INNOVATIONS IN LOGISTICS NETWORKS ON THE BASIS OF THE DIGITAL TWIN

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ABSTRACT

Innovations in logistics networks could be developed on the basis of advances in networking technology allowing to link previously autonomous physical assets in logistics networks with modern digital models. So, the changes experienced by the physical object in the logistics infrastructure are reflected in the digital model, and the conclusions drawn from the model allow making decisions about the physical object, the control of which becomes unprecedentedly accurate. Research gap consists in the fact that there is a lot of research in the field of digital twins as well as on the study and optimization of logistic paths, enterprises, cities, route sections, but there are no developments in the evolution and synchronization of separate objects' digital twins into a single network. The article aims in examining the constituent elements of the digital twin of the logistics hub as an infrastructure innovation. The proposed model of the digital twin is considered at various scales, starting from the characteristics of the simplest digital twin and moving towards the constituents of the most complex digital twin capable of simulating entire logistics terminals and cities. The authors analysed specific examples of digital twins in infrastructure and urban planning. The research includes various implementations of digital twins in logistics infrastructure globally. Building a mathematical model, the authors take into account the potential applications of the digital twin technology in routine operation.

Keywords: Innovations, Logistics Networks, Logistics Digital Hub, Digital Twin

INTRODUCTION

In the modern world, the mathematical models and network technologies created are increasingly becoming technologically complex (Hartley & Sawaya, 2019; Zhuang et al., 2021; Genkin & Mikheev, 2020), leading to the emergence of digital twins. Although the concept of a digital twin (Kritzinger et al., 2018) has only existed since the early 21st century, this approach is now reaching a tipping point and it is likely that the technology will become widespread in the near future. It is worth noting that a number of key technologies have already reached a certain level of maturity required to support the use of digital twins for enterprise applications. These technologies include low-cost storage, processing power, reliable high-speed wired and wireless networks, and so on (Barykin et al., 2020c, 2020b; Marmolejo-Saucedo, 2020). Since physical objects were critical assets and were quite expensive, this makes it difficult to create digital twins and limits their use. At the same time, there are already a relatively small number of other applications that use the same combination of expensive assets that justify a large capital investment (Merdan et al., 2019; Qi et al., 2018).

With the practical implementation of this project, the prospect of continuous routing of both planned and current logistics processes at an automatic level will open up for the entire logistics block.

The purpose of the study is a detailed analysis and consideration of digital twins as logistics innovations including innovations in logistics' infrastructure, transportation, container shipping etc. The researchers attempt to develop the approach to logistics innovations on the basis of the digital technologies, constituting elements of digital twins at various scales, as well as creating a twin of the logistics block of digital hubs. Advances in networking technology allow to link previously autonomous logistics infrastructure physical assets with modern digital models. Therefore, the changes experienced by the logistics physical object are reflected in the digital model. So, conclusions drawn from the model allow making decisions about the physical object, the control of which becomes unprecedentedly accurate.

LITERATURE REVIEW AND METHOD

Literature Review

The Main Features of the Digital Twin as Logistics' Innovation

Today, companies use their own products as part of their normal business processes. A new model termed the Open Innovation has emerged for organizing technological innovation in large R&D-intensive companies. It is important to understand how the open innovation concept can be analyzed from an industrial dynamics perspective, particularly considering the complex interplay between technology entrepreneurs and incumbents (Christensen, Olesen & Kjær, 2005). Open innovation channels can be explored through specifically constructed concept models, which can be useful to motivate engineering research increasing the development of open innovation and new open business models (Yun, Kim & Yan, 2020).

Companies rely a diverse range of tools to generate much of the data needed to create a digital twin. For example, Computer-Aided Design (CAD) and modeling tools are commonly used in product development (Ramnath et al., 2020; Zhang & Zhou, 2019). Many products, including consumer electronics, automobiles, and even home appliances, now include transmitters as standard.

It is worth noting that many "tech" players are watching this potentially lucrative space. The wide range of underlying technologies required for digital twins is prompting both small companies and large technology companies such as SAP, Microsoft and IBM to enter the market (Bevilacqua et al., 2020; Lu et al., 2020; Wang et al., 2019). These organizations are well positioned to leverage their cloud computing, artificial intelligence, and corporate security to create digital twins. In addition, automation and industrial equipment manufacturers such as GE, Siemens and Honeywell are ushering in a new era of digital twin-based industrial equipment and services (Baskaran et al., 2019; Saqlain et al., 2019). Examples include companies offering Product Lifecycle Management (PLM) such as PTC and Dassault Systèmes (Camba et al., 2017; Sodhro, Pirbhulal, and Sangaiah, 2018). The aforementioned companies use digital twins as the fundamental underlying technology to manage product development from initial concept to end of life. The capabilities of digital twins are also gaining attention from startups, with players like Cityzenith, NavVis and SWIM. AI developing their own offerings tailored to specific niches and use cases (Heller, Liu & Gianniou, 2017; Ray, Dash & De, 2019; Wei & Akinci, 2019).

