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IMPROVING PROCESS MANAGEMENT IN CONTAINER TERMINALS THROUGH MODELING

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Abstract: *Container terminal operations are vital for global supply chain efficiency. As container volumes grow, process optimization becomes crucial. While current research emphasizes simulation, machine learning, and lean management, structured methodologies like IDEF0 are less applied. This paper uses IDEF0 to model and analyze key operations as container handling or vessel loading/unloading, identifying inefficiencies such as idle times and poor equipment use. It highlights the importance of automation, digitalization, and improved scheduling. The findings support the development of better Terminal Operating Systems, enhance real-time decisions, and promote port sustainability. The study offers a replicable framework and practical insights for boosting terminal productivity and competitiveness.*
Key words: *Container terminal operations, IDEF0 modeling, process optimization, continuous improvement.*

1. INTRODUCTION

The efficiency of container terminal operations plays an important role in the performance of global supply chains, influencing cargo throughput, port congestion, and overall logistics costs. As international trade volumes continue to rise, terminals face increasing pressure to optimize their operational processes to maintain competitiveness and service quality. Traditionally, research in this field has focused on simulation models, machine learning techniques, and lean management practices to identify and address inefficiencies. However, there has been limited exploration of structured process modeling methodologies within this context.

This paper addresses this gap by introducing the Integration Definition for Function Modeling (IDEF0) as a systematic tool for analyzing and improving container terminal operations. By applying IDEF0 to critical processes such as container handling, vessel operations, yard management or intermodal transport coordination, we aim to uncover operational bottlenecks, enhance resource utilization, and support real-time decision-making. Furthermore, we explore the role of automation and digitalization in modern terminal management, offering insights that can contribute to the development of more sustainable and efficient port operations.

This paper introduces IDEF0 as a structured modelling tool to address inefficiencies in container terminal operations, offering a systematic alternative to traditional simulation approaches and highlighting its potential for integrating automation, optimization, and sustainable process improvements.

2. PROBLEM DESCRIPTION

Ports are inherently multifunctional entities, often comprising several specialized terminals, each dedicated to handling specific types of cargo such as containers, grains, oil, or iron ore [1]. While previous studies have examined general categories of terminal operator processes across various terminal types, this paper focuses specifically on container terminal operators. Given that each terminal type is characterized by distinct designs, equipment, and operational processes tailored to the cargo it serves, it is essential to narrow the research scope to container terminals for a more precise analysis.

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The advent of containerization transformed maritime transport, making cargo handling more efficient and cost-effective. Originating in the early 20th century and revolutionized by Malcom McLean's invention of the intermodal shipping container in the 1950s [2], containerization enabled seamless transfer between trucks, trains, and ships without unpacking cargo at each transfer point. Today, containers are used for transporting 90% of non-bulk global cargo, underlining their central role in facilitating international trade.

The emergence of container terminals in the 1960s led to substantial changes in port infrastructure, particularly due to the large land areas required for short-term container storage. Many early container terminals were created by repurposing general cargo terminals, leading to a variety of configurations and operational challenges. The lack of available space in many ports necessitated the development of new terminal facilities, providing opportunities for innovation in terminal design.

Handling millions of containers annually while minimizing vessel turnaround times places considerable operational demands on container terminals. Terminal operators are increasingly seeking new technologies and methodologies to boost efficiency, expand capacity, and reduce social and environmental impacts. Despite limited changes in basic terminal layouts over recent decades, next-generation terminal designs are seen as a promising pathway to achieving these goals [3].

Today, container terminals are critical nodes in global supply chains, linking maritime and inland transport networks. However, they must navigate the complex and sometimes conflicting demands of stakeholders such as ship owners, shipping lines, freight forwarders, importers, exporters, dockworkers, and government agencies. Balancing efficiency, profitability, and stakeholder interests presents an ongoing challenge for terminal operators in an increasingly globalized trade environment.

The container terminal operator is a port organization, and like any organization, it carries out at least four main categories of processes. These can be classified as follows: management or strategic processes, operational or core processes (directly related to delivering products or services), support processes (which facilitate the execution of central activities), and evaluation and improvement processes (focused on ensuring customer satisfaction through monitoring, measurement, analysis, and evaluation). This categorization aligns with the ISO 9001:2015 standard.

