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MARITIME SECTOR AND DIGITAL TRANSFORMATION

МОРСЬКИЙ СЕКТОР ТА ЦИФРОВА ТРАНСФОРМАЦІЯ

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Abstract. *Aim.* The aim of this study is to apply Capability-Driven Design (CDD) to enhance energy efficiency in refrigeration systems within the cold chain, with a particular focus on digital transformation. This includes optimizing energy system performance and integrating a robust risk management system.
Methodology. Petri Net modeling and the alpha algorithm were employed to optimize energy system performance through Process Mining techniques. The methodology emphasized the development of a digital refrigeration enterprise using an Object-Based Capability-Driven Design and Improvement pattern. Data analytics, Domain Specific Big Data Platforms, and decentralized IT-integrated platforms tailored to cold chain operations were utilized to ensure real-time access to crucial information and support strategic decision-making.
Results. The study found that employing the Capability-Driven Design Methodology in refrigeration applications leads to significant improvements in energy efficiency, reductions in environmental impact, and enhancements in system performance. The integration of risk management within an object-based, capability-driven design framework enabled comprehensive data management, real-time decision support, and streamlined organizational processes, fostering greater efficiency.
Scientific Novelty. This research highlights the innovative application of Capability-Driven Design to the digital transformation of cold chain refrigeration systems. The study provides an approach by combining Petri Net modeling, the alpha algorithm, and Process Mining techniques to optimize energy systems and integrate risk management effectively.
Practical Significance. The findings underscore the importance of proactive measures aimed at climate management, resilience, and energy efficiency in addressing advanced challenges across refrigerated storage, transportation, and system components. The digital transformation of the cold chain is identified as crucial for achieving sustainable, efficient, and intelligent cooling solutions, thereby positioning organizations competitively in a rapidly evolving market. The practical application of this research supports industry efforts to meet increasing demands for refrigerated transport and cold storage through innovative technology integration.
Key words: smart refrigeration; cold chain; digital transformation; capability driven design; risk management system, process Mining.

Анотація. *Метою* цього дослідження є застосування проектування, орієнтованого на можливості (CDD), для підвищення енергоефективності холодильних систем у холодильному ланцюзі, з особливим акцентом на цифровій трансформації. Це включає оптимізацію ефективності енергетичної системи та інтеграцію надійної системи управління ризиками.
Методологія. Моделювання за допомогою Petri Net і альфа-алгоритму були використані для оптимізації єфективності енергетичної системи за допомогою методів Process Mining. Методологія наголошує на розробці цифрового холодильного підприємства з використанням шаблону об’єктно-орієнтованого проектування та вдоско-

налення, орієнтованого на можливості. Для забезпечення доступу в режимі реального часу до важливої інформації та підтримки прийняття стратегічних рішень використовувалися аналітика даних, платформи Big Data для конкретного домену та децентралізовані IT-інтегровані платформи, адаптовані до операцій холодового ланцюга.
Результати. Дослідження показало, що застосування методології проектування, орієнтованої на можливості, у холодильних системах призводить до значного підвищення енергоефективності, зменшення впливу на навколишнє середовище та покращення продуктивності системи. Інтеграція управління ризиками в об'єктно-орієнтовану структуру розробки, орієнтовану на можливості, уможливила комплексне керування даними, підтримку прийняття рішень у режимі реального часу та оптимізовані організаційні процеси, сприяючи підвищенню ефективності.
Наукова новизна. Це дослідження підкреслює інноваційне застосування проектування, орієнтованого на можливості, для цифрової трансформації холодильних систем холодильного ланцюга. Дослідження пропонує підхід шляхом поєднання моделювання Petri Net, альфа-алгоритму та методів Process Mining для оптимізації енергетичних систем та ефективної інтеграції управління ризиками.
Практичне значення. Отримані результати підкреслюють важливість проактивних заходів, спрямованих на управління кліматом, стійкість та енергоефективність у вирішенні складних завдань, пов'язаних із холодильним зберіганням, транспортуванням і системними компонентами. Цифрова трансформація холодового ланцюга визначена як вирішальна для досягнення стійких, ефективних та інтелектуальних рішень для охолодження, що забезпечує конкурентоспроможність організацій на ринку, що швидко розвивається. Практичне застосування цього дослідження підтримує зусилля промисловості щодо задоволення зростаючих попитів на охолоджене транспортування та холодильне зберігання за допомогою інтеграції інноваційних технологій.
Ключові слова: розумний холод; холодовий ланцюг; цифрова трансформація; методологія розробки на основі можливостей; система менеджменту ризиками; процес Майнінг.

INTRODUCTION

In modern society, digital technologies are increasingly recognized as a crucial factor and catalyst for innovation. Digital transformation in the industry offers unprecedented opportunities and potential for growth and value creation. However, realizing these new opportunities requires at least mitigating the associated risks. Managing these risks in the evolving digital era is essential for the sustainability of both the energy system, energy-efficient projects, and the organization as a whole.