For the research purpose the authors consider a conceptual apparatus.

A Digital Twin (DT) is a virtual prototype of a real object, a group of objects or processes (Tao et al., 2019). A digital twin is a complex software product that is created using a wide variety of data. The digital twin is not limited to collecting data obtained during the development and production of a product, it continues to collect and analyze data throughout the entire life cycle of a real object, including using numerous IoT sensors.

Combining definitions from various sources, we can give the following list of features of the concept of DT:

- A digital twin is a digital copy of a specific physical object, which shows what the parameters are, such as the intensity of operation, failures that have occurred, as well as the history of internal processes and possible consequences (Ivanov & Dolgui, 2020);
- The digital twin is based on multiphysics mathematical modeling of various physical processes that determine the properties and behavior of an object;
- The digital twin is associated with the specific conditions in which the real object operates. This is a model that accumulates information about a real object as it is used in specific conditions. For two structurally identical objects of research, the digital twin will be different if they are operated in different conditions (Barykin et al., 2020a);
- Digital twin allows to use the work of a virtual object to better understand how to optimize the work of a physical object (Qi & Tao, 2018);
- The digital twin helps to understand how the physical twin (real object) works in the real world, and can predict how this will work in case of timely adjustments in the future (Ait-Alla et al., 2019);
- The digital twin allows you to collect data about a physical object and, using predictive analytics tools, make predictions about the state and real capabilities of this object;
- The digital twin allows you to troubleshoot remote equipment and perform remote maintenance;
- A digital twin based on the simulation of physical processes uses data that cannot be obtained on a physical object.

Thus, the concept of digital twin technology allows simulating a variety of situations that arise during the production process. Thus, the technology allows avoiding failures and force majeure circumstances, projected optimal scenarios of technological processes.

Components of the Digital Twin

Mathematical models constructed for real objects have become increasingly technologically complex over the years. In practice, with so many different applications and stakeholders, there is little consensus on what constitutes a digital twin. As the research examples show, digital twins come in different forms using different tools.

When analyzing opinions from open data, many agree on key characteristics that are inherent in most digital twins. Below are the attributes that help to distinguish "real" digital twins from existing computer models, simulators of other types (Lee, Bagheri & Kao, 2015):

- A digital twin is a virtual model of a real object.
- The digital twin simulates both the physical state and the behavioral characteristics of the object.
- A digital twin is unique and associated with one specific instance of an object.
- The digital twin is associated with an object, updating itself in response to known changes in its state or context.
- The digital twin provides its need for visualization, analysis, forecasting or optimization of the necessary processes.

In this situation, it is worth noting that the digital twin can exist before its physical counterpart is created and persist long after the object reaches the end of its service life. One object can have more than one twin, with different models created for different users and use cases, such as planning a what-if scenario or predicting the behaviour of an object in future operating conditions. For example, management organizations, customs authorities, or charterers can create multiple models of an existing facility as they assess the impact of changes in layout or workflow.

Researchers and technology companies today are looking at modelling digital twins at different scales: the smallest digital twin can represent the behaviour of certain materials, chemical reactions, or drug interactions. On the other hand, the “big” digital twin can simulate entire megacities (Cocchia, 2014; Sutherland, 2018; Yun & Lee, 2019).

One notable trend is the development of larger and more complex digital twins as organizations move from modelling single products or machines to modelling entire production lines, factories and facilities. Likewise, efforts are being made to create digital twins of entire cities or even national energy infrastructure and transport networks. In this article, the potential possibility of introducing digital twin technology into the system of digital logistics hubs will be presented for consideration.

Technological Base of the Digital Twin

Let's take a look at the main digital twin technologies. To create digital technologies, five technological trends complement each other, namely Internet objects, cloud computing, APIs (Application Programming Interface) and open standards, artificial intelligence and digital reality technologies (Kurfess et al., 2020).

Each trend could be considered as follows:

Internet of Things (IoT). The rapid growth of Internet objects is one of the important factors contributing to the introduction of digital twins. Internet object technologies are making digital twins possible because it is now technically and economically feasible to collect large amounts of data for a wider range of objects than before (Errandonea, Beltrán & Arrizabalaga, 2020; Malik & Bilberg, 2018; Singh et al., 2019). Companies often underestimate the complexity and volume of data generated by Internet object products and platforms, in need of a set of tools to help them manage all the data they collect. The digital twin is often the ideal tool and way to structure, analyze & analyze complex product-related data. Digital twins rely on many underlying technologies that are only now reaching the point where they can be applied reliably, economically, and at scale.

Cloud computing: Designing, maintaining and using digital twins is a computationally intensive task. The ever-falling cost of computing power allows companies to acquire exactly the computing power they need, exactly when they need it, while keeping costs in check.

API and open standards: Closed, highly focused modelling tools as well as manufacturing automation platforms are increasingly becoming a thing of the past. Tech companies created and protected their own data models, which required intensive software development from scratch in order to build infrastructure from scratch for each new product. Now the availability of open standards and publicly available application programming interfaces (hereinafter referred to as API) greatly simplifies the use and exchange of data, which, in turn, allows users to quickly and reliably combine data from multiple systems.

Artificial Intelligence (AI): Artificial intelligence is driving significant improvements in the power and usability of advanced analytics tools have changed the way companies extract useful information from large and complex datasets. Machine learning frameworks allow you to design systems that can make decisions autonomously and predict future conditions based on historical and real-time data.

Augmented, mixed and virtual reality: Today, most digital twins are rendered in two-dimensional space, as modern computer regulations limit us to displays on monitors, laptops and other screens. In order to use and effectively apply the ideas obtained with the digital twin, they must be displayed either on the screen (2D) or in physical space (3D) (Bouwman et al., 2018; Zhu, Liu & Xu, 2019). In the digital age, more and more augmented reality allows us to display digital content in 3D. In addition, mixed reality allows us to interact with digital content in our existing physical environment. Virtual reality allows us to create a completely new environment for visualizing digital twins with full immersion, ensuring maximum consumption of information and interaction with it.

While the aforementioned technologies-Internet Objects, Cloud Computing, APIs, and Artificial Intelligence - provide the basic perceptual and processing infrastructure needed to create a digital twin, augmented, mixed and virtual reality are tools for visualizing digital twins and making them a reality.

Ultimately, digital twins can represent any physical object, from nano materials to entire cities and logistics networks. In some cases, even people and their behaviour can be modelled by digital twins in order to determine the likelihood of this behaviour. The following examples show how digital twins can solve a wide range of business challenges and open up many different sources of value.

The Theoretical Foundations of the Digital Twin as a Logtistics' Innovation

Digital Twins in Logistics

Although digital twins have yet to gain ground in logistics, many of the key twins already exist. In the logistics sector, markers are used to place loads. Today, the industry is also increasingly adopting open API strategies and migrating to cloud IT systems (Wu et al., 2015). Companies are applying machine learning and advanced analytics to optimize their supply chains and extract new insights from operational data and historical shipping data. Logistics professionals are also deploying augmented, mixed and virtual reality applications for tasks such as task data well suited for creating digital twins for this environment.

However, the combination of these and other technologies in a full-fledged digital dual mode of complex work. The cost sensitivity of many logistics operations may explain why few companies have been willing to invest so far. It is clear that the study of the use cases of digital twins in the logistics space is justified. As costs decrease and confidence in technology increases, the business case for some of the approaches in this article could become completely descriptive in the coming years.

Digital Twins in Container Shipping

Digital twins can also help logistics companies manage their container fleets more efficiently. Reusable containers are the industry standard in the logistics industry. These include standard ocean-going containers, ULDs for aircraft, reusable crates for transporting auto parts between factories, and containers for delivering food and beverages to retail stores and end consumers.

Tracking such containers can be difficult. Companies must not only manage the movement of containers from the last destination to where they are needed next time, but they must also check for damage and contamination that could jeopardize future shipments or pose a hazard to personnel or other property.

New technologies in 3D photography, such as those developed by the German startup Metrilus, allow the rapid creation of a detailed model of a container, which in turn automatically identifies potential problems such as dents or cracks in a container (Krasnov et al., 2019; Lim, Zheng & Chen, 2020). This information can be combined with previously obtained container usage and movement data to create a digital twin. This use of the digital twin will allow decisions to be made about when a particular container should be used, repaired or discarded.

Moreover, aggregating such data across a fleet of containers can help owners make optimal decisions about the size and distribution of the fleet and identify problems such as a lack of integrity in the container design or rough handling of the container, which, in turn, occurs at specific points in the supply chain.

Digital twins in Shipping

The next logical step is to include the contents of a package or container in its digital twin. If the digital twin of the item to be sent has already been created, the data describing its geometry can be obtained, for example, from this already existing source. Alternatively, item data can be generated during shipment preparation using 3D scanning and the same computer vision technologies mentioned in the previous section.

Consolidating product and packaging data can help companies improve efficiency, for example, by automating packaging selection and container loading optimization strategies to make the most efficient use of usable space and increase the likelihood of cargo retaining without disrupting product packaging.

It is already customary to ship fragile and expensive products, such as pharmaceuticals and electronic components, with sensors that monitor temperature, packaging orientation in space, shock and vibration. The latest version of this type of equipment, such as those developed by the companies "Roambee", "Blulog", "Kizy" and others, include sensors that are supposed to continuously transmit data during cargo transportation (Foroughi, 2020; Jedermann, Praeger & Lang, 2017).

The digital twin of the shipment will act as a repository for the data collected by these sensors. Digital twin technologies can also allow this data to be used in new ways (Gromova, 2019). For example, a model that incorporates the thermal insulation and damping characteristics of a package may allow extrapolation of cargo performance based on data collected by external sensors.

Digital twins

Warehouse and distribution center

Digital twins can have a significant impact on the design, operation and optimization of logistics infrastructure, such as warehouses, distribution centers and transfer stations (Korth, Schwede & Zajac, 2018). These digital twins can combine a 3D model of the object itself with Internet object data collected from connected warehouse platforms, as well as inventory and operational data, including size, quantity, location and characteristics for each item.

Warehouse digital twins can support the design and layout of new facilities, allowing companies to optimize space use and simulate the movement of products, personnel, and handling equipment.

During warehouse operations, the digital twin can be constantly updated with data obtained using various automation technologies that are becoming more common in warehouses. These include drone-based inventory systems, automated guided vehicles, personnel collection systems, and automated storage and retrieval equipment. Digital twins will also further optimize the performance of these automation systems, for example by leveraging sensor data, simulations and monitoring technologies to reduce energy consumption while maintaining the required bandwidth.

Comprehensive 3D asset data can also be used to improve the productivity of warehouse staff. Companies can develop virtual reality learning tools such as augmented reality picking systems using host devices such as Google Glass Enterprise Edition or Microsoft HoloLens, tools that are already being piloted by DHL Supply Chain internationally (Siriborvornratanakul, 2018).

Perhaps the most compelling argument for using digital twins in warehouses and similar facilities is their contribution to continuous productivity improvements. Comprehensive data on the movement of inventory, equipment and personnel can help in identifying and eliminating the problem of inefficient use of time resources during operations in the warehouse: from congestion in busy aisles to poor productivity or recruiting errors. Before making field changes, simulations using digital twins can allow site managers to test and evaluate the potential impact of layout changes or the introduction of new equipment and new processes.

In environments such as e-commerce, which must accommodate rapid changes in volume and inventory, digital twins can also support dynamic optimization of operations. Stock locations, staffing, and equipment placement can be continuously adjusted to meet current or projected demand.

Digital Twins in Logistics Infrastructure

Warehouses and distribution centers are only part of the entire logistics infrastructure. The flow of goods from destination depends on the consistency of many elements, including ships, trucks and airplanes, ordering and information systems, and most of all people.

This complex multi-stakeholder environment can be seen most clearly in large global logistics hubs such as cargo airports and container ports. At these sites today, the problem of efficient operation is compounded by imperfect communication systems, where many participants rely on autonomous processes that are subject to errors and delays.

A project is currently underway in Singapore to use digital twin technologies to address the above issues. The Port of Singapore Authority is working with a consortium of partners, including the National University of Singapore, to create a digital twin of the country's new megahub for container shipping.

University professor Lee Hu Hei is leading the technical and research development of this initiative (Lu et al., 2019). He says digital twin technology is finally becoming a reality through the convergence of technological advances. “Simulation Driven Optimization, Industry 4.0, and Internet Objects have been around for a while. However, it was the boom in artificial intelligence and its predictive capabilities that gave digital twins such a big boost in value creation. In the past, creating spatial models in digital form was promising, but it was not something global, like a way to statically render an object. Today, all the data we receive from analytic markers, historical characteristics and behaviour inputs can be associated with a spatial model and predict future behaviour by changing various inputs. In fact, data and predictive capabilities bring the spatial model to life. ”

The new “approach” of the digital twin is already providing advantages at the design stage of the Singapore project (Bolton et al., 2018). The consortium uses its digital models to accelerate the creation of potential schematics, and its modelling systems to evaluate various operational scenarios. Ultimately, the Port Authority hopes the digital twin will help streamline the management of the new facility. Using simulation, for example, he will be able to choose the optimal anchorage for a ship of any given size, taking into account the assets, space and personnel required for loading and unloading operations, and the need to share these resources between several ships at any time.

While Singapore has a bold vision for the use of digital twins in large scale logistics infrastructure, the ultimate success of any such initiative depends on the willingness and technical capabilities of all stakeholders. A living digital twin of a port or airport will require each organization using such a facility to manage and maintain the digital twin of its own assets and personnel, and to exchange relevant data in real time with other users.

In logistics, the ultimate digital twin will be the model for the entire network, including not only logistics assets, but also oceans, railways, highways, streets, homes and customer workplaces. The idea of such an all-encompassing twin, even the one described earlier in this chapter, is now largely a development ambition for the logistics industry. However, it is important to foresee what the full implementation of logistic digital twins can lead to (Grieves & Vickers, 2016).

The Methodology of the Research

Within the framework of this study, 7 representatives of the sphere of providing logistics services were interviewed, they included both brokerage organizations and transport organizers. During the anonymous survey, the respondents were asked the following questions with the following generalized thesis answers:

1. Have you heard about digital twin technology and do you think its application is possible in the field of logistics?
   - The use of digital twins of supply chains is possible and is a very rational approach, since it allows you to monitor, predict and simulate the situation in the logistics market.
2. In your opinion, what impact will the organization of economic ties have in the creation of logistics hubs on a territorial basis, positive or negative?
   - -Positive, since it will simplify the procedure for preliminary declaration of goods, will allow the introduction of a system for standardization of goods and the abolition of fictitious certification centers.
3. Will the integration of the digital twin system into logistics hubs and the logistics inter-hub network be positively or negatively?
   - -Yes, this tool will allow predicting the traffic saturation of logistics routes, based on data collected from all network nodes.
4. Will the system of the logistics network of hubs with integrated digital twins accelerate the transportation process?
   - -Yes, this will make it possible to implement "tunnel transportation" along a pre-calculated route, taking into account the automated calculation of many factors.
5. In your opinion, will there be a positive effect from the implementation of the digital logistics inter-hub network project?
   - Yes, within the framework of this project, it will become possible to unite the participants in customs clearance, formalize all control processes between customs posts and authorities, transparent registration of goods without certification commercial companies, eliminate the problems of office disunity, strengthen control over weight trans shipments, which means an increase in the number of traffic - volume work and jobs.

As for the possibility of making optimal decisions in the process of managing the supply chain, these data become the arguments of the mathematical model. The main task is the formation of algorithms for the development of management decisions in relation to supply chains. The development of a set of formalisms underlying an adequate mathematical description provides a solution to a number of important problems in the field of freight traffic management, which will make it possible to move on to the algorithmization of this particular type of digital twins:

- The possibility of end-to-end support of any commercial transactions
- Strategic planning using innovative methods based on leading economic, political and other indicators
- Use of well-formalized methods of the mathematical theory of stochastic control to find solutions to logistics problems in the face of global uncertainty
- Interaction in real time with a dynamically changing demand for logistics services
- Simulation of stress tests, which will allow maintaining high indicators of sustainability of management decisions and their effectiveness

In terms of the size of the physical objects that digital twins represent, some of the largest twins today are replicas of urban infrastructure such as energy and transportation networks and urban environments.

One example of the successful integration of the digital twin technology into the transport and logistics system is the project of the British company "Alstom". Alstom, a UK-based railway equipment company, has created a digital twin to simplify the management of train maintenance operations on the West Coast main line.

Alstom's digital twin includes detailed information about each fleet, as well as work schedules and maintenance mode. It simulates the available capacity at each of Alstom's five service stations. The model, running in the AnyLogic simulation environment, uses a heuristic algorithm to schedule maintenance work and distribute it to the most appropriate storage. Since the system is connected to real-time information about the location and planned movements of trains, it can constantly adapt maintenance plans for urgent repairs. Maintenance planners also use what-if analysis to examine the impact of changes on maintenance strategies.

A system of a similar action has already been adopted by Russian Railways and is currently undergoing beta testing.

Finnish transmission system operator Fingrid has worked with IBM, Siemens and other partners to create a digital twin of Finland's electricity grid. The Electricity Verkko or ELVIS Information System combines eight different systems into one application, providing Fingrid with a consistent, comprehensive and constantly updated model of its network. The digital twin is used in the day-to-day operation of the network, helping personnel manage power flows and protection settings to meet demand without overloading transformers and transmission lines. It also supports design and planning activities by allowing the operator to simulate the likely impact of changes in network configuration or investments in upgraded assets.

Meanwhile, in Andhra Pradesh, India, a digital twin of a brand new city is being developed. Designed by Foster and Partners, the Amaravati doppelganger will serve as the new capital of the state, which is needed following the reshuffling of regional boundaries torn away from the original capital, Hyderabad.

RESULTS

Digital Twins of Global Logistics Networks

The whole process of creating a global digital twin can be divided into several stages:

- At the first stage, it is necessary to create local “rough” digital twins of cargo distribution centers of customs zones. This measure will allow an analysis of the real processes of distribution and clearance of goods in parallel with the theoretical model in order to identify vulnerabilities.

As part of the first stage, a base should be created for digitizing the processes of customs authorities' activities with parallel integration of customs document management software into the «local customs digital twin» (LCDigTwin) system, as well as a base of managing organizations with models of warehouse acceptance points, distribution centers, controlled by them, temporary storage warehouse, etc. Implementation of the set task will allow eliminating ineffective elements from the local system, unifying all processes and bringing them to a single standard for the digital hub «Local digital hub» (Guinan, Parise & Langowitz, 2019).

- The second stage includes the creation of digital templates for commercial participants in the logistics network with the possibility of restructuring and modifying elements for each specific participant. This project will contribute to the standardization of users and the attraction of private capital. As part of the second stage, in order to create a full-fledged digital hub, doubles of private warehouses for group age cargo, specialized storage centers (dangerous goods, freezing, cargo subject to special accounting, etc.), container parks and specialized parks should be created in the digital space. Containers, car parks and repacking sites, as well as brokerage organizations and certification bodies.

The cumulative result of the first and second stages of creating a digital twin system of the logistics network will allow compiling data on the interactions of participants in the supply chain "Seller - Logist - Buyer" and the created customs clearance algorithm into a local digital hub (Figure 1).

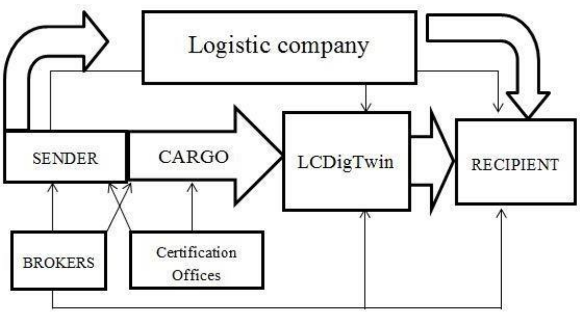

FIGURE 1
SCHEME OF A LOCAL DIGITAL HUB

The third step is to integrate the system of the dispatching center "Control Tower" into each local digital hub with its digital twin, the functionality of which will include the collection of local results of interactions of each subgroup of participants in the supply chain within a certain logistic zone (Barykin et al., 2020b; Bolton et al., 2018; Glaessgen & Stargel, 2012). This measure will allow to promptly process incoming information (about the types and volumes of cargo, their senders, recipients, registration stages and planned points of arrival), divided according to the territorial principle for further data exchange between dispatch centers of various hubs and calculating optimal solutions.

The fourth final stage involves the development of economic relations and connections between autonomous digital dispatch centers in order to create a single digital network of the DHNT logistics unit (digital hub network twin) (Grieves and Vickers, 2016). If this project is implemented, we will receive a single digital information and logistics network with a parallel developing digital twin (Figure 2).

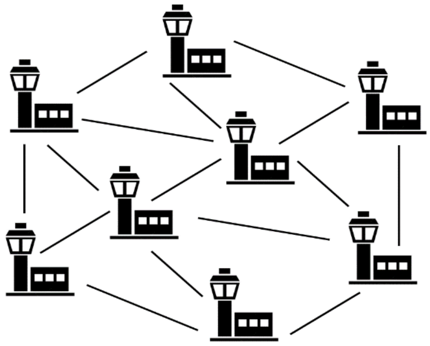

FIGURE 2
SCHEME OF INTERACTION BETWEEN DIGITAL DISPATCH CENTERS "CONTROL TOWER"

A network capable of automatically analyzing, predicting and building the routing of logistics flows between hubs, taking into account all kinds of variables by creating several scenarios and choosing the optimal option, depending on the current situation. The development of optimal scenarios for management decisions by the digital twin is conditioned by the integrated “What if” system. By reflecting the behavior and rationale of the supply chain in the simulation model, it will be possible to predict the dynamics of the logistics system both as a whole and in its individual elements, and to identify potential problems, analyze risks, assess insurance stocks, and optimize the transportation system.

Mathematical Modelling of a Logistics Network Planning System

Proceeding from the fact that the activity of the logistics network can be represented as a multi-level process, in this study, out of a multitude of levels, the two most important levels in formalizing the functioning of the logistics network are considered.

The first of these levels, the top one in the management hierarchy, is a group of hubs that make up the structure of the logistics block. Such a group of top-level participants is controlled by a single management in terms of distribution of logistics flows in a centralized manner.

The second level in the hierarchy already refers to the constituent elements of the network node - the hub, which is under the direct supervision of the upper level. Management of the second level receives general directives for the planning period and can optimally allocate its resources according to competencies in order to maximize efficiency.