The main activities specific to container terminal operators include loading and unloading containers, handling them with cranes and specialized equipment, and managing containers carrying special cargo. Additionally, container terminals are responsible for the temporary storage of containers and their intermodal transfer. Based on these core activities, the specific operational processes of the port organization can be further defined and analyzed.

While global container throughput has grown dramatically over the past decades, recent years have brought operational challenges such as system inefficiencies, resource-intensive processes, and heightened environmental concerns. Traditional terminal operations often lack integration, suffer from delays, and are heavily dependent on manual labor and fossil fuel-based equipment, resulting in high operational costs and a significant carbon footprint.

Moreover, the growing global emphasis on sustainability, reflected in environmental standards and Environmental, Social, and Governance (ESG) requirements, demands a strategic shift toward greener and more efficient practices. Despite advancements like semi-automation and data analytics, many terminals still struggle to effectively model, optimize, and coordinate complex workflows. There is a clear need for a structured methodology that can provide visibility into processes, enhance coordination among stakeholders, and support continuous improvement in performance, resource utilization, and environmental compliance.

3. ANALYSIS OF OPERATIONAL PROCESSES IN THE CONTAINER TERMINAL

The operational processes in a container terminal operator require complex planning of activities and the use of specialized equipment. In planning activities and defining and designing operational processes, it is necessary to take into account the types, sizes of containers, the terminal design, the available equipment and the traffic flow inside and outside the terminal. Good planning of these elements contributes to more efficient operation of the terminal and to prevent delays.

Within a container terminal, the primary activity is the movement of containers, while storage serves as a secondary function. These key missions can be divided into distinct categories [4]:

- Container handling – involves unloading a container, temporarily storing it at the terminal, and subsequently reloading it onto another mode of transport for further shipment.
- Direct transshipment – refers to the immediate transfer of a container from one mode of transport to another without intermediate storage.

At the terminal level, three essential types of activities are performed:

- Vessel-related services: unloading and loading vessels, direct transshipment, and securing containers on board.
- Yard-related services: handling full and empty containers, temporary storage, grouping, cleaning, maintenance, and repair of containers.
- Other services: container production, leasing/sales, collection and distribution, physical transportation of containers, monitoring, and other logistical support activities.

The core operational processes of a container terminal are represented by the first two service categories and can be classified into vessel-related operational processes and yard-related operational processes.

A process map outlines the key steps in a business or operational process, showing how different activities flow and interact to achieve a specific goal. For a container terminal operator, the process map focuses on the main tasks associated with managing container handling throughout the terminal. Key considerations for the process map:

- Capacity and efficiency: Such a flow chart can help identify bottlenecks in operations, such as delays in unloading or picking up containers, and ensure that the terminal is operating efficiently.
- Technology integration: Terminal management systems and automated guided vehicles can be part of the process map, managing container location tracking and automated container movement.
- Safety and compliance: Ensuring that safety checkpoints are part of the process (e.g., securing containers, managing traffic within the terminal).
- Resource allocation: In such a flow, it is important to take into account the use of equipment and the allocation of personnel (e.g. crane operators, truck drivers).
- The process map diagram helps to visualize and understand the flow of activities and resources within the terminal operations. It is an important tool for identifying and analyzing key processes, facilitating the management and improvement of the efficiency of operations.
- The diagram provides a clear view of the steps involved in each process, from unloading containers to loading them onto ships, including handling, storage and internal transport. This helps to understand the interdependence between the different processes. By analyzing the process map, areas where delays, redundancies or bottlenecks exist can be identified. This information allows for continuous improvement and reduction of waiting times or operational costs. The process map helps to clarify the roles and responsibilities of the different teams involved in the operation of the terminal (e.g. loading/unloading teams, internal transport, warehouse management), thus improving collaboration and communication (Figure 1).