Object-based capability-driven design and improvement patterns as shown in Figure 2 address how business capabilities can be practically implemented. Together with Value Streams as shown in Figure 1, which establish a comprehensive link between Business Capabilities and value delivery in a specific context, they ensure a coherent and effective approach to achieving organizational goals.

They depict how an organization achieves value for stakeholders through a defined set of business activities. By cross-mapping to enabling business capabilities, Value Streams illustrate how an organization orchestrates these capabilities to create stakeholder value. This approach ensures a clear understanding of how various capabilities contribute to the overall value creation process, aligning operational activities with strategic objectives to enhance efficiency and effectiveness.

The refrigeration industry has its own definition of the concept of "Digital", "Digital Transformation" and what it means for the Cold Sector. Top management is actively discussing the transition to digital technologies within organizations, emphasizing digital transformation. The industry can no longer avoid the uncertainties associated with digital transformation, as digital technologies have become a real necessity. It is the most effective tool for creating new advantages, distinctive and unique, capable of giving a product a higher competitiveness in the market. Today, "Digital Thinking" and the necessary capital investments in digital transformation are critical factors for successfully implementing this transformation. Therefore, digital transformation is a relevant task in the maritime sector.

PROBLEM STATEMENT

The absence of a suitable approach, methodology, and pattern for developing energy systems, along with the rising demands for digital transformation in the modern maritime industry, calls for the exploration of new opportunities to improve the system performance of energy systems. This research objectives to implement a capability-driven design within an object-based capability-driven design and improvement pattern for the development of energy systems. Additionally, it seeks to adopt digital transformation for the refrigeration sector (cold chain) to further enhance energy performance.

LITERATURE ANALYSIS

The concept of «smart shipping» [1] involves the integration of digital technologies [2], such as IoT devices [3], sensors, and connectivity solutions, to enhance the efficiency [4] and safety of maritime operations [5]. Smart shipping includes predictive maintenance [6], real-time monitoring, and data-driven decision-making [7]. The development and testing of autonomous or unmanned vessels have been facilitated by digitization. These vessels utilize advanced technologies, including sensors, machine learning, and automation, to navigate and operate without direct human intervention. Digital navigation

