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IOT IN CONTAINER SHIPPING INDUSTRY: APPLICATIONS AND EXAMPLES OF SOLUTIONS

The study analyzes the participation of technologies related to the development of the Internet of Things (IoT) network concept in the intermodal container transportation system. Since the beginning of the XXI century, IoT-related technologies have been dynamically spreading in almost all areas of international business, and this has changed the understanding of cargo owners about the quality of transportation services, among other things. Since transparency in monitoring the location of high-value goods is extremely important for transport companies, cargo owners, and all other stakeholders, and the intermodal transportation system is extremely complex due to the number and diversity of communications, the need to use IoT is obvious. As analysts predict that the introduction of IoT technologies in containerization will become widespread in the coming years, a study to assess the level of research on the introduction of such technologies and implementation in the practical activities of transport enterprises is relevant. The aim of the proposed review is to determine the degree of IoT implementation in the container transportation industry, areas of research on the topic, and identify factors that may impede the predicted rapid development of IoT in containerization. The proposed study includes an analysis of scientific publications related to the use of the Internet of Things in the field of international container transportation, identifies the main priority areas of such publications, establishes the areas of current implementation of IoT technology and determines the prospects for its use. Since the solutions that can potentially be obtained with the help of IoT are quite heterogeneous, the literature analysis is organized by grouping such publications into the following areas: container monitoring and tracking, enhancing supply chain transparency and visibility, optimization of operational efficiency, security and risk management, environmental impact and sustainability, challenges and barriers. The paper provides examples of online platforms and applications currently offered by major container operators that are related to this technology.

Key words: *container, shipping, intermodal, transport, internet of things, IoT.*

Дрожжин О. Л. «Інтернет речей» в галузі контейнерних перевезень: сфери застосування та приклади рішень

В статті представлений аналіз участі технологій, які пов'язані з розвитком залучення мережевої концепції «Інтернет речей» (англ. IoT) в системі інтермодальних контейнерних перевезень. Технології, пов'язані з IoT з початку XXI сторіччя динамічно ширяться майже в усіх сферах міжнародного бізнесу, і це певним чином змінило розуміння вантажовласників про якість транспортного обслуговування в тому числі. Оскільки прозорість моніторингу перебування високовартісних товарів є вкрай важливою для транспортних підприємств, вантажовласників, і усіх інших зацікавлених сторін, а інтермодальна система перевезень є вкрай складною внаслідок кількості і різнохарактерності комунікацій, необхідність залучення IoT є очевидною. Оскільки аналітиками прогнозується, що впровадження технологій Інтернету речей у контейнеризації стане загальновживаним у найближчі роки, дослідження з оцінки рівня вивченості щодо впровадження таких технологій та імплементації в практичній діяльності транспортних підприємств є актуальною. Мета запропонованого огляду полягає в визначенні ступеню запровадженості IoT в контейнерну індустрію перевезень, напрямків наукових досліджень за темою та виявленні факторів, які можуть перешкоджати прогнозованому швидкому розвитку IoT у контейнеризації. Запропоноване дослідження включає в себе аналіз наукових публікацій, які стосуються використання «інтернету речей» в сфері міжнародних контейнерних перевезень, визначає основні пріоритетні напрямки таких публікацій, встановлює сфери сучасної імплементації технології IoT і визначає перспективи її використання. Оскільки рішення, які потенційно може бути отримано за допомогою IoT є достатньо різнорідними, аналіз літератури побудований групуванням таких публікацій за напрямками: моніторинг та відстеження контейнерів, підвищення прозорості ланцюгів поставок, оптимізація операційної ефективності, безпека та управління ризиками, вплив на навколишнє середовище та сталий розвиток, виклики та перепони. В роботі зазначені приклади інтернет-платформ, додатків, які сьогодні пропонуються потужними контейнерними операторами, які пов'язані із зазначеною технологією.

Ключові слова: *контейнер, судноплавство, інтермодальні перевезення, транспорт, інтернет речей, IoT.*

Introduction. The IoT has transformed various industries, and container shipping is no exception. Container shipping involves the global transport of goods in standardized containers, a process characterized by complexity, vast supply chains, and stringent time-sensitive requirements. IoT technology, by facilitating real-time tracking, data collection, and automated operations, has emerged as a significant enabler of efficiency, transparency, and innovation in this field. This review aims to synthesize key themes and findings from the scientific literature on IoT applications in container shipping.