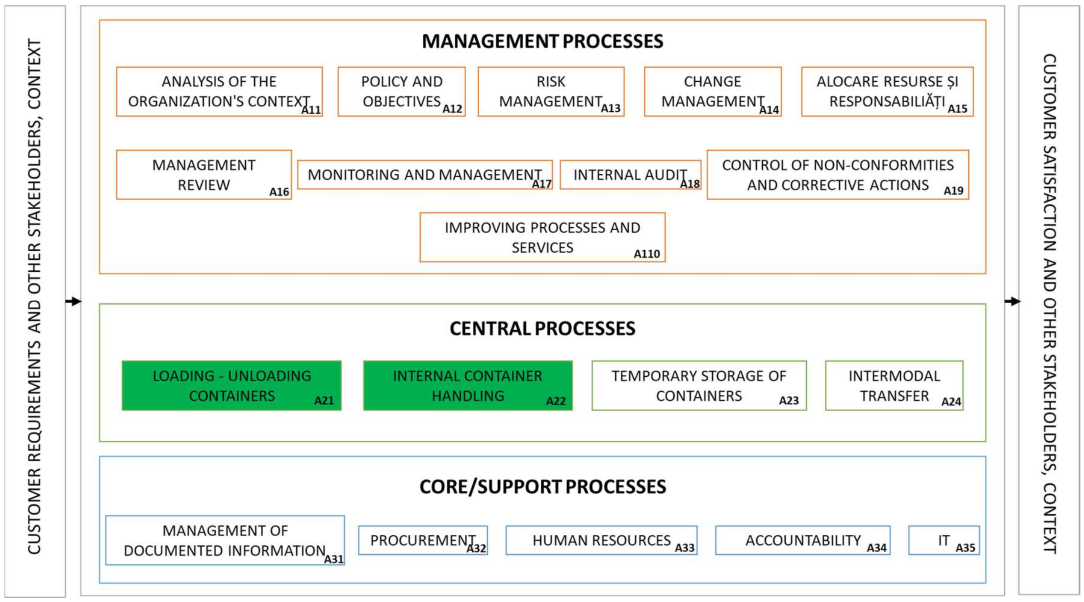

Fig. 1. Processes map in a container terminal operator

It can include performance indicators for each process, allowing for monitoring efficiency and the rapid identification of any deviations from established standards.

When implementing new technologies or practices, the process diagram helps to integrate them into existing flows, facilitating a smoother transition and reducing the risks of disruption to operations. By fully understanding the processes, managers and decision-makers can make informed decisions about the necessary investments, technological improvements or organizational changes to increase the efficiency and safety of the terminal.

4. METHODS USED

IDEF (Integrated Definition) is a graphical methodology for process modeling, initially developed by the U.S. Air Force in the mid-1970s. Originally designed for documenting and analyzing manufacturing systems, it has since evolved into a structured approach for enterprise analysis, process modeling, and software development.

One of the most widely used versions, IDEF0, breaks down a system into four levels of abstraction: context, decomposition, detailed, and implementation. Each level is represented through diagrams that illustrate system functions and their interactions. IDEF0 diagram includes six main elements: Function, Input, Output, Control, Mechanism, and Resource, providing a clear, structured view of how processes operate within a system (Figure 2).

Functions are shown as labeled boxes; arrows entering the left side represent inputs, those exiting the right indicate outputs, and arrows from above represent controls. Mechanisms, or the resources enabling each function, are shown from below [5].

To build an IDEF0 model, the system's purpose and boundaries are first defined, forming the context diagram. The main function is then decomposed into sub-functions (decomposition diagram), followed by a detailed breakdown with additional inputs, outputs, controls, and mechanisms (detailed diagram). Finally, the implementation level identifies the system's components and their interfaces.

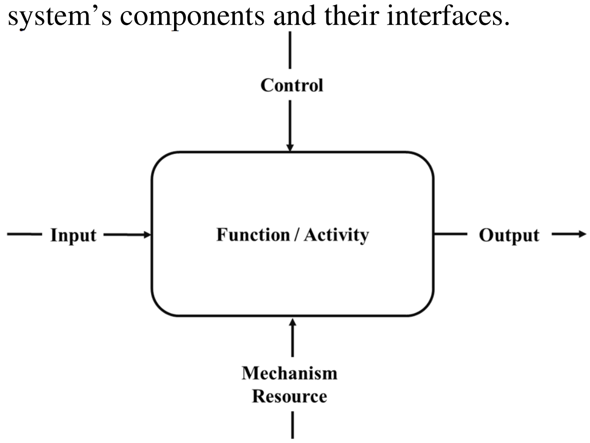

Fig. 2. IDEF0 representation [6]

In the context of the selected port organization, the container terminal, the application of the IDEF0 methodology to operational processes proves to be highly valuable. This modeling approach is particularly effective in clarifying functions and operations by breaking them down into distinct, manageable activities such as container unloading, temporary storage, loading, and dispatch tracking. Each of these can be treated as an individual function, allowing for a clearer understanding of the scope and interconnections between processes.