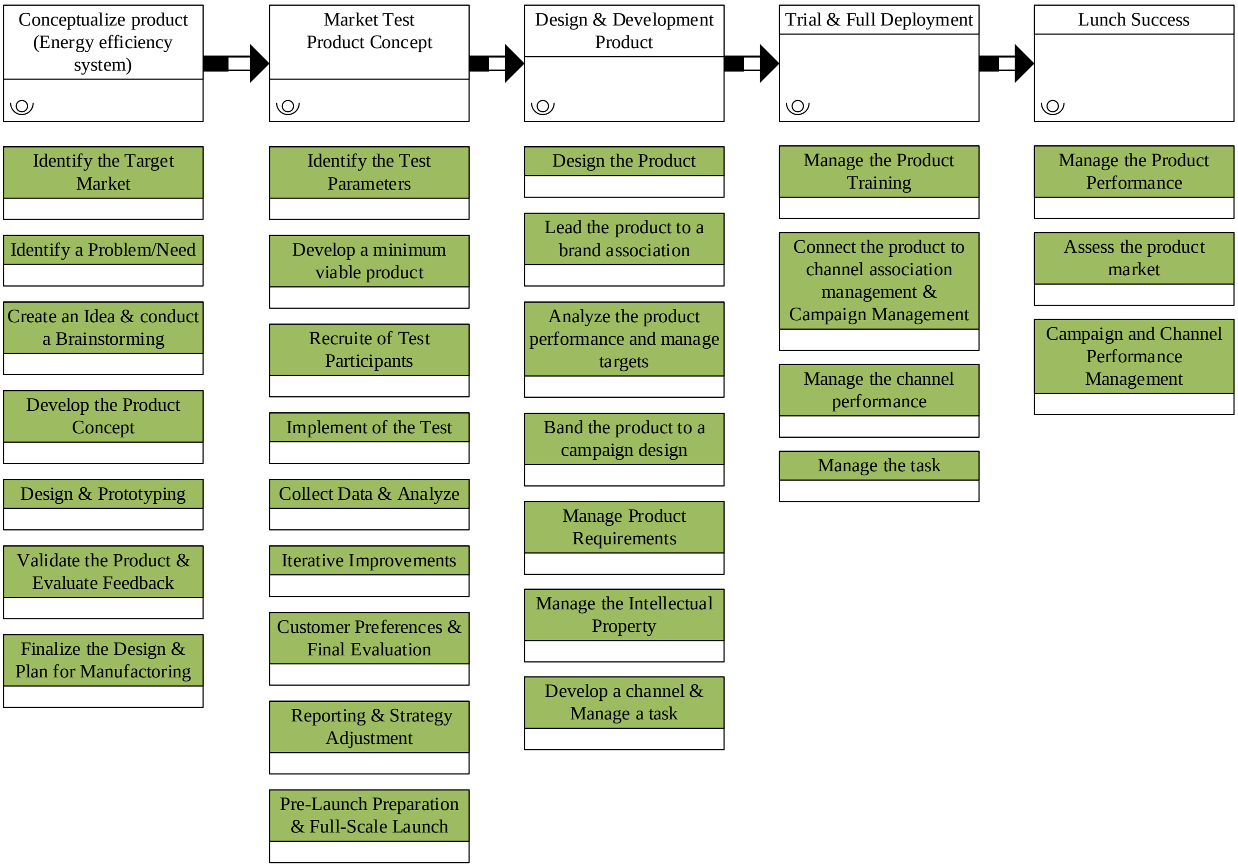

Fig. 1. Develop & Launch Product

systems [8] equipped with real-time data, GPS, and weather information help optimize routes, improve fuel efficiency, and ensure maritime navigation safety. Electronic charts and Electronic Chart Display and Information Systems [9] have become integral parts of modern vessels. Ports and terminals use digital technologies to enhance the efficiency of cargo handling, berthing, and logistics. Automated container terminals, digital cargo tracking, and intelligent port solutions contribute to the optimization of port operations. Digital Transformation [10] enables condition-based maintenance of maritime assets. Sensors and monitoring systems collect data on the condition of ship components, allowing operators to plan maintenance based on actual wear and tear rather than fixed time intervals.

SEPARATION OF UNRESOLVED PREVIOUS PARTS OF THE OVERALL PROBLEM

Digital platforms and technologies provide better visibility into the maritime supply chain. From goods delivery to customs clearance, stakeholders can track shipments in real-time, reducing delays and improving overall supply chain management. As digital systems become more widespread, ensuring the cybersecurity of maritime assets is crucial. When creating energy-efficient projects for energy systems (refrigeration systems), there is a lack of methodology for project development and providing the opportunity to manage risks throughout the project lifecycle.

RESEARCH AIM

The aim of this research is to apply the Capability-Driven Design to develop energy systems for energy-efficient projects. This will be done in conjunction with digitally transforming the cold chain to improve the energy efficiency of refrigeration systems. The approach involves utilizing Petri Net modelling language and the alpha algorithm to optimize energy system performance.

METHODS, OBJECTS, AND SUBJECTS OF RESEARCH

This study utilizes the Process Mining approach and Capability-Driven Design methodology. The primary focus is on investigating the Cold Chain and its Digital Transformation, utilizing the Petri Net modelling language and the alpha algorithm. The study subjects revolve around the development of a digital refrigeration enterprise within the Object-Based Capability-Driven Design and Improvement pattern for energy system development. Furthermore, it includes the integration of an effective risk management system to mitigate risks throughout the project lifecycle.

MAIN MATERIAL

Object based capability-driven design and improvement for refrigeration application.

Capability-Driven Design Methodology [11-15] is an approach used in system and software engineering to design and develop systems based on identified capabilities. In this methodology, the focus is on defining and delivering specific capabilities that align with the strategic goals and objectives of an organization. The methodology is presented in the Figure 1 where expert can go through phases and deliver result.

Management phase. Work is planned with creative cross-functional teams. It is necessary to organize cross-functional teams that can collaboratively work on providing full capabilities. These are experts with different skills, such as developers, designers, testers, and analysts. Modelling phase involves the integration of the following models: goals, processes, actors, rules, concepts, and technical components. Information about the energy project in the cold industry is modelled and presented as a meta-model connecting discussed models, allowing visualization of details for improvement and providing new capabilities to both the executing and ordering companies. Design decisions phase are made based on capabilities, and an assessment of the capabilities is performed, checking their readiness for adaptation. Intentions of using capabilities with subprocesses (definition, alignment, prioritization) are evaluated. Identification takes place where high-level capabilities or functions essential for achieving the organization's strategic goals in project adaptation are determined. When mapping capabilities, strategic alignment occurs when the identified project capabilities are compared with the organization's strategic goals to ensure that development efforts align with overall business objectives. The prioritization of capabilities is determined based on their perceived value to the business, involving an understanding of the impact of each capability on achieving strategic outcomes. The results of the modelling and design stages are stored in information repositories. Delivery or Implementation and Feedback phases. Suitability assessment of the context, consistency check, and reporting on the status of the proposed indicator are performed. It is possible to develop a gradual project delivery to the organization by breaking down the development process into phased releases, each providing a specific set of capabilities. This allows delivering value to the organization in a timely and continuous manner (we are talking about modification and improvement of energy facilities to increase energy efficiency).

