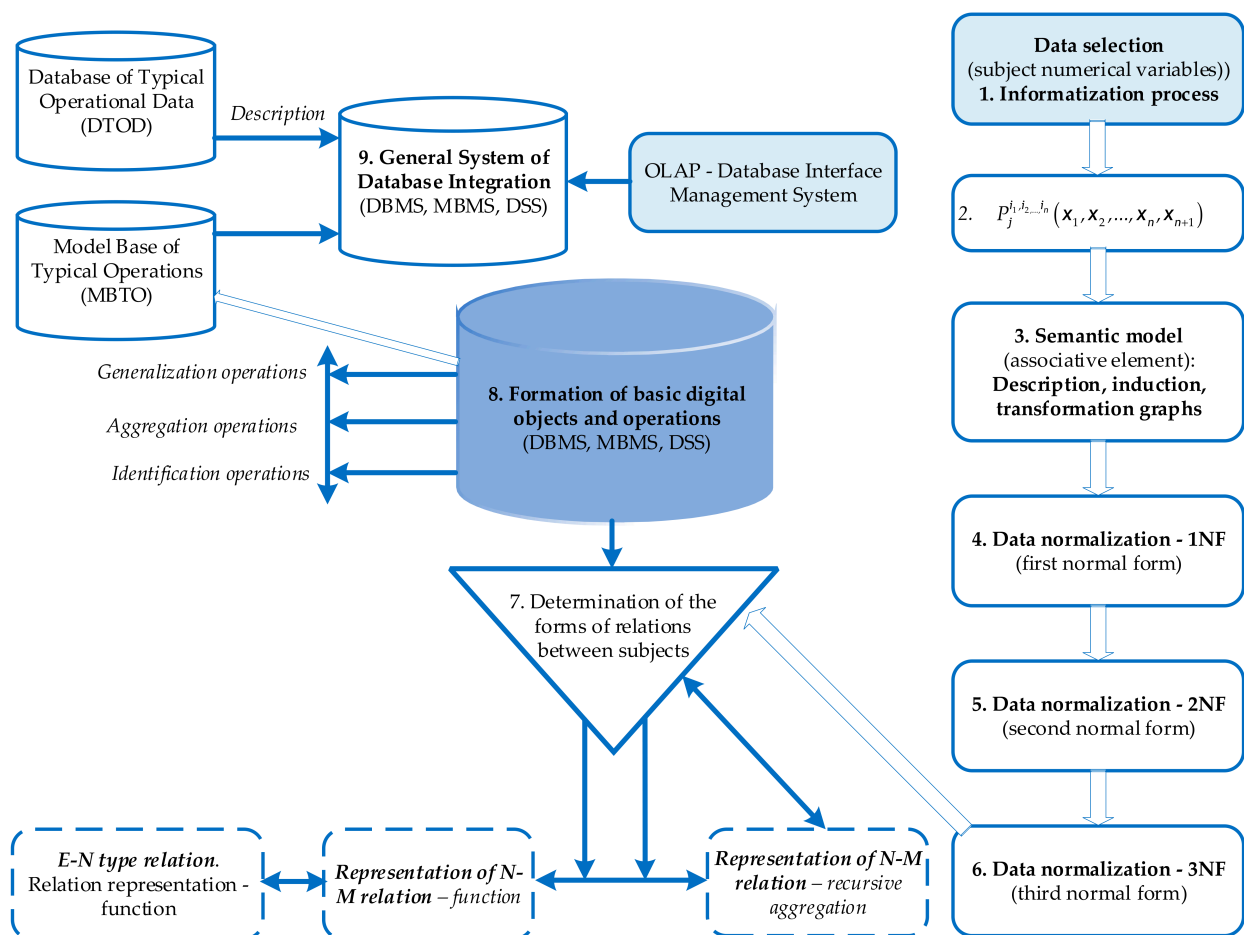


Figure 10. Step-by-step algorithm for the digital transformation of the subject set into the conceptual, logical, and physical representation of the corporate database [1,35,36].