IDEF0 also helps define the key components of each process:

- Inputs: data, materials, or resources required (e.g., incoming cargo).
- Outputs: the results or products of a process (e.g., containers ready for shipment).
- Controls: rules and constraints that govern the process (e.g., safety standards, customs protocols).
- Mechanisms: tools and resources used to carry out the process (e.g., cranes, trucks, personnel).

By mapping these elements, the entire system can be visualized, showing how resources flow and how processes depend on one another throughout the terminal.

Another major advantage of IDEF0 is its ability to improve communication and coordination within the terminal's operations. By providing a visual representation of complex activities, it becomes easier for various stakeholders, such as port authorities, shipping companies, and cargo handlers—to align around a shared understanding of operational workflows.

Moreover, this structured modeling facilitates the identification of inefficiencies or bottlenecks. For instance, if container unloading is taking longer than expected, root causes such as equipment shortages, scheduling issues, or insufficient staffing can be analyzed.

IDEF0 also enables exploration of alternative process strategies, such as optimizing container storage layouts or improving loading/unloading sequences. This supports strategic decision-making aimed at boosting overall terminal performance.

Container terminals typically integrate multiple subsystems, including automated tracking tools, logistics management software, and physical handling equipment. IDEF0 aids in understanding how these elements interact, ensuring seamless integration between technology and human resources.

Applying IDEF0 to a container terminal provides a systematic, well-documented framework for organizing, visualizing, and enhancing operational processes. It allows both a high-level overview and detailed insights into the specific components necessary for efficient, coordinated terminal operations.

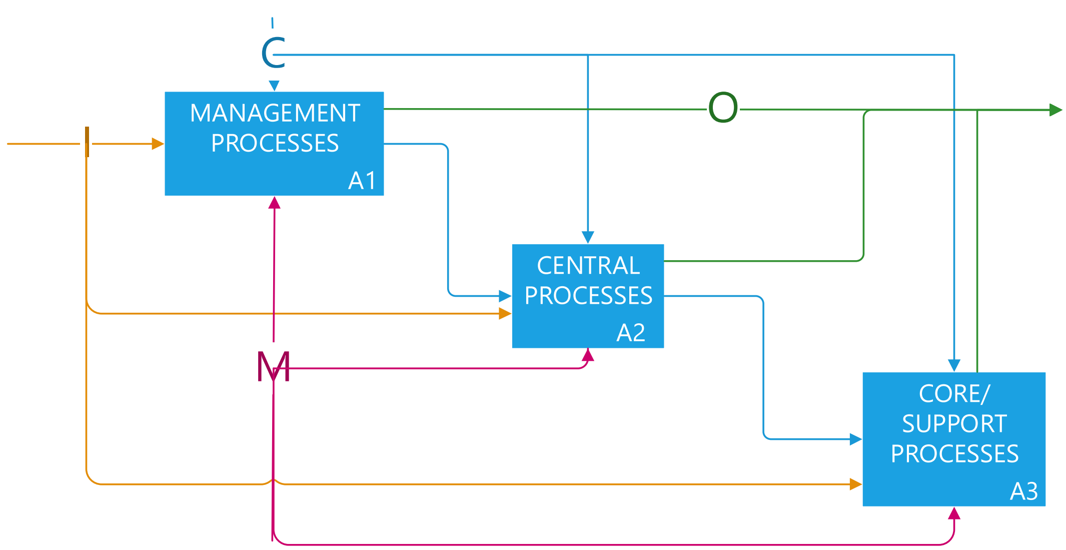

Fig. 3. Process map in a container terminal operator according to the IDEF 0 methodology

The process map diagram is a valuable tool for visualizing and understanding the flow of activities and resources within terminal operations. It plays a key role in identifying and analyzing critical processes (Figure 3), thereby supporting more effective management and operational efficiency.

This diagram provides a clear view of each step involved from container unloading to loading onto vessels covering handling, storage, and internal transport. It helps illustrate how various processes are interdependent. By analyzing the process map, areas of delay, redundancy, or bottlenecks can be identified, enabling continuous improvement and the reduction of waiting times and operational costs. The process map also clarifies the roles and responsibilities of the different teams involved in terminal operations (e.g., loading/unloading crews, internal transport teams, warehouse management), which in turn enhances communication and collaboration.