A metrics are provided to measure the result and determine key performance indicators related to the success of the implementation of each capability, helping to assess the impact and effectiveness of the provided functions: dependency management, identification of dependencies, adaptability or flexibility, continuous improvement, risk management.

Top-level method components. The methodology is structured with top-level method components. Each top-level component corresponds to a specific application area. These components include method components related to specific areas.

The concept includes:

– Definition, where concepts are the key elements that define which aspects of reality are considered relevant in the modelling process;

– Role, where it is determined what is important and what needs to be reflected in the model;

– Specification, discussing the relevant concepts and their relationships named and explained in the method component; – Purpose, where concepts form the basis for the modelling process.

The procedure involves:

– Determination, where the procedure describes how to identify relevant concepts in the method component, may also cover prerequisites and resources needed for the identification process;

– Work stages described in specific terms, work steps detailed to describe the actions to be performed, including input, output, and tool support. In some cases, the procedure also includes modelling guidelines;

– Notation, specifying how the results of the procedure should be documented. As a rule, this must provide appropriate expressions for each concept and for the potential relationships between them. In graphic notations, these are the symbols to be used, also providing standardized and understandable documentation of modelling results.

The Capability-Driven Design Methodology offers a pattern for creating and implementing systems that are both technically robust and aligned with the strategic goals of the organization, enabling the monitoring, control, and management of risks.

The Integrated Risk Management System (Sycle) involves multiple phases: initial screening with historical and recent data, automated filtering analysis, ongoing monitoring, selective evaluation using simulations and diverse factors, and re-assessment of risk treatment results.

Main objective of the procedure - to design a capability that allows reaching a business goal in a particular context (energy efficiency, environmental impact).

Procedure of CDD refers to a structured set of steps or activities involved in designing capabilities within a specific methodology or pattern. This procedure typically outlines the systematic process followed to identify, develop, and implement capabilities that align with the strategic goals and objectives of an organization. It may include tasks such as defining requirements, modelling, evaluation, and the creation of artifacts that contribute to the overall capability design process.

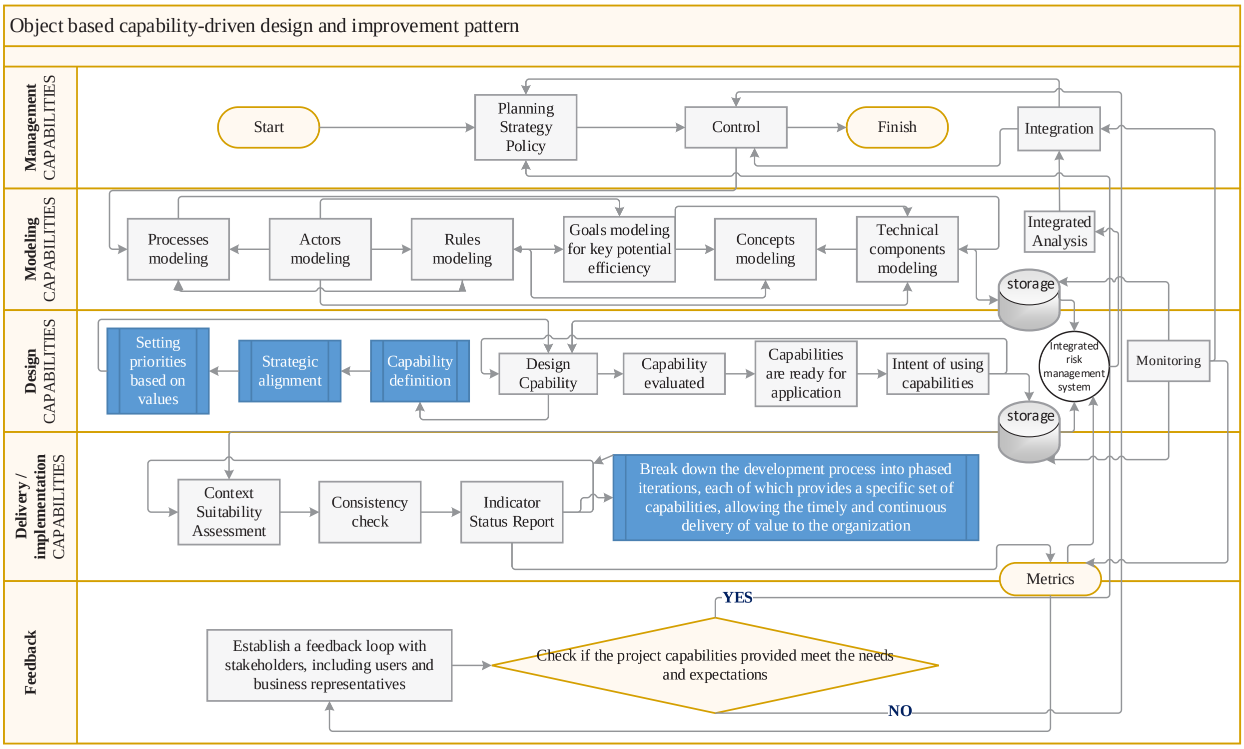

Fig. 2. Capability-driven design methodology with integrated Risk Management System

In essence, this procedure provides a detailed guide for capability designers, specifying how to go about designing capabilities effectively within a given context or methodology.

Start from input Existing enterprise models where client intent to implement energy efficiency project for refrigeration system, e.g. goals models, business process models, concepts models as well as existing patterns.

Activities implies in the goals first capability design path. The Capability Design a key step involves:

– ***a meticulous analysis of the entire business vision and its associated goals***. This scrutiny is essential for identifying specific goals that warrant support from carefully designed capabilities. The hierarchical structure of goals, ranging from more strategic at the top to operational at the bottom, is considered in this analysis. The primary focus lies on operational goals, given that capabilities are intricately linked with explicit business designs and tangible actions. The selection process involves pinpointing goals that necessitate support from capabilities, with an openness to considering even some top-level goals for such support. To ensure a comprehensive approach, the chosen goals intended for capability design should boast well-defined Key Performance Indicators (KPIs). This data-driven aspect enables the measurement of the efficiency of capabilities in achieving these goals. Moreover, a critical aspect of this step involves verifying and, if necessary, refining the existing design to establish a clear connection between corporate KPIs and goals. In cases where this linkage is absent, the enterprise modelling method component, that proves to be a valuable ally in supporting and enhancing this analytical process. Through this strategic alignment, the capability design becomes a potent force in driving the organization towards its overarching vision and objective

– the ***meticulous identification of specific capabilities required to fulfill the organizational goals***. During this activity, a thorough analysis of the goals takes place, leading to the definition of relevant capabilities. Additionally, the relationships between these capabilities and the goals are established, elucidating how the capabilities intricately support and contribute to the achievement of these goals. A nuanced approach is adopted during this stage, considering the hierarchical structure of goals. The analysis extends beyond mere identification to assess how a capability contributes to the entire goal hierarchy. For instance, if a capability is identified as supporting multiple sub-goals within the same hierarchy, careful consideration is given to whether it would be more appropriate to associate it with the overarching top-level goal. This analytical process ensures a strategic alignment between capabilities and goals, providing a comprehensive understanding of how each capability plays a distinctive role in supporting the organization's objectives. The outcome is a robust Capability Design that not only meets immediate goals but is also strategically positioned within the broader organizational landscape.

– ***the analysis of existing business processes***. Once the relationships between capabilities and goals have been established, the next phase is to connect these capabilities to the organization's existing business processes. In an already documented business design, business processes are typically outlined, and if these processes are linked to specific goals, the identified capabilities should be associated with the same business processes. This association ensures a clear alignment between capabilities, goals, and the operational aspects of the organization. It's important to note that, at this stage, establishing a general relationship between capabilities and existing business processes is sufficient. The detailed design of process variants will be undertaken in subsequent stages, particularly once the application context is fully modelled. This analytical approach ensures a seamless integration between capabilities and the operational workflows of the organization, laying the foundation for a coherent and strategically aligned business design.

– ***the identification and modelling of the context surrounding the identified capabilities are crucial steps***. Each capability needs to be understood within a specific context set, determining the conditions under which it is applicable. This involves defining the relevant context elements and specifying their ranges within which the capability holds relevance. This activity is often facilitated by employing the context modelling method component. This component provides a systematic approach to defining and representing the contextual factors that influence the application and effectiveness of capabilities. By clearly defining the context in which each capability operates, organizations gain a comprehensive understanding of the situational factors that may impact the successful deployment and utilization of these capabilities. This contextual insight is essential for ensuring that capabilities are appropriately adapted and responsive to varying conditions within the business environment.

– ***the analysis and definition of process variants associated with the realization of a capability***. A capability, being implemented through a set of business processes, may require adjustments in its delivery to accommodate changes in the context. Therefore, a comprehensive examination of the overall business process is conducted. This analysis involves assessing potential changes in the context and identifying variations in capability delivery. The outcome of this analysis is the definition of process variants and the identification of variation points. These process variants represent different adaptations or adjustments in how the capability is delivered, taking into account diverse contextual conditions. The context modelling method component is often utilized in this activity to systematically model and represent the contextual factors influencing the variations in capability delivery. By identifying process variants and understanding the points at which variations can occur, organizations can enhance the adaptability of capabilities to different contextual scenarios. This adaptability is crucial for ensuring the continued effectiveness of capabilities in a dynamic business environment.

– ***the model delivery adjustments focus*** is on detailing the specific adjustments required for the delivery of a capability. This involves specifying any modifications, enhancements, or variations identified in the previous steps and linking them back to the overall capability design. During this phase, organizations articulate the changes necessary for the effective implementation of the capability. This can include adjustments to business processes, changes in resource allocation, or modifications in the use of technology. The goal is to ensure that the capability aligns seamlessly with the identified goals, business processes, and contextual factors. By explicitly modeling these delivery adjustments and establishing clear links to the broader capability design, organizations enhance their ability to implement changes systematically. This step contributes to the overall adaptability and effectiveness of capabilities in responding to evolving business needs and environmental conditions.

– ***the review and/or incorporate relevant patterns*** the emphasis is on leveraging existing best practices and patterns to enhance the capability design. This involves a systematic review of patterns that encapsulate proven approaches, process variants, concept models, and algorithms relevant to the specific context of the capability being designed. The intention is to tap into established knowledge and solutions that align with the goals and requirements of the capability. By incorporating relevant patterns, organizations benefit from tested and refined practices, improving the overall quality and efficiency of the capability design. This step acknowledges the importance of learning from industry standards, successful implementations, and recognized methodologies. It encourages capability designers to stay informed about existing patterns and to adopt them judiciously, ensuring that the resulting capability design is robust, effective, and aligned with established best practices.

The process of modernizing a refrigeration system, and through conceptual design and BPMN modelling language was presented by Yalama, 2022 [16]. It is understood that there may be specific variations due to certain characteristics of the analyzed refrigeration system and the refrigerants used. BPMN provide an idea of how this workflow operates during the modernization of refrigeration equipment with HFCs.

RESULTS AND DISCUSSIONS

During the lifecycle of energy efficiency projects, companies' employees, assets, data, and customer information may enter risk zones depending on risk domains and their integration into the digital organization. Technology-related risks encompass the potential for

Table 1. Cold Chain Event Log

Case number	Order number	Event properties			
		timestamp	**activity**	**resources**	*******
1	412851	21-10-2022: 12.20	Acceptance of fish by the refrigeration vessel	Alex	
	412852	22-10-2022: 10.10	Freezing	Pete	
	412853	22-10-2022: 12.35	Cooling	Pete	
	412854	24-10-2022: 15.10	Delivery to the distribution refrigeration center	Valeriy	
	412855	25-10-2022: 16.50	Goods inspection	Yevgen	
	412856	25-10-2022: 17.50	Goods reception for storage	Jukka	
2	412871	10-11-2022: 12.20	Acceptance of fish by the refrigeration vessel	Alex	
	412872	11-11-2022: 10.10	Freezing	Pete	
	412873	11-10-2022: 12.35	Cooling	Pete	
	412874	13-10-2022: 08.10	Delivery to the distribution refrigeration center	Valeriy	
	412875	13-10-2022: 09.10	Goods inspection	Yevgen	
	412876	13-10-2022: 10.15	Rejection of substandard goods	Leif	
	412877	21-10-2022: 12.20	Compensation receipt	Alex	

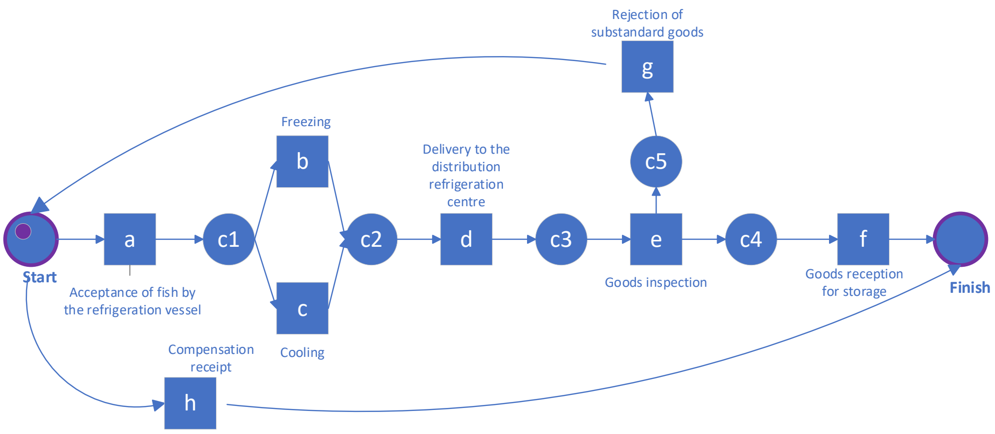

Fig. 3. Cold Chain Process Model provided by the α-Algorithm based on a set of traces

losses due to technology failures or obsolescence. These risks affect systems, people, and processes, with key areas of concern including scalability, compatibility, and the accuracy of the implemented technology's functionality.

When designing control measures for digital initiatives, it is essential to consider applicable risk areas and adhere to leading standards and industry practices. A critical aspect of defining these controls involves accounting for the nature and extent of digitization in operations. Since many areas are still in early stages and closely integrated with systems or manual processes, there may be constraints in implementing these controls. Therefore, a careful analysis of the specific context and digitization level is necessary to develop effective and feasible control measures.

The integrated risk management system into Object based capability-driven design and improvement pattern, presented in Figure 2, allows for automatic data integration and segmentation, as well as providing information on request based on priority. This system enables the dissemination of necessary information and the establishment of verification criteria along with the formulation of risk factors when using indicators for selecting complex goals.

Utilizing Petri Nets and process mining, and alpha-algorithm for modelling the cold chain

Through process mining in the development of the domain-oriented big data integration platform Yalama, 26th IIR International Congress of Refrigeration, 2023 [17] along with the decentralized IT-integrated platform for the cold chain and the cold chain itself, as an element, can also undergo digitization. Starting from the event log in Table 3.1, using Petri Nets in Figure 2 and the alpha-algorithm [18-20], a model of the cold chain process is presented.

$L_1=\{<a,b,c,d,e,f>^3,<a,c,b,d,e,f>^3,<a,c,b,d,e,g,h>, <a,b,c,d,e,f>, <a,c,d,e,f>, <a,b,d,e,f>^2, <a,c,d,e,g,h> \}$

Direct succession x>y if in some cases y follows x sequentially

Causality x $\rightarrow$ y, if sometimes x>y and never y>x
Concurrency x||y, if x>y, та y>x
Choice x#y, if never x>y, and never y>x

Table 2. Footprint of L1

	a	b	c	d	e	f	g	h
a	$\#L_1$	$\rightarrow L_1$	$\rightarrow L_1$	$\# L_1$	$\# L_1$	$\# L_1$	$\# L_1$	$\parallel L_1$
b	$\leftarrow L_1$	$\# L_1$	$\parallel L_1$	$\rightarrow L_1$	$\# L_1$	$\# L_1$	$\# L_1$	$\# L_1$
c	$\leftarrow L_1$	$\parallel L_1$	$\# L_1$	$\leftarrow L_1$	$\# L_1$	$\# L_1$	$\# L_1$	$\# L_1$
d	$\# L_1$	$\leftarrow L_1$	$\leftarrow L_1$	$\# L_1$	$\rightarrow L_1$	$\# L_1$	$\# L_1$	$\# L_1$
e	$\# L_1$	$\# L_1$	$\# L_1$	$\leftarrow L_1$	$\# L_1$	$\rightarrow L_1$	$\leftarrow L_1$	$\# L_1$
f	$\# L_1$	$\# L_1$	$\# L_1$	$\# L_1$	$\leftarrow L_1$	$\# L_1$	$\# L_1$	$\# L_1$
g	$\rightarrow L_1$	$\# L_1$	$\# L_1$	$\# L_1$	$\leftarrow L_1$	$\# L_1$	$\# L_1$	$\rightarrow L_1$
h	$\#L_1$	$\#L_1$	$\#L_1$	$\#L_1$	$\#L_1$	$\#L_1$	$\leftarrow L_1$	$\# L_1$

α-algorithm by Van der Aalst

Let's assume that the function L is the event log of M.

Then $M_L = \{m \in M \,/\, \exists_{\sigma \in L} m \in \sigma\}$,

Each action in L corresponds to a transaction in M α(L)

$M_i = \{m \in M \,/\, \exists_{\sigma \in L} m = first(\sigma)\}$

Creating a set of initial actions means identifying the first elements of each trace: $\langle m_1\ldots,m_n\rangle,\ldots\langle m'_1\ldots,m'_n\rangle$

$$M_o = \{m \in M \,/\, \exists_{\sigma \in L} m = last(\sigma)\}$$

Creating a set of final actions involves identifying the elements that appear at the end of each trace $\langle m_1\ldots,m_n\rangle,\ldots\langle m'_1\ldots,m'_n\rangle$

To count the pairs at the entrance and exit to the city (labeled C1-C5), refer to Figure 4.

$$X_L = \{(A,B) \mid A \subseteq M_L \wedge A \neq \varnothing \wedge B \subseteq M_L \wedge B \neq \varnothing$$

$$\wedge \forall_{a \in A} \forall_{b \in B}\, a \rightarrow \#_L\, b$$

$$\wedge \forall_{a1, a2 \in A}\, a_1 \#_L a_2$$

$$\wedge \forall_{b1, b2 \in B}\, b_1 \#_L b_2 \},$$

$$5.\ Y_L = \{(A,B) \in X_L \mid \forall_{(A',B' \in X_L)} A \subseteq A' \wedge B \subseteq B' \Rightarrow (A,B) = (A',B')\}$$