The CIS and its modules can manage processing, logistics, distribution, inventory, delivery, invoicing, and accounting [50]. The structure of the customer relationship management (CRM) module has been developed. The CRM concept is used to substantiate a new approach to the application of contemporary information technologies, enabling the ef-

fective management of a multimodal transport and logistics company and the coordination of client interactions in the execution of maritime and railway transportation. This concept offers a distinctive pathway for attaining and maintaining a strong competitive position.

Such systems enable operation within an integrated information field accessible to a multitude of remote users, ensuring maximum effect in the management of large-scale productions and corporations [36].

The data warehouse is a data bank of a specific structure containing information on the transport processes of a multimodal transport and logistics company, including data on maritime and railway transportation and intermodal operations.

The primary purpose of the database is to ensure the rapid execution of formulated analytical queries.

On-line analytical processing (OLAP) serves as a tool for the analysis of large data volumes in real time. By interacting with the OLAP system, the user can perform flexible information review, obtain arbitrary data segments, and execute analytical operations of drill-down, roll-up, cross-sectional distribution, and time-based comparison. All work with the OLAP system is carried out in terms of the subject domain.

The database architecture of the multimodal transport and logistics company is constructed on the principle of dividing data into three principal blocks: maritime transport, railway transport, and intermodal operations. The maritime transport block contains information on vessels, ports, maritime routes, and container transportation. The railway transport block includes data on rolling stock, railway stations, train movement schedules, and track infrastructure. The intermodal operations block provides the linkage between the first two blocks through data on transport nodes, transshipment points, and the synchronization of arrival and departure of vehicles of different types.

The DSS implements a complex of analytical functions for multimodal transportation. The tariffication module accounts for the specific characteristics of each transport mode, seasonal demand fluctuations, and the competitive environment. Route optimization is based on multi-criteria analysis of cost, time, and delivery reliability. The system automatically generates alternative variants with different proportions of maritime and railway segments, enabling the selection of an optimal solution depending on client priorities.

The calculation of vehicle performance indicators includes an analysis of vessel and wagon capacity utilization coefficients, average delivery speed, rolling stock turnover time, and the economic efficiency of each transport unit's operation.

The design of optimal intermodal routes with minimization of transshipment time is based on mathematical models that account for the throughput capacity of transport nodes, arrival and departure schedules of vehicles of different types, and technological standards for transshipment operations.

Transport node management involves the optimization of transshipment resource allocation among different clients, forecasting of port and railway station load, planning of the vehicle service sequence, and minimization of idle time during transshipment.

The proposed decision support system provides analytical support for addressing optimization tasks related to route planning, tariff calculation, transport node management, and resource allocation. Within the proposed methodology, these optimization tasks are addressed at the conceptual level. The selection of specific mathematical models, objective functions, operational constraints, and optimization algorithms depends on the practical implementation of the system and falls outside the scope of the present study.

Cargo movement monitoring in multimodal supply chains ensures tracking of transport units at all delivery stages, forecasting of arrival times accounting for current delays, automatic client notification of schedule changes, and generation of recommendations for operative route adjustments upon the occurrence of deviations.

Client classification based on CRM technologies enables the identification of the most profitable client categories for the proposed vehicles and the existing service portfolio of the multimodal transport and logistics company [36,37].

The presented system enables the resolution of the tasks formulated above. CRM technology substantially enhances the effectiveness of marketing planning by ensuring automatic information collection and maximum utilization of all data sources—primarily regarding existing and potential clients. Furthermore, CRM technology presupposes the availability of analytical tools, enabling the prompt and informed adoption of strategic decisions. The effectiveness of CRM application is inextricably linked to the resolution of strategic business objectives; consequently, the primary emphasis is to be directed at the company's actual business processes. The company's approach to effective client relationship management implies the encompassing of all business processes that combine both operational and analytical client interaction procedures.

The proposed solution (Figure 11) is constructed on the principle of end-to-end automation of information flows and is based on the interaction of several key segments. The primary system element "Client Order" simultaneously initiates the recording of information in the "Clients Database" and directs an analytical data set to the "CIS OLAP Technology" block for subsequent multidimensional analysis of operational indicators in real time. The central DSS information corpus is divided into a collection of specialized databases that accumulate data on documents, cargo and service nomenclature, transport modes and information messages, operational procedures, and specific characteristics of maritime, railway, and road transport, ports, and distances between logistics nodes. The link between the client base and the analytical core of the platform is provided by the transportation conditions formation module, which interacts with the "model base," containing a complex of mathematical, statistical, and optimization algorithms for calculating delivery parameters. Based on the processing of data from specialized repositories and CIS OLAP, three foundational decision support calculation modules operate—the first of which is the optimal route and port determination module, which performs direct spatial–technological optimization of the delivery chain. Legal and financial process support is automated within the contract, invoice, and payment determination module, while cost calculation and pricing are implemented through the tariff, freight rate, and performance indicator calculation module.

Figure 11 illustrates the logical sequence of decision-making performed by the decision support system. The input information comprises transportation requests, available routes, tariffs, and operational constraints. The DSS analyzes these data and generates recommendations regarding route selection, carrier assignment, and transportation scheduling.

The results of these modules are integrated with the "CRM Module" and forwarded to the "Accounting Database" subsystem. The final closure of information and financial flows occurs in the central repository "CIS Integrated Operational Information Database," which serves as the single source for generating the final analytical block "Reports and Information" for the company's management. Thus, the proposed integration scheme enables the replacement of local calculations with a unified information space and ensures the automatic transition from the moment of order registration to the generation of summary reporting. The result of the research is the structure of a modern CIS and an integrated DSS for the effective operation of multimodal transport and logistics company managers in different market regions, enabling the determination of tariff rates for different transport modes, the optimization of multimodal routes, the calculation of transportation volumes, the selection of optimal transport nodes and transshipment points, the management of the service portfolio, the coordination of client interactions, and the forecasting of intermodal transportation sales volumes and profitability.

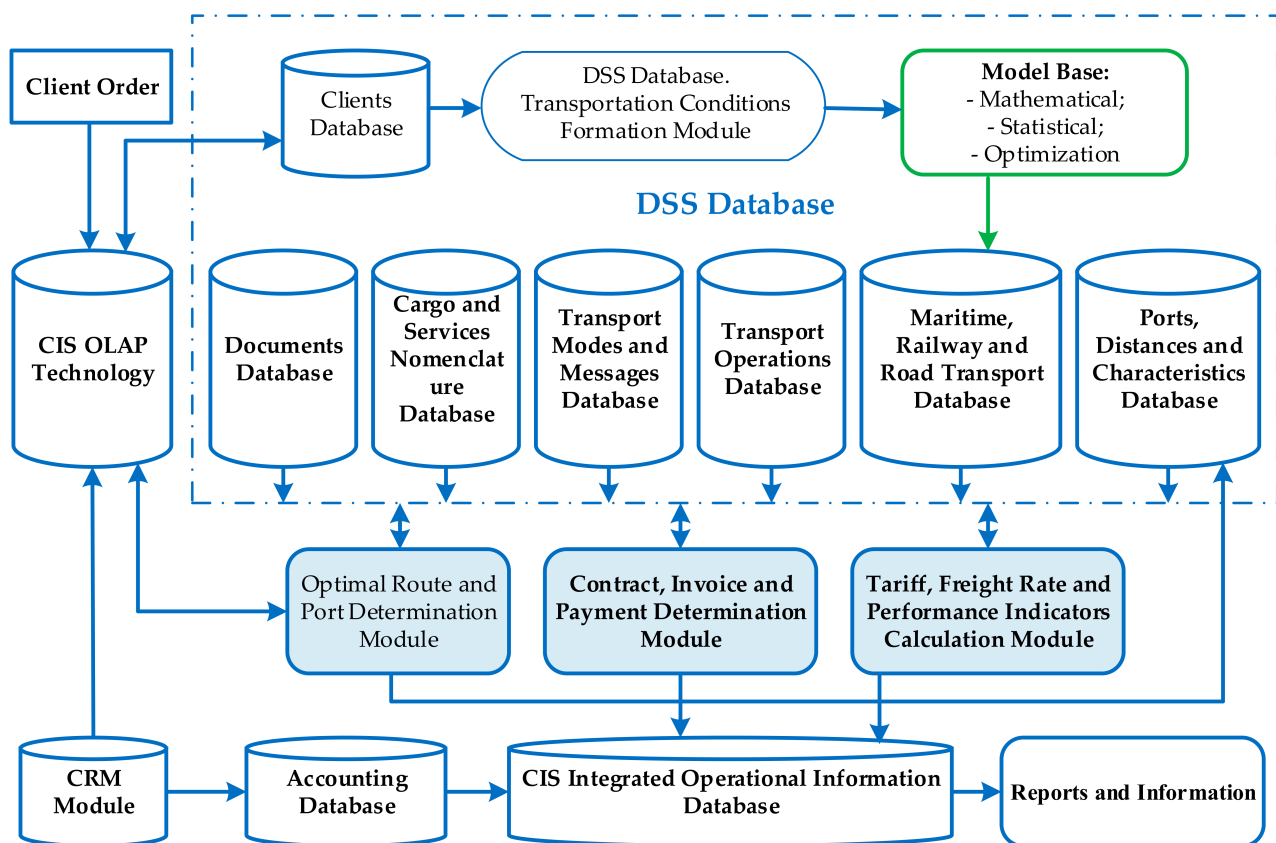


Figure 11. Scheme of integration of the decision support system into the corporate information management and planning system of a multimodal transport and logistics company [1,35,36].

5. Discussion of Results

Digital transformation enables the implementation of corporate information systems (CISs) as a mechanism for the effective realization of new management methods. To achieve the research objectives, an analysis was conducted of existing methodological and practical foundations of digital transformation as an instrument of information modeling.

Based on the results of the analysis, it was established that methodological and scientific foundations for the construction of a unified transport process management system—oriented toward the specific characteristics of multimodal transport and logistics companies engaged in maritime and railway transportation—are absent.

Contemporary work lacks a unified methodological approach to the design of corporate information systems. In the practical domain, there is an absence of a methodology for implementing the technology for constructing a CIS (ERP), and for creating, on this basis, data management systems (the DSS) for different user conditions [49].

Accordingly, it is timely to execute the project of constructing a unified structure (information and physical models) of the management system for the operations of a multimodal transport and logistics company (database). The design of this unified data warehouse—the database—ensures sustainable business development in the face of dynamic environmental change.

The presentation of a methodology for conducting digital transformation as an instrument of information modeling and for constructing a corporate information system in the management of multimodal transport and logistics companies may constitute an option for overcoming the difficulties associated with operative and strategic management and analysis. The implementation of the CIS and DSS, as an integral component, ensures

competitiveness and sustainable business development given the dynamic nature of the operating environment.

The result of the research is a step-by-step methodology for constructing an information management and planning system for a multimodal transport company within the structure of a standard CIS (Figure 10). This is an IT-based integrated system for managing the internal and external resources of an enterprise. The integrated information database system for multimodal transport and logistics enterprises enables, in the practical domain (Figure 10):

1. Forecasting, operation, and analysis of transport and logistics activities. Effective and rapid implementation of the decisions embedded therein.
2. Investigation of system dynamics. The possibility exists of applying a broad palette of contemporary instrumental tools for system modeling and design.
3. The application of the CIS enables the use of a single integrated program in place of several disparate systems [1,30,36,50]. A unified integrated system capable of managing processing, logistics, distribution, inventory, delivery, invoicing, and accounting (Figure 10).
4. Digital transformation enhances the company's competitiveness through prompt access to the database (Figure 9). The presented enterprise information management system—the CIS—consists of the following elements: data warehouse architecture, including storage structures and management process models, databases and model bases (Figure 9), and the model for managing and analyzing information flows for the enterprise (Figure 10).
5. Statistical analysis tools for “data mining” are provided for the selection of software products suited to the architecture and requirements of the client by means of the corporate database as a unified information storage environment.

The access differentiation system implemented in the CIS, deployed jointly with CRM systems, is aimed at maximizing the satisfaction of companies' business management tool requirements. The scope of the research does not permit the presentation of complete database models for financial and accounting sections pertaining to multimodal transportation. Likewise, detailed structures of the model base for the operational activities of the transport fleet and rolling stock are not presented. The database and data model for passenger transportation by maritime and railway transport require further development.

The development of this research consists of the design of a contemporary DSS applied in marketing research and assisting managers of multimodal transport and logistics companies in constructing a market operations map, determining tariff rates for different transport modes, optimizing the proportion of maritime and railway route segments, calculating transportation volumes, investigating operating regions, selecting optimal transport nodes and transshipment points, identifying promotion channels, analyzing the impact of marketing measures, and managing the service portfolio for different transport modes. The DSS can forecast sales volumes and profitability of multimodal transportation.

The indicated directions will be developed in subsequent works, which will present the following:

- DSS for managing cruise fleet and passenger railway transport operations.
- Systems for forecasting multimodal transportation volumes for determining the critical profitability threshold.
- Models for optimizing transport nodes and transshipment points between transport modes.
- Statistical analysis tools for data mining and selection of software products suited to the architecture and requirements of the client.

The quantitative improvements cited in this study are drawn from previously published research on the implementation of corporate information systems and decision support systems in transport and logistics. These figures are presented as comparative reference values demonstrating the potential benefits of digital integration. The quantitative evaluation of the proposed corporate information system and decision support system will be conducted at the next stage of the research, following the development of a software prototype and its experimental validation.

6. Conclusions

This paper proposes a methodology for the design of corporate information systems with integrated decision support for transport and logistics companies.

The analysis conducted revealed the absence of a unified methodological approach to the design of corporate information systems for multimodal transport and logistics companies. It is proposed that the development of a unified corporate information system be guided by the principle of “total costs,” which requires that the decision-maker—when selecting transport modes, methods of transportation, carriers, routing, and auxiliary intermediaries (insurer, stevedore, bank, and customs broker)—address the problem as an integrated whole. To achieve the research objective, the following tasks were accomplished:

1. Information modeling of the business processes of multimodal transport and logistics companies was conducted.
2. An optimal model of the transport process for maritime and railway transportation was constructed using IDEF (integrated computer automated manufacturing definition) and SADT modeling.
3. A multilevel unified database structure for the coordination of different transport modes was designed.
4. A decision-making and support system for managing the operational activities of a multimodal transport and logistics company engaged in maritime and railway transportation was developed.

The proposed methodology at the current stage constitutes a conceptual design. A limitation of the study is the absence of industrial verification, which necessitates the conduct of further simulation experiments for the qualitative evaluation of decision-making by means of the developed DSS.

Future research will focus on the implementation of the proposed corporate information system and decision support system as a software prototype, with subsequent quantitative assessment and validation based on real-world operational data from multimodal transport and logistics enterprises.

A further promising direction for future research is the sensitivity analysis of the proposed DSS under varying tariff scenarios and freight market conditions.

Particular attention will be devoted to simulation modeling, experimental performance evaluation, and comparative analysis with existing information systems for the precise measurement of transportation costs, overall operational efficiency, and decision-making quality. Another important direction for future research is the adaptation and extension of the proposed methodology to the passenger transportation sector, specifically for the management of passenger railway and maritime transport operations, including cruise services. Further research will also focus on the development of specialized mathematical models, including objective functions and forecasting of multimodal freight and passenger transportation volumes, enabling transport and logistics companies to determine profitability thresholds with greater precision.

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Abbreviations

The following abbreviations are used in this manuscript:

IDEF	Integrated Computer Automated Manufacturing Definition
SADT	Structured Analysis and Design Technique
CIS	Corporate Information System
CAGR	Compound Annual Growth Rate
IoT	Internet of Things
GAIN	Global Analysis and Information Network
RDX	Rail Data Exchange
ERTMS	European Railway Traffic Management System
ETCS	European Train Control System
ERP	Enterprise Resource Planning
IDEF0	Function Modeling Method
IDEF1	Information Modeling Method
IDEF2	Dynamic Modeling Method
DDL	Data Description Language
DML	Data Manipulation Language
DB	Database
DBMS	Database Management System
MBMS	Model Base Management System
IDB	Integrated Database
CRM	Customer Relationship Management
OLAP	On-Line Analytical Processing

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