Additionally, the diagram can incorporate performance indicators for each process, allowing efficiency to be monitored and deviations from established standards to be detected quickly.

When new technologies or practices are introduced, the process diagram helps integrate them into existing workflows, supporting a smoother transition and minimizing the risk of operational disruptions. With a full understanding of how processes function, managers and decision-makers are better equipped to make informed choices about necessary investments, technological upgrades, or organizational changes aimed at improving the terminal's efficiency and safety.

5. RESULTS

To exemplify the use of the IDEF 0 methodology in the selected organization, we identified two operational processes relevant to the study that we modeled according to the analyzed methodology. The diagram regarding the flow of activities carried out within the container loading-unloading process modeled using the IDEF0 methodology is presented in Figure 4.

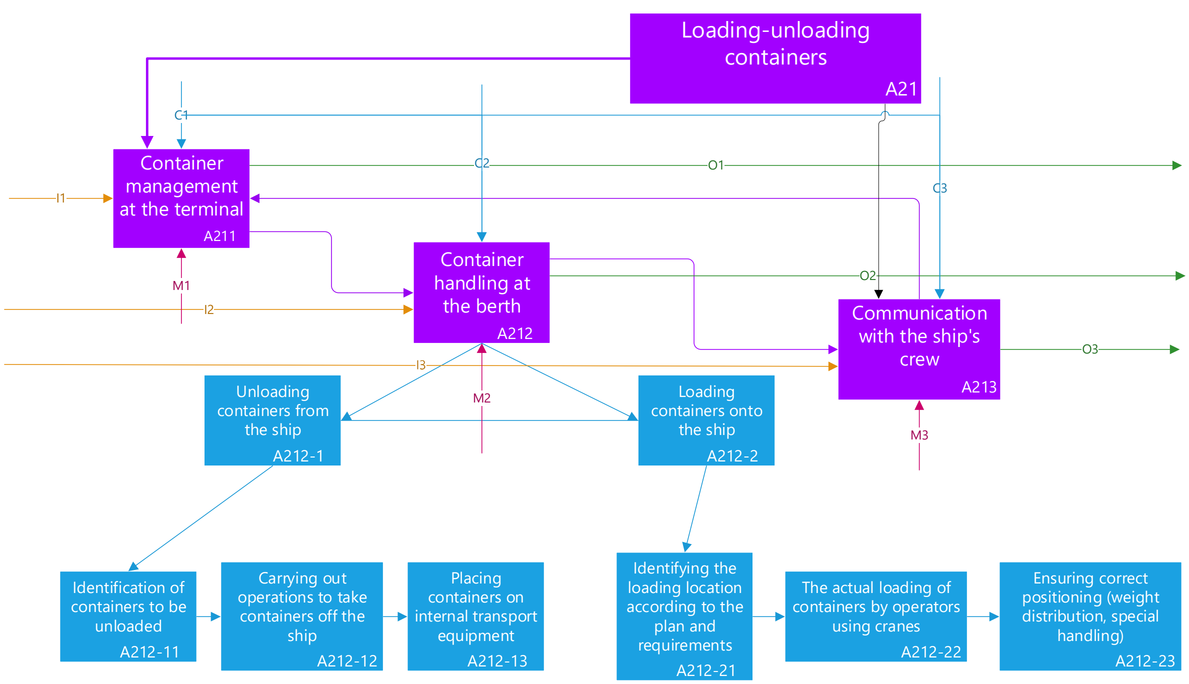

Fig. 4. Diagram regarding the flow of activities carried out within the container loading and unloading process

Detailed functions for container loading and unloading:

- A211: Container handling at the terminal
  - Inputs: containers, shipping schedule, terminal resources
  - Controls: safety regulations, operational procedures
  - Outputs: containers loaded/unloaded, shipping documentation
- A212: Container handling at the berth
  - Inputs: docked ship, container handling equipment
  - Controls: docking authorization, safety protocols
  - Mechanisms: cranes, forklifts, trucks
- A212-1: Unloading container from ship
  - Inputs: Container, Unloading schedule
  - Controls: damage prevention, sorting
  - Mechanisms: crane operations, sorting systems
- A212-2: Loading container onto ship
  - Inputs: container, ship behavior
  - Controls: weight distribution, lifting capacity
  - Mechanisms: crane operation, securing
- A213: Communication with ship's crew
  - Inputs: loading/unloading plan, safety check
  - Controls: communication protocols, language translation
  - Mechanisms: radio, visual signals

Figure 5 shows the IDEF0 modeling of the second selected operational process, internal container handling.

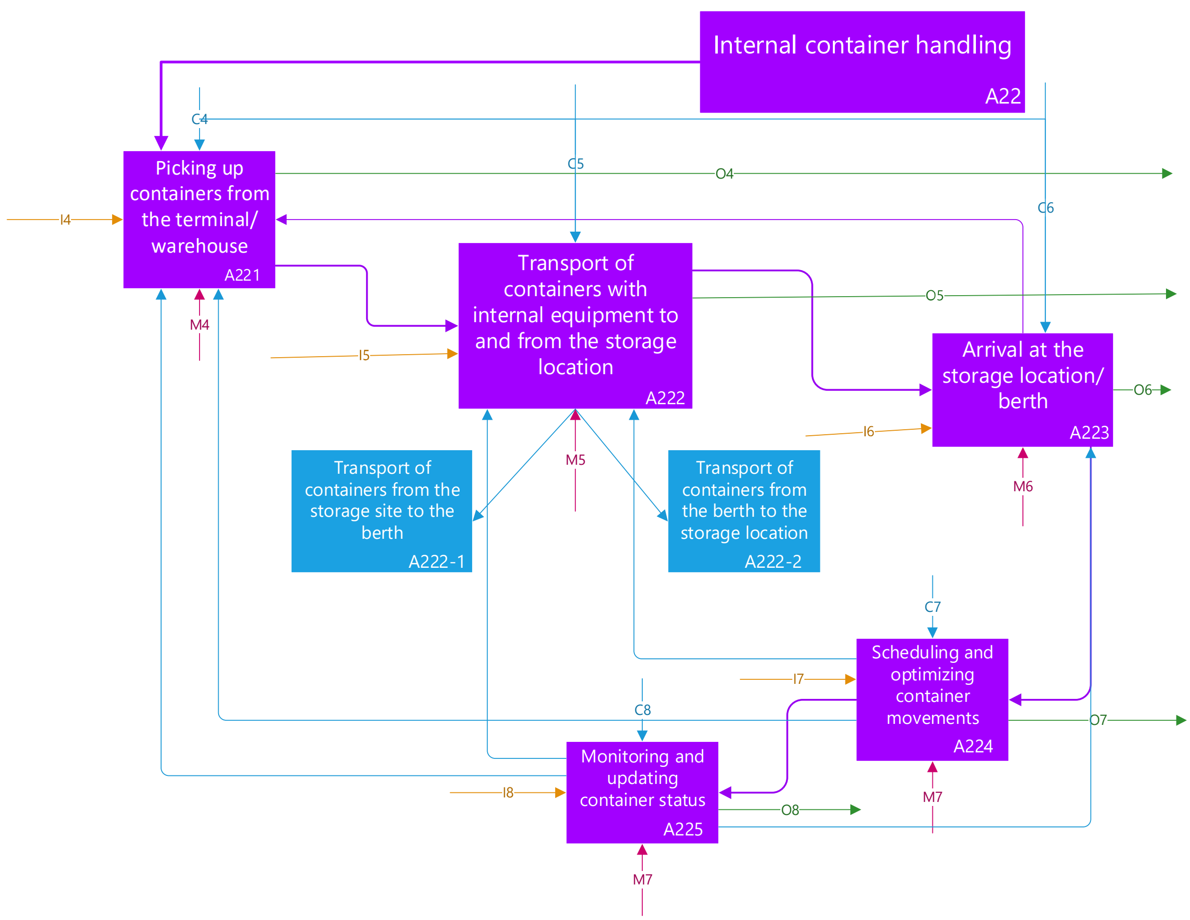

Fig. 5. Diagram regarding the flow of activities carried out within the internal container handling process

Detailed functions in internal container handling:

- A221:

  Picking up containers from the terminal
  - Inputs: containers, transport equipment, storage location allocation
  - Controls: traffic management, priority handling, safety procedures
  - Mechanisms: forklifts, riders, automated guided vehicles (AGVs), operators
  - Outputs: containers stored in a suitable location, updated storage system

  Picking up containers from the warehouse
  - Inputs: retrieval request, storage location, transport equipment
  - Controls: inventory system, order priority, safety guide
  - Mechanisms: forklifts, AGVs, operators
  - Outputs: containers retrieved, updated storage system
- A222: Transporting containers between storage and loading areas
  - Inputs: container loaded/unloaded, transport equipment, loading schedule
  - Controls: route planning, traffic management, safety protocols
  - Mechanisms: forklifts, riders, AGVs, operators
  - Outputs: containers delivered to loading areas or storage areas
- A223: Containers arrive at storage location/berth
  - Inputs: containers, transport equipment, storage location allocation
  - Controls: traffic management, priority handling, safety procedures
  - Mechanisms: forklifts, riders, AGVs, operators
  - Outputs: containers unloaded at appropriate location, updated storage system
- A224: Scheduling and optimizing container movements
  - Inputs: movement requests, container priorities, available equipment
  - Controls: internal traffic management system, equipment availability, safety standards
  - Mechanisms: terminal control system, scheduling software
  - Outputs: optimized travel plans, equipment assigned to tasks
- A225: Monitoring and updating container status
  - Inputs: container location, status handling, movement updates
  - Controls: Inventory control system, real-time data updates
  - Mechanisms: Terminal management system, operators
  - Outputs: Updated container status, real-time container movement data

The transport of containers between storage and loading areas (A222) depends on real-time updates from Container Status Monitoring and Update (A225) to ensure correct handling of containers according to the updated status information.

The Container Movement Scheduling and Optimization function (A224) works in conjunction with the other functions, ensuring that internal handling processes are optimized for efficiency and safety.

Container terminals are facing growing pressure in terms of volume, time, and service demands as the maritime transport sector continues to evolve. The widespread adoption of containerization and the rise of globalization led to consistent growth in container port activity, ranging from 5% to 10% annually between the 1980s and early 2000s. Although global trade has since stabilized and slowed growth during the 2010s, container throughput increased significantly: from 36 million TEUs in 1980 to 237 million in 2000, 545 million in 2010, and over 740 million in 2017. After disruptions caused by the COVID-19 pandemic, the industry rebounded, reaching 849 million TEUs by 2021 [7].

To meet rising demands, terminal operations must become more efficient, safer, and more productive.

- Semi-Automation: As operations grow more complex, semi-automation blends automated systems with human control, balancing safety and efficiency. It reduces human error and speeds up container handling, enhancing productivity while maintaining flexibility.
- Process Improvement: Streamlining workflows through better resource planning,

effective management systems, and improved use of existing technology helps terminals meet performance targets more rapidly and efficiently.

- Sustainable Practices: Integrating sustainability is vital for reducing environmental impact and boosting operational efficiency. This involves using renewable energy, minimizing waste, optimizing logistics, and working with suppliers on eco-friendly solutions.
- Data Analytics: Leveraging data from sensors and automated systems provides insights into terminal performance. These insights support process optimization, cost reduction, and targeted improvements.

Modeling two core operational processes reveals the complexity and resource intensity involved. These operations also consume significant energy and fuel, contributing both to financial costs and environmental impact, notably increasing the port's carbon footprint, including that of the hinterland. Some important key performance indicators (KPIs) that can be measured in follow-up implementations and simulations – which will provide the basis for quantitative validation in future research – are equipment utilization rate, container dwell time, and internal transport efficiency, which are inferred through process modelling.

Given today's global sustainability targets, container terminal operators must act responsibly. Since emissions from terminal activities can affect clients and suppliers (classified under Scope 3 emissions), implementing carbon footprint analysis and reporting systems supports improvements aligned with ISO standards and ESG principles.

7. FURTHER RESEARCH

The current study lays a foundation for process optimization in container terminal operations through the application of the IDEF0 methodology. However, several avenues remain open for further exploration and enhancement.

Future research should aim to expand the modeling scope to cover additional operational areas such as intermodal transfers, gate operations, and maintenance processes, providing a more holistic view of terminal performance.

A promising direction is the integration of real-time data sources, such as IoT sensors, Radio Frequency Identification (RFID) systems [8], and AI-based monitoring, into the modeled workflows. This would enable dynamic, data-driven decision-making and enhance predictive capabilities for container handling and equipment usage.