At each of these two levels, the mathematical model is built according to the following limiting conditions:

- The planning horizon is predetermined; upon its expiration, the final assessment of the economic performance indicators is formed;
- The total length of the planning horizon is divided into smaller periods or planning stages;

- Based on the performance results for each of the interim periods, an interim assessment of the economic performance indicators is formed;
- On the basis of interim estimates of economic performance indicators, management makes management decisions for the next planned interim period;
- A set of key indicators is determined, formulated as a vector that describes the current state of the logistics network.

The task of management is to determine a set of management decisions before starting each of the intermediate stages in such a way as to maximize the final assessment of economic performance. This means that the criterion for the quality of managerial decision-making takes into account performance indicators for all intermediate periods. This concept corresponds to the modern principle of transition to a system of advanced economic planning indicators.

The construction of a mathematical model should take into account the discreteness of data on the activities of economic entities and, accordingly, function arguments (Zhabko, Shindyapin & Provotorov, 2019).

Mathematical Formalization of the Management System of the Logistics Network

Let us introduce the concept of a system for the logistics network, denoting the system by the symbol *S*. The state of this system *S* is uniquely determined by a set of indicators. Depending on the time *t*, the quantitative values of the indicators can change, which fully corresponds to the current state of the system *S*.

The set of such admissible states will be described by the phase space *S*. Thus, the top management of the logistics network has the ability to influence the operation of the system through the adoption of a set of management decisions. At the same time, the quality of management is assessed by the criterion *W*. Since the value of *W* is determined by the decisions made *U*, the following dependence takes place:

$$W = W(U), \tag{1}$$

Let us formulate the problem of managing a logistics network in the form of finding such a set of management decisions *U**, in which the quality criterion will be maximized:

$$W^* = W(U^*) = \max_U [W(U)], \tag{2}$$

In this case, there is a limitation in the area of initial states $\square_0$, which corresponds to the moment in time t=0, and the area of final states $\square_{FIN}$ is represented as:

$$S_0 \in S_0 ;\ S_{FIN} \in S_{FIN},$$

where S_0 is a region of the phase space at $t = 0$, and S_{FIN}, is, respectively, a set of admissible state at $t = t_{FIN}$.

Also, according to the accepted assumptions, the planning horizon from t to t_{FIN} is divided into *n* intermediate periods. At the end of each of these periods, the value W_i for i=1,…,n is calculated.
Under these conditions, we will assume that the final *W* value for the entire planning horizon will be calculated using the additive criterion formula:

$$W = \sum_{i=1}^{n} \theta_i W_i, \tag{3}$$

In the general case, the values θ_i=1, $\forall i$=1,…,n, but since, as a rule, the activities of commercial entities are assessed through financial indicators, to take into account the inflationary component and the possibility of reinvestment, the criteria take into account the discount factors θ_i.
Next, we introduce U_i, where i=1,…,n, that is, sets of management decisions at each of the intermediate periods. Let us define that the change in state $\square_{i-1}$ to state $\square_i$ is determined by a set of management decisions U_i and the previous state $\square_{i-1}$, that is, the ratio is provided:

$$S_{i-1i} = S_{i-1i}(S_{i-1}, U_i), \tag{4}$$

If formulated in the above terms, then using formulas (3) and (4), expression (1) can be defined in the following form (5):

$$W = \sum_{i=1}^{n} W_i(S_{i-1}, U_i) \quad (5)$$

Thus, the goal of the task is to find a set of management decisions U_i^* defined in the form of a vector: $U_i^* = \{U_1^*, U_2^*, ..., U_n^*\}$, the action of which within the logistic network or in terms of a mathematical model transfers the system S under consideration from the initial state (the beginning of the planning period) $\square_0$ to the final state $\square_{FIN}$ through intermediate periods *n*. The sequence of management decisions $U_1, U_2, \ldots, U_n$ can be shown in (Figure 3).

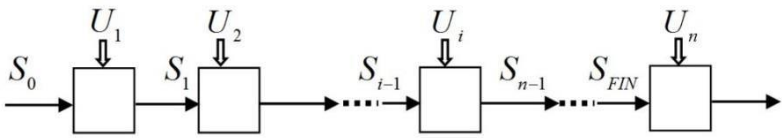

FIGURE 3
SEQUENCE OF IMPACT OF MANAGEMENT DECISIONS

Thus, based on the sequence of the impact of management decisions, it is possible to represent a two-dimensional matrix-system for optimizing and planning the operation of routes between logistics hubs within the framework of the logistics block (Figure 4).

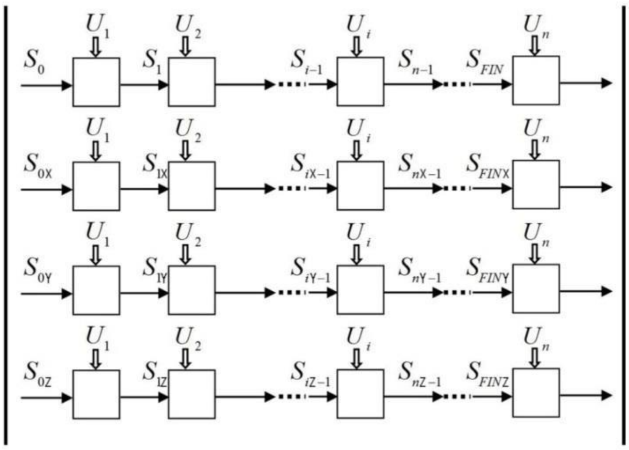

FIGURE 4
TWO-DIMENSIONAL SUPPLY CHAIN OPTIMIZATION MATRIX

This matrix-system displays an algorithm for the automated development of such scenarios from a variety of possible ones, in which the choice of the optimal option will be presented, taking into account the specified variables.

DISCUSSION

Currently the logistics networks face new challenges (Genkin & Mikheev, 2020). According to the study, it can be noted that the digital twin is used in the day-to-day operation of various networks, ranging from helping staff manage electricity flows and setting protection to meet demand without overloading transformers and transmission lines to automatically analyzing forecasting and organizing logistics traffic flows within entire logistics blocks. It also supports design and planning activities by allowing you to model the likely impact of changes in network configuration or investments in upgraded assets.

In the field of unanalyzed components of this article, one can single out the financial component and the issue of software development for this project. Obvious is the high cost of the Digital Block project and the need to develop serious software for wide analytical and predictive software - this aspect is the basis for further research in the future with the study of the most advanced software technologies. The researchers should take into account the fundamental theory developed by JinHyo Joseph Yun of the open innovation engineering model including both open-innovation engineering channels and determining ways of operating the channels through conceptual experiments (Yun et al., 2020). The JinHyo Joseph Yun theoretical approach significantly adds the Christensen’s determinants of open innovation model associated with the industrial dynamics of an industry segment undergoing a process of radical technological innovation (Christensen et al., 2005) unraveling the Chesbrough’s Open Innovation concept which was initially studied by from the company-level perspective (in contrary to the closed innovation old model).

CONCLUSION

This paper presents the characteristics of innovations in logistics networks on the basis of the concept of a digital twin, the necessary components of its technological base. Considering the innovations based on the digital twins in logistics, it is worth noting that in this sector, cargo tracking markers are of the greatest importance, as well as the use of an open "API" strategy and migration to cloud IT systems. The creation of digital twins in this sector is the most difficult and time-consuming task: to create twins of logistics hubs, in order to optimize logistics systems, logistics specialists are introducing augmented and virtual reality technologies, which allows optimizing the loading of existing vehicles in the network, regardless of their location at a given moment.

The researchers analyzed examples of digital twins in infrastructure and urban planning, for example, the digital twin of Alstom, German startup Metrilus. This information, for example, can be combined with previously acquired data on container usage and movement to create a digital twin.

The Alstom case (a UK-based railway equipment company) shows that within the framework of a city project, the digital twin accumulates information about each resource of the park, including an analysis of the work schedules of all nodes and points of maintenance, which makes it possible to simulate the available capacity of each of the service stations.

The study analyzes the advanced technology of 3D photography (German startup Metrilus), which allows to quickly create a detailed model of the container, which allows not only to optimize the loading process, but also to automatically identify possible problems even before they actually occur.

Very interesting case regarding the innovations in logistics networks considers the digitizing processes of customs authorities' activities with parallel integration of customs document management software into the "Local Customs Digital Twin" (LCDigTwin) system shows the optimal way of managing warehouse acceptance points, distribution centers, controlled by them, temporary storage warehouse, proceeding from the fact that the activity of the logistics network can be represented as a multi-level process, in this study.

The first of these levels, the top one in the management hierarchy, is a group of hubs that make up the structure of the logistics block. Such a group of top-level participants is controlled by a single management in terms of distribution of logistics flows in a centralized manner.

The second level in the hierarchy already refers to the constituent elements of the network node - the hub, which is under the direct supervision of the upper level. Management of the second level receives general directives for the planning period and can optimally allocate its resources according to competencies in order to maximize efficiency.

This complex multi-stakeholder environment can be seen most clearly in large global logistics hubs such as cargo airports and container ports. At these sites today, the problem of efficient operation is compounded by imperfect communication systems, where many participants rely on autonomous processes that are subject to errors and delays.

The open innovation detailed models for innovations in logistics infrastructure should be the topic of the future research when developing the approach being implemented into the "local customs digital twin" (LCDigTwin) system.

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