The application of IoT in the container industry can be traced back to the early 2000's when global trade began to witness rapid growth in containerized shipping. Traditionally, container transportation relied heavily on manual processes and basic tracking systems, making it difficult to obtain real-time data about the location, condition, and security of containers.

Initial efforts to integrate IoT involved using Radio Frequency Identification (RFID) tags to track containers. RFID technology allowed for automated identification and data capture, but it had limitations regarding the range of communication and lack of real-time updates. At the same time, the development of GPS tracking systems provided an early method for monitoring container movements but was often limited to high-value cargo.

By the late 2000s, advancements in wireless communication technologies and sensor devices enabled the industry to explore more sophisticated IoT applications. The ability to install low-cost sensors on containers, paired with cellular, satellite, and wireless network technologies, laid the foundation for real-time data collection and remote monitoring, ushering in the era of «smart containers».

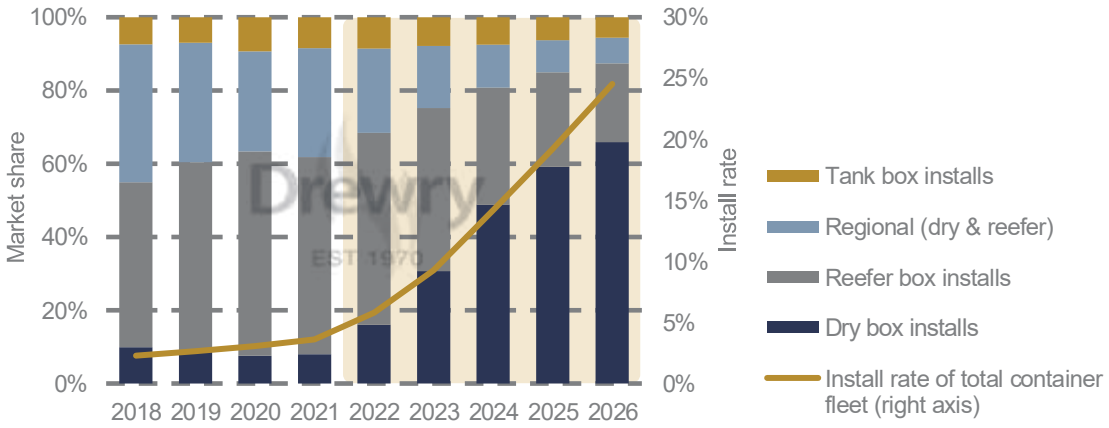

Fig. 1. IoT in Container Shipping development forecast

Source: Drewry [1]

As predicted by Drewry Agency, the number of smart containers in the global fleet will grow to more than 8.7 mln. TEU by 2026, accounting for up to 25 % of global container volumes. It is expected that the development of IoT technologies over time will increase the value of IOT-devices for carriers, operators and cargo owners will reduce the cost of the devices [1].

The purpose of the article. The adoption of IoT technologies in containerization is expected to become ubiquitous in the coming years, so assessing the level of research into the adoption of such technologies and implementation in practice is relevant. The purpose of the proposed review was to identify the extent of IoT implementation in container industry, to determine the degree of scientific study on application areas, and to try to identify factors that may hinder the rapid development of IoT in containerization.

The main material. The expansion of IoT applications in the container industry over the last decade has been driven by several factors, including advancements in connectivity (such as 4G/5G networks), cloud computing, big data analytics, and the demand for real-time supply chain visibility. The key applications of IoT in container shipping can be categorized into the following:

Real-Time Tracking and Monitoring. IoT sensors embedded within containers allow operators to monitor their location, movement, and environmental conditions in real time. This is crucial for industries that deal with perishable goods, pharmaceuticals, and high-value cargo that require strict temperature and humidity control. Smart containers equipped with GPS sensors, temperature sensors, and accelerometers provide real-time data on location, cargo status, and environmental conditions, enabling proactive decision-making in case of deviations.

Supply Chain Optimization. IoT helps optimize logistics processes by providing end-to-end visibility of the supply chain. Real-time data on container movements help shipping companies and logistics providers optimize routes, manage fuel consumption, and avoid delays caused by congested ports or other disruptions. Predictive analytics, powered by IoT data, can forecast demand, allowing better management of container fleets and improving asset utilization.

Security and Risk Management. Security concerns in container shipping, such as cargo theft, smuggling, and damage, have long been a challenge. IoT devices help mitigate these risks by providing enhanced security features. Smart locks, intrusion detection sensors, and geofencing technology enable operators to monitor for unauthorized access or tampering with containers. In the case of hazardous goods, sensors can also detect leaks or temperature changes that might pose safety risks.

Automation and Efficiency. The integration of IoT into ports and terminals has streamlined operations through automation. IoT-enabled cranes, container handling equipment, and automated guided vehicles (AGVs) at smart ports reduce labor costs, increase throughput, and minimize human error. Additionally, IoT facilitates faster customs clearance processes by providing authorities with real-time data on container contents and movements, improving the overall efficiency of global trade.

While IoT has significantly improved the container industry, several challenges remain:

– connectivity issues: despite advances in communication technologies, containers often pass through remote areas (e.g., during ocean transit) where network coverage is limited or unreliable. Satellite connectivity, though available, can be costly and may not be feasible for all operators.

– data overload and integration: the vast amount of data generated by IoT sensors can be overwhelming if not properly managed. Integration of IoT data into existing logistics management systems is another challenge, particularly for smaller companies with limited technological infrastructure.

– cybersecurity risks: as more containers become connected to the internet, cybersecurity threats increase. IoT devices are vulnerable to hacking, which could lead to theft, disruptions in supply chains, or tampering with critical data.

– standardization: the lack of industry-wide standards for IoT devices, protocols, and data formats complicates the interoperability between different stakeholders in the shipping ecosystem. This can lead to fragmented solutions that hinder the seamless flow of information across the supply chain.

Literature survey.

One of the first research articles on the application of IoT in shipping and intermodal transportation is a 2010 study that describes the implementation of telematics technologies to improve the management of cargo operations using IoT. The article touches on aspects such as real-time monitoring of containers using RFID and sensor technologies to help improve transparency and efficiency in supply chains [2].

To streamline the literature analysis, we will divide them into 7 groups, according to the directions of research in this field: 1). container monitoring and tracking; 2). enhancing supply chain transparency and visibility; 3). optimization of operational efficiency; 4). security and risk management 5). environmental impact and sustainability; 6) challenges and barriers.

Container Monitoring and Tracking. One of the most immediate and impactful applications of IoT in container shipping is real-time tracking and monitoring. IoT-enabled sensors are embedded in containers to provide real-time data on location, temperature, humidity, and security status. This capability is particularly valuable for sensitive cargo, such as pharmaceuticals and perishable goods.

The key results in this sector are as follows: IoT enables precise container tracking across oceans and international borders, thus reducing delays and improving logistics management [3]. IoT sensors help in ensuring compliance with international regulations related to the transport of sensitive materials, especially by maintaining optimal temperature ranges during transit [4]. Predictive analytics derived from IoT data can anticipate delays and mitigate disruptions by suggesting alternate routes or adjustments to scheduling [5].

Enhancing Supply Chain Transparency and Visibility. IoT plays a vital role in enhancing supply chain visibility. It enables real-time communication among stakeholders, including shippers, carriers, port operators, and customs authorities, fostering a more integrated and transparent supply chain network. The main conclusions on this direction are proved in scientific articles in the works: enhanced visibility allows stakeholders to monitor the exact movement of goods, leading to reduced instances of cargo theft, misplacement, or delays at checkpoints [6]. Supply chain visibility offered by IoT has shown to improve inventory management and demand forecasting, reducing overstocking or understocking issues [7]. IoT facilitates blockchain applications in shipping, which improve trust, transparency, and the traceability of goods across the supply chain [8].

Optimization of Operational Efficiency. Another major benefit of IoT in container shipping is the optimization of operations through data-driven insights. Smart ports, automated cranes, and container-handling equipment integrated with IoT technologies streamline processes, thus reducing operational inefficiencies. The integration of IoT with artificial intelligence (AI) and machine learning (ML) allows for more efficient loading and unloading processes by forecasting peak times and allocating resources accordingly [9]. Automated guided vehicles (AGVs) used in ports, powered by IoT, reduce human intervention and improve safety while enhancing throughput [10]. IoT data supports predictive maintenance, reducing equipment downtime by preemptively identifying potential mechanical failures in ships and port infrastructure [11].

Security and Risk Management. The container shipping industry faces various security challenges, from piracy and theft to container tampering. IoT technologies can mitigate these risks by offering real-time monitoring and alerts. IoT-enabled seals and locks equipped with sensors can detect and report unauthorized access or tampering

during shipment [12]. Risk management is enhanced through early warning systems that monitor environmental factors, such as storms or sea conditions, allowing vessels to avoid hazardous routes [13]. IoT systems also aid in ensuring the safety of crew and assets by integrating with maritime safety systems to monitor ship stability and provide alerts about potential safety risks [14].

Environmental Impact and Sustainability. Sustainability is an increasingly important issue in global shipping. IoT has shown promise in reducing the environmental footprint of container shipping by enabling smarter resource management and more efficient fuel use. The conclusions of this research area are as follows: IoT sensors monitor fuel consumption and engine performance, enabling shipping companies to optimize routes, reduce fuel usage, and minimize emissions [15]. Smart containers equipped with IoT devices help in the efficient loading of ships, reducing ballast water use [16] and lowering the overall energy consumption per voyage (17). IoT-enabled waste and emissions monitoring systems ensure that ships comply with international environmental regulations, such as the International Maritime Organization's (IMO) emissions standards [18].

Challenges and Barriers. Despite the numerous advantages, several barriers limit the widespread adoption of IoT in container shipping, including data security concerns, the high cost of implementation, and interoperability issues. The researchers' main findings are: data security is a significant challenge, as IoT systems are vulnerable to cyber-attacks, including hacking and data breaches. Encryption and other cybersecurity measures are critical for protecting sensitive shipment data [19]. A lack of standardization in IoT technologies across countries and ports limits the seamless integration of systems, which hampers the full potential of IoT-enabled global logistics [21].

Recognizing the rapid pace of IoT development, some researchers give an estimate for future directions of IoT implementation. The literature suggests that the future of IoT in container shipping will involve more widespread adoption of smart ports, integration with other emerging technologies like blockchain and AI, and increased focus on sustainability and resilience. Smart ports, equipped with IoT, AI, and 5G technologies, are likely to become the norm, facilitating faster and more secure processing of containers [22]. Continued advancements in IoT security protocols and standardized frameworks will make global IoT systems more interoperable and scalable [21]. There is potential for IoT-enabled systems to help container shipping adapt to global challenges, such as climate change and pandemics, by providing more resilient and adaptive supply chain networks [23].

IoT's implementation areas. The IoT plays a transformative role in intermodal transport, which involves the seamless movement of goods across multiple modes of transportation (e.g., ships, trucks, trains). IoT technologies are used to enhance visibility, efficiency, safety, and overall operational effectiveness across the logistics chain. Below are key IoT applications in intermodal transport (fig. 2).

Real-Time Tracking and Monitoring. IoT-enabled devices like GPS sensors, RFID tags, and telematics systems allow for real-time tracking of cargo and vehicles throughout the intermodal network. This data provides: accurate location of goods in transit, condition monitoring for perishable or sensitive items (e.g., temperature, humidity, vibrations), timely alerts for delays, route changes, or cargo theft, enabling proactive responses (fig. 3).

Asset Management. Intermodal transport requires efficient use of assets such as containers, trailers, and railcars. IoT helps by: tracking container utilization to prevent idle assets and optimize space, monitoring wear and tear of equipment, enabling predictive maintenance and minimizing downtime, automating inventory updates, which helps operators avoid loss and theft.

Fleet Management. IoT solutions improve fleet management by: optimizing routes through real-time traffic data and weather conditions, reducing fuel consumption and delivery times, monitoring vehicle health via sensors that track engine performance, tire pressure, and other critical parameters, reducing breakdowns and maintenance costs, driver behavior analysis, promoting safe driving practices and reducing accidents.

Automation and Smart Warehousing. IoT plays a role in automated handling of goods and warehouse operations: automated loading and unloading processes using IoT-linked robots and sensors, smart inventory management through IoT-enabled systems that track goods entering and leaving warehouses in real time, minimizing manual labor, dynamic storage allocation based on the type of goods, temperature requirements, or shipment schedules.

Smart Port and Terminal Operations. In seaports and rail terminals, IoT enhances operational efficiency by: automating container handling through smart cranes and IoT-connected equipment, predictive maintenance of port machinery based on sensor data to minimize equipment failures, optimizing traffic flow within the terminal by monitoring the movement of vehicles and coordinating load scheduling.

Data Analytics for Decision-Making. IoT generates massive volumes of data that can be used for: predictive analytics, forecasting delays or disruptions in transport based on historical patterns, optimizing supply chain networks by analyzing bottlenecks and inefficiencies in real time, improving customer satisfaction through data-driven insights that enhance delivery accuracy and speed.

Environmental Monitoring and Sustainability. IoT is crucial for improving sustainability in intermodal transport by: monitoring emissions and optimizing fuel usage, leading to reduced environmental impact, energy-efficient route planning, which minimizes unnecessary detours and fuel consumption, smart containers that maintain optimal conditions for perishable goods, reducing spoilage and waste.

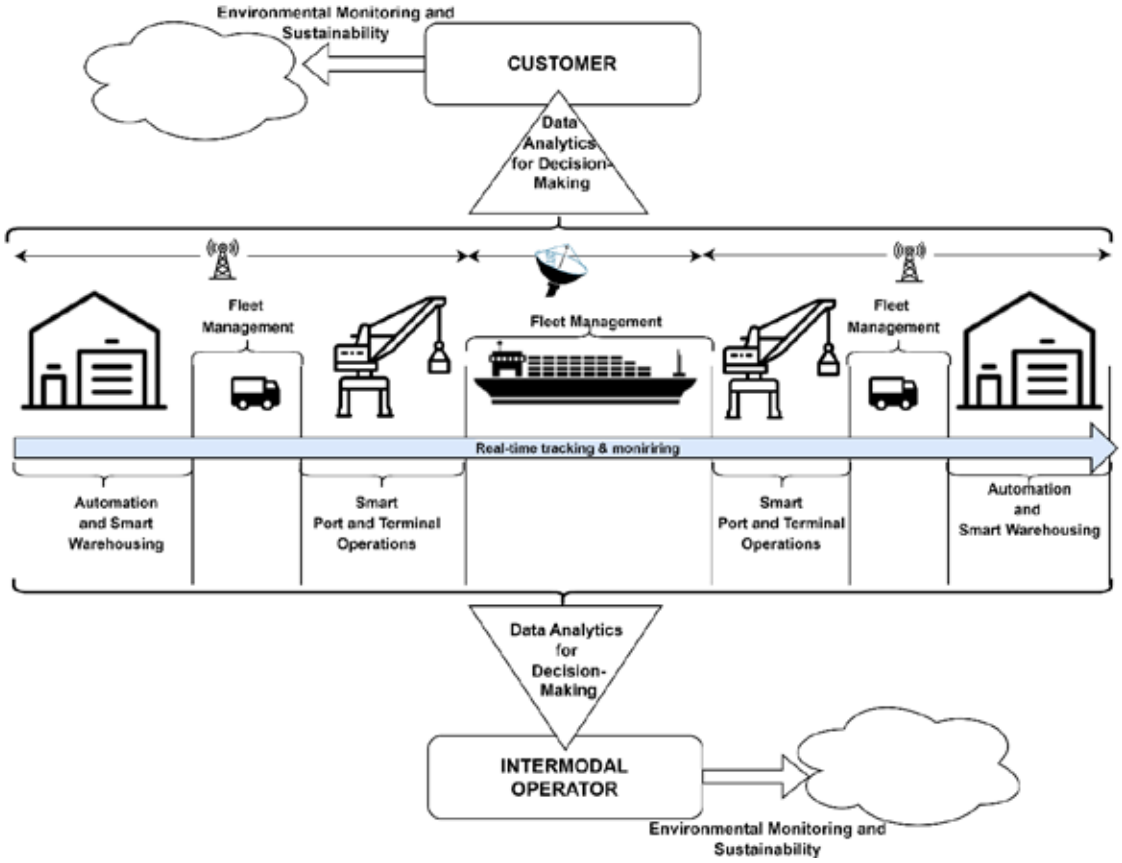

Fig. 2. IoT's implementation areas in containerization

Source: Compiled by the author

Fig. 3. Container IoT sensors data output

Source: Compiled by the author based on [25-31]