Moreover, future studies could explore how advanced optimization algorithms (genetic algorithms for container scheduling and resource allocation, with a focus on minimizing crane idle time and yard congestion) and machine learning techniques (supervised learning models such as random forests to predict container dwell times and equipment failures based on historical data) can be applied in conjunction with IDEF0 models to automate scheduling, routing, and resource allocation at a higher level of intelligence. Also, future research should embed carbon metrics and ESG indicators into process models to assess environmental impacts and support decisions aligned with green port goals and regulations.

By extending the current modelling approach and integrating it with advanced digital tools (Terminal Operating Systems such as Navis N4 to allow seamless deployment of real-time IDEF0-driven models into existing port IT infrastructure) and sustainability frameworks, researchers can develop more resilient, efficient, and environmentally responsible terminal operations.

8. CONCLUSIONS

The IDEF0 modelling successfully breaks down complex terminal activities into structured, manageable functions. This clear functional decomposition helps expose operational relationships and dependencies, making hidden more visible and addressable.

Through detailed flow mapping, the model highlights potential sources of delays such as suboptimal scheduling (in A224), outdated or manual monitoring (in A225), and poor coordination between storage and transport (in A222). These insights enable targeted interventions to streamline operations and reduce container dwell time.

The model highlights opportunities to enhance the use of semi-automated systems (e.g., AGVs, cranes, scheduling tools) within terminal workflows for greater efficiency. Real-time decision-making is supported by data-driven functions like container status monitoring (in A225) and movement scheduling (in A224), underscoring the need for integrated Terminal Operating Systems (TOS). By mapping resource-intensive processes, the model aids in identifying energy-saving strategies and supports alignment with ISO and ESG sustainability goals. Including crew communication (in A213) emphasizes the value of stakeholder coordination, ensuring better integration between ship and terminal operations to minimize berth delays.

IDEF0 offers a replicable, visual method for analyzing terminal operations, supporting a generalizable framework to improve efficiency across terminals.

9. REFERENCES

[1] Notteboom, T., Pallis, A., & Rodrigue, J. P., *Port Economics, Management and Policy*. (Routledge, Ed.) New York, 2022.

[2] Foundation for Economic Education, *Malcom McLean: Truck Driver, Entrepreneur, Billionaire*. https://fee.org/articles/malcom-mclean-truck-driver-entrepreneur-billionaire/

[3] Gharehgozli, A., Zaerpour, N., & de Koster, R., *Container terminal layout design: transition and future*. Marit Econ Logist, 66, 610–639, 2022.

[4] Honexpres Blog, *Cum se desfășoară activitatea într-un terminal de containere maritime?* https://honexpres.ro/blog/terminal-de-containere/

[5] Yan-Ling, N. X., Fu-Yuan, N. X., & Wen-Bo, N. H., *Business process reengineering based on IDEF methods*. Proceedings of the 2004 IEEE International Conference on Information Reuse and Integration, 265–270, 2005.

[6] Wang, B., Yao, C., Li, X., & Wei, G., *A Green Cooperative development method based on the IDEF0 model of Manufacturing knowledge: case study of a Carton-Filling machine*. Sustainability, 15(5), 4047, 2023.

[7] Kim, B., Kim, G., & Kang, M., *Study on Comparing the Performance of Fully Automated Container Terminals during the COVID-19 Pandemic*. Sustainability, 14(15), 9415, 2022.

[8] Hebrard, P., *Improving container terminal operations*. Identec Solutions. https://www.identecsolutions.com/news/improving-container-terminal-operations

Îmbunătățirea managementului proceselor în terminalele de containere prin intermediul modelării

Operațiunile terminalelor de containere sunt vitale pentru eficiența lanțului global de aprovizionare. Pe măsură ce volumele containerelor cresc, optimizarea proceselor devine esențială. În timp ce cercetările actuale pun accent pe simulare, învățarea automată și managementul Lean, metodologiile structurate precum IDEF0 sunt mai puțin aplicate. Această lucrare folosește IDEF0 pentru a modela și analiza operațiuni cheie precum manipularea containerelor sau încărcarea/descărcarea navelor, identificând ineficiențe precum timpii de inactivitate și utilizarea defectuoasă a echipamentelor. Subliniază importanța automatizării, a digitalizării și a îmbunătățirii programelor de funcționare. Rezultatele susțin dezvoltarea unor sisteme de operare a terminalelor mai bune, luarea deciziilor în timp real și promovează sustenabilitatea porturilor. Studiul oferă un cadru replicabil și perspective practice pentru creșterea productivității terminalelor de containere și a competitivității.

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