$$6.\ P_L = \{C_{(A,B)} \mid (A,B) \in Y_L\} \cup \{i_L, o_L\},$$

$$7.\ F_L = \{(a, C_{(A,B)}) \mid (A,B) \in Y_L \wedge a \in A\}$$

$$\cup \{(C_{(A,B)}, b) \mid (A,B) \in Y_L \wedge b \in B\}$$

$$\cup \{(i_L, m) \mid (m \in M_I) \cup \{(m, o_L \mid m \in M_O\}$$

Establish the following relations: connect each location $C_{(A,B)}$ with each element in the set $\boldsymbol{A}$ of transaction sources and with each element in the set $\boldsymbol{B}$ of target transactions. In addition, draw an arc from the initial place $\boldsymbol{i_L}$ to each starting transaction $\boldsymbol{m} \in \boldsymbol{M_I}$, and an arc from each end of the transaction $\boldsymbol{m} \in \boldsymbol{M_O}$ to the final place $\boldsymbol{o_L}$

8. $\alpha(L)=(P_L, M_L, F_L)$

X_{L1} =*{({a},{b}), ({a},{c}), ({b},{d}), ({c},{d}), ({a},{b,c}), ({b,c},{d}), ({d},{e}), ({e},{g}), ({e},{f}), ({g},{h})}*

Y_{L1} =*{({a},{b,c}),({b,c},{d}),({d},{e}),({e},{g}),({e},{f}),({g},{h})}*

The use of process mining with BPMN and Petri Net languages enables the modelling of various process systems in the refrigeration sector, from modernizing HVAC and refrigeration systems (by transitioning to new environmentally friendly refrigerants) to modelling the cold chain. This facilitates the digital transformation process for effective data management and control within the system.

CONCLUSIONS

The strategy for digitizing cold chains leverages data analytics technologies, Domain Specific Big Data Platforms, and a decentralized IT-integrated platform tailored to specific cold chains. Ensuring access to critical information from primary and secondary actors within these platforms is vital for managing refrigeration system emergencies effectively. Cold Chain enterprises should focus on capitalizing on emerging opportunities and meeting evolving customer demands.

The Capability Driven Design Methodology for refrigeration applications involves a strategic and systematic approach to developing refrigeration systems, emphasizing specific capabilities. This methodology entails a structured process to identify key functionalities

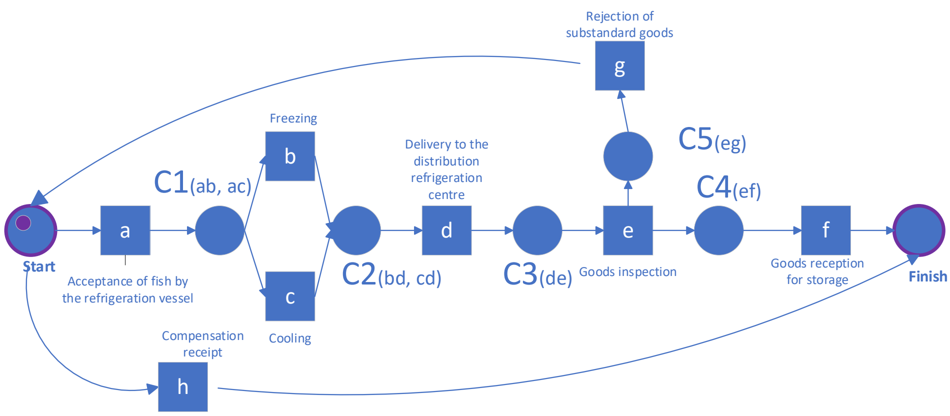

Fig. 4. Model of the refrigeration process with the included locations C1-C5 within the network with pairs

required in refrigeration applications, translating them into effective system designs. It suggests breaking down the design process into iterative stages, ensuring each phase contributes distinct capabilities to enhance the overall system. This approach aligns with broader strategic goals, considering factors like energy efficiency, environmental impact, and performance criteria, fostering innovation and adaptability in the refrigeration technology field.

To develop targeted programs addressing climate management, resilience, and energy efficiency, proactive measures must be implemented. Focus should be on tackling advanced challenges in all facets of the cold chain, including refrigerated storage, transportation, and system components. Industry experts must leverage their knowledge and explore technologies aligned with sustainable development goals to meet evolving demands.

Integrating the Risk Management System within an Object-based, capability-driven design and improvement pattern allows energy efficiency projects to generate comprehensive data with enhanced reconciliation capabilities, manage real-time data with minimal delays, shift focus from error correction to proactive prevention, support decision-making across divisions, and streamline organizational integration for greater efficiencies.

The foreseeable future predicts a sustained increase in demand for refrigerated transport and cold storage, driving investments, the development of new technologies, and the integration of existing solutions within the cooling sector. Advances in refrigerated cargo transport and enhanced cooling systems for refrigerated vessels significantly contribute to overall sustainability. The rising demand positions organizations competitively in the broader market, with future market leaders providing efficient, intelligent, and controlled cooling solutions. The digital transformation of the cold chain emerges as a critical strategy for achieving these goals.

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