Security Enhancements. IoT systems contribute to higher security standards in intermodal transport by: enabling geofencing, where alerts are triggered if a vehicle or container deviates from its pre-set route, monitoring cargo conditions, such as tampering or unauthorized access to goods, biometric or RFID-based access control for secure areas in transport hubs, enhancing cargo security.

Collaborative Networks. IoT connects stakeholders across the intermodal transport network (shipping companies, port operators, rail companies, truck fleets) for better coordination: information sharing through IoT platforms that allow real-time data exchange. integration of different systems, enabling end-to-end tracking across multiple transport modes, collaborative planning using shared data to optimize shipping schedules and cargo handling. So, IoT applications make intermodal transport smarter, more efficient, and responsive, significantly enhancing global supply chain operations.

IoT-technology practical implementation. The intermodal transportation companies (global forwarders, container operators, NVOCC) each use a variety of IoT products and solutions to monitor freight, vehicles, and optimize operations. Here are examples of specific IoT products and technologies used by leading companies in the industry:

Maersk uses its own RCM system to monitor refrigerated containers. It incorporates IoT sensors to measure temperature, humidity and location in real time. This data is transmitted via satellite communication for analysis and control [31]. The partners of Maersk are AT&T, Ericsson (for data transmission via satellites).

Another major container operator, CMA CGM TRAXENS uses an IoT-solution for container monitoring that provides data on location, shock, vibration, temperature and opening/closing of container doors. It helps to monitor the condition of containers in real time and prevent cargo damage. The technology is based on IoT-based sensors connected via GSM or satellite communication. Other intermodal companies such as MSC, Kuehne+Nagel, Schenker, Bollore Logistics are also customers of TRAXENS.

Hapag-Lloyd uses IoT to track the temperature and location of containers. The system helps customers get real-time data on the status of transportation, which is especially important for perishable goods. Hapag uses IoT devices made by Orbcromm and Nexxiot to provide customers with container location information through its «Live Position» digital tool. The tracking service is free of charge when Hapag acts as a Carrier's Haulage, and costs 15 USD as a special fee (LPC) for cases when the client organizes ground transportation on their own (Merchant's Haulage).

UPS uses a product ORION (On-Road Integrated Optimization and Navigation), an IoT-based system that analyzes real-time data to optimize delivery routes. It reduces fuel costs and delivery time, improving the efficiency of UPS operations. The technology includes GPS sensors, vehicle condition sensors, and machine learning algorithms [30].

Kuehne+Nagel's IoT-enabled platform that provides real-time visibility of shipments across all transport modes. It's leverages IoT sensors to collect data on the exact location, environmental conditions (temperature, humidity), and the security status of goods. It allows customers to track their cargo in real-time, offering greater transparency and control throughout the supply chain. This logistic company has introduced IoT-enabled smart containers to monitor cargo during ocean freight. These containers are equipped with sensors that track real-time data on temperature, location, and movement. This is particularly important for industries requiring high levels of security or specific environmental conditions, like food and beverages or pharmaceuticals.

Conclusions. As a result of analyzing the scientific literature and examples of technology use, several conclusions can be drawn. Both of them lie on a purely technical level: since the sensor is mounted locally inside the container (e.g. at the container's door), how much the sensor readings reflect the situation in the container as a whole. Considering the cost of the devices or ordering a monitoring service from the carrier, the need for multiple sensors inside a single container to adequately display data can be a serious problem for highly sensitive good's transportation or for smaller transportation companies (or cargo owners).

The lag between the development of standards and the practical application of IoT is a serious threat to the container industry, as the lack of standards makes it difficult for different devices and systems in the system to communicate and work together seamlessly. Because IoT devices are manufactured by different companies and can use a wide range of communication protocols and data formats, making it difficult to develop a single standard that will work across all devices. The lack of standardization creates interoperability issues that can lead to compatibility problems and limited functionality.

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