THE PLACE AND ROLE OF DIGITAL TWIN IN SUPPLY CHAIN MANAGEMENT

Sergey Yevgenievich Barykin, Graduate School of Service and Trade, Peter the Great St. Petersburg Polytechnic University
Andrey Aleksandrovich Bochkarev, National Research University Higher School of Economics
Evgeny Dobronravin, Genobium LLC, Russian Federation
Sergey Mikhailovich Sergeev, Graduate School of Service and Trade, Peter the Great St. Petersburg Polytechnic University

ABSTRACT

In theoretical research and practical approaches to implementing innovative developments, there is a gap in the holistic understanding of terms related to the digital economy, the scope and content of this concept. The research problem is to understand the concepts of digital twin, its place and role in digital economy, digitalization, and industry 4.0. The purpose of this study is to clarify the content of these concepts, with the formation of a comprehensive management approach to their practical implementation in industrial supply chains, with the harmonious participation of various specialists related to the problems of modern production. Technologies, methods, technical solutions, and best practices should become significant in the processes of modern supply chains. The article provides an overview of theoretical research and current trends in the development of the concept of "digital economy", analyzes the technical and economic grounds for such changes, and defines the directions for further development of such research. The difference between engineering and economic approaches to the problem of production management is shown. The authors substantiate the urgency of the translation of models of supply chains in a digital format. The goal of the proposed digital model is to find the optimal criterion of economic efficiency and get recommendations for building a logistics cycle for the selected planning horizon on the example of the Huawei enterprise. In conclusion, the article considers the concept of "digital twin" of supply chain processes, which is correlated with simulation methods. The simulation and digital twin are considered as the optimization procedures for optimal control, important and promising technical procedures of industry 4.0. Based on the study of the literature, the characteristics and properties of "digital twins", the importance for production management and other processes of supply chains are highlighted.

Keywords: Digital logistics**,** Supply Chain Management 4.0, Digital Twin, Dynamic Modeling

INTRODUCTION

The concept of the digital economy is actively incorporated in our life, but defining its content is still an urgent task that needs to be solved. Along with solving problems of high-quality management of economic flows, this requires the participation of specialists in various fields. Economics itself differs in that it gives us differentiated knowledge for such categories as commodity, value, price, margin, increment of value and surplus value, rent, commodity circulation, capital, factors of production, and for many other categories related to the above. But, on the other hand, there are many tasks that require an exclusively technical approach, for example, in such areas as robotics, additive technologies, information technology, etc. The establishment and consistent study of the subject by technical specialists is relatively independent. But taken together, all this serves the purpose of efficient production.

Production is usually considered as a technical and economic process (Groover, 2015). Technologically, it is the application of physical and chemical processes to change the geometry, properties, and/or appearance of a given starting material in the production of products, using a combination of machines, tools, energy, and human labor, usually through a directed sequence of operations.

Economically, production is the transformation of material into products that have increased in value through one or more processing or assembly operations (Bogoviz et al., 2021). The key is that manufacturing adds value to the material by changing its shape or properties, or by combining it with other materials. Similarly, the material flow in production in the supply chain is a complex phenomenon, which integrates and transfers the value brought at each stage by different specialists of the "knowledge economy" to the target markets (Chopra, 2019).

The differences between technical and economic approaches are clearly shown in detail in the Austrian school of Economics, by sociologist Schumpeter (Schumpeter, 1983); (von Mises, 1996). As Schumpeter notes in the Theory of economic development, innovations are brought to life - by social demand, and not by engineering methods available to society.

These problems of production and supply chains in the digital economy therefore require a comprehensive, technical and economic approach. The purpose of this study is to determine the place and role of economic and engineering approaches in Industry 4.0, as applied to the problems of supply chain management using "digital twins" technology.

METHODOLOGY

Methodological Foundations and Literature Review

Materials and Methods should be described with sufficient details to allow others to replicate and build on published results. Please note that publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

Methodology of the Study

By methodology, we mean a system of basic principles and methods, rules, standards, methods, techniques and means, logic, technology and the result of obtaining true knowledge in the organization and construction of scientific and practical activities of people.

The methodology of our research is connected with thinking about the scope and content of such theoretical concepts as: "ideal" supply chain, supply chain as a form of material flow organization, digital economy, Industry 4.0 and supply chain management 4.0 in the content of roadmaps, "digital twin" and procedure simulation and process optimization, digital twins of objects and processes, supply chain processes, economic and technical approach to production management, production process in supply chain processes, margin and value increment. In a deductive, meaningful inference, the rules of logic are used.

The following concepts and provisions were selected as the initial ones: the material flow is a physical entity and an integrator, as well as capital and a bearer of value, a technical and economic process. The participants in the supply chain are united by the goal, which is economic reproduction. Material flow is the main category of logistics and supply chain management.

As the results, the following conclusions were obtained: economic and technical goals, means and methods, their application are aimed at meeting the needs in target markets.

Both organizational and systemic, process and integrated approach to the study of economic flow, process and integrated approach to the study of the organization, an analytical approach to the concept of a chain of value increments are used. Since the supply chain can be represented as a system, then a technical approach, technical means of optimization and integration can also be used in application to it.

Taking into account modern trends (Schniederjans, Curado & Khalajhedayati, 2020) in the development of the concept of a digital economy, the following were chosen as the principles of designing supply chains: the use of operations with idealized objects, consideration of a system of nodes and transport connections in the process of movement of material flow as a logistics object, the use of mainly quantitative performance indicators in logistics, in an integrated assessment orientation not so much to costs as to the criterion of value increment, the use of modeling in management, including simulation modeling, the use of automation tools for logistics systems, consideration of the stock as a key element of the logistics system, centralization of strategic management of logistics systems.

Despite the relative difference, the conclusion is made about the unity of goals and the similarity of economic and technical approaches in building modern supply chains, and the supply chain, as a form of organization, corresponds to them. Based on existing practice, a conclusion is drawn about the special role of digital convergence. Found common technical and economic foundations for such a concept as a digital twin. - both objects and processes. Thus, a theoretical conclusion follows about the place and role of such a new concept as a “digital twin” in the organization of material flow in modern conditions.

We use differentiation methods in our work, both as applied to the concept of "digital twin" and the supply chain. A statistical analysis of the definitions of the digital twin and the contexts of its application is applied. A structural approach to the concept of a digital twin is used, the differentiation of this concept.

As Schumpeter wrote (Schumpeter, 1983), innovation begins with social needs (Figure 1). There is a request for a new type of organization — a supply chain with digital characteristics.

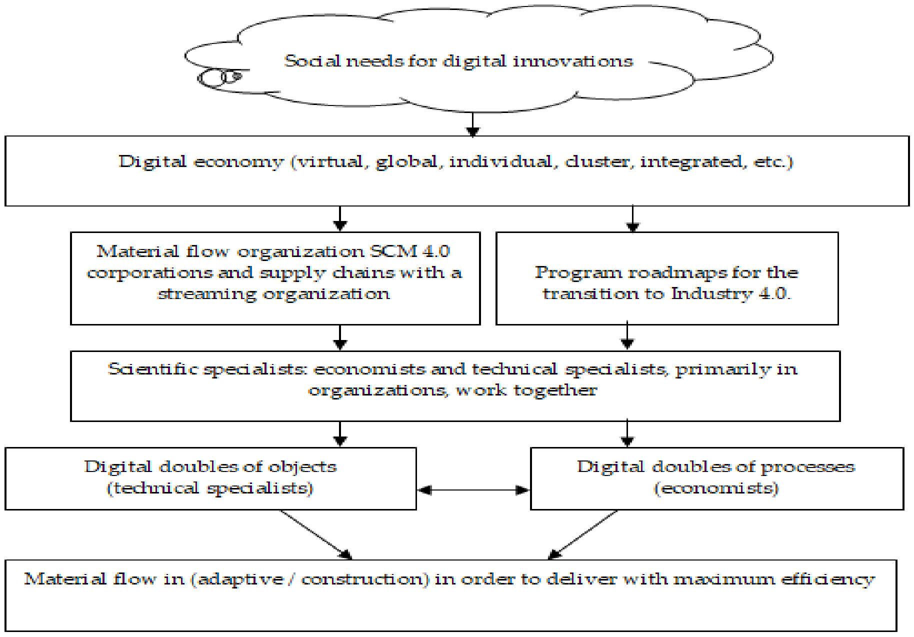

FIGURE 1
SOCIAL NEEDS FOR DIGITAL INNOVATIONS IN THE ECONOMY BASED ON DIGITAL TWINS OF SUPPLY CHAINS

The execution of the order is carried out by knowledge works, which fully absorb the needs of the strategy of such organizations, while they cannot but have the freedom of choice in the new conditions, according to (von Mises, 1996), performing the functions of both an employee and an entrepreneur. The material flow that is being worked on to improve its efficiency is capital, and its consideration in the process of the reproductive cycle is a great economic tradition, which we omit here. It has a number of economic and technical characteristics: it is a technical system, an integrator, and a carrier of value that can be represented analytically (Bowersox & Closs, 1996; Handfield & Nichols, 2002; kaplinsky, 2004; Marshall, 2013; Porter, 1998).

The theoretical and methodological basis of the work was research, fundamental and applied developments of domestic and foreign scientists in the field of economic value theory, value chain theory, inventory management theory, probability theory, compromise theory, systems theory, modeling and forecasting methodology, logistics theory, management theory, the supply chains management, the theoretical approaches of integrated management systems, operational management and a process approach to management, quantitative optimization methods, applied aspects of logistics and supply chain management, inventory management, methodological approaches to managing certain types of logistics activities.

LITERATURE REVIEW

Today, a great number of publications and reviews present about digital supply chains and advantages that digitalization carries (Dossou, 2018; Hallikas et al., 2019; Shao et al., 2021). In Russia, the digital economy and the concept of industry 4.0 is only a continuation of the global trend. In Russia, the national technology initiative has developed a number of interrelated roadmaps that also distinguish between technical and economic approaches. For example, innovations related to product design and development and to the design and development of production processes in the supply chain are differentiated and highlighted.

In essence, the "digital economy", advanced technologies of industry 4.0 is based on the principle of speed (Ehie & Ferreira, 2019; Nasiri et al., 2020). The idea of being able to transmit and store information digitally is not new and has been around since the advent of arithmetic counting. Such opportunities create prerequisites for "convergence", that is, the merging and mutual conversion of various products and technologies to form their new quality, as happened with the smartphone, a device that has become firmly established in our lives. The digital economy could be considered as a product of convergent technologies (Presutti, 2003; Shashi et al., 2020). The economic meaning of such innovations consists in obtaining a competitive advantage (or reducing the cost of concrete labor in comparison with that of socially necessary - for the production of the same product, if we say in the language of classical economic theory), a number of economic imputations (percentage, time, or technological imputation etc.), *i.e.* obtaining a new value, a source of entrepreneurial profit, profit and rent. As a result, the market, "external" and "internal" consumers get a product that is cheap in terms of costs and versatile in functions, and also "lean and agile" production and supply chains.

Considering the newly emerging concept of open innovation, it is essential to address how it can be analyzed from an industrial dynamics perspective, focusing closely on the complex interplay between technology entrepreneurs and incumbents (Christensen, Olesen & Kjær, 2005). A concept model of open innovation built in (Yun, Kim & Yan, 2020) is aimed at exploring the existing open innovation channels, and how these channels operate as a knowledge conduit that helps combat the growth limit of capitalism in the 4th industrial revolution.

Nevertheless, when solving complex problems of industrial development, it is still necessary to have knowledge of specialists from various disciplines-economists, technical specialists, engineers, psychologists, sociologists, etc., similarly, it is impossible to deny the technical part of changes in products and their production processes. And we can talk only about changing roles and the possibility of joint, integrated, "convergent" approaches. Let's consider in more detail the technical and economic approaches from practice that are being developed in the elements of the "digital economy", that is, products and methods of their production, presented in Table 1.

Table 1
LEVELS OF INDUSTRY 4.0 (“FACTORIES OF THE FUTURE” NTI) FROM THE POINT OF VIEW OF THE RUSSIAN NATIONAL TECHNOLOGICAL INITIATIVE, “FACTORIES OF THE FUTURE” IN THE DIGITAL ECONOMY

Components	“Digital” factory	"Smart factory	“Virtual” factory
Content	Digital design and modeling concept	Flexible production and mass personalization	Distributed network production
Product Life-cycle stages	Product planning, product design, production planning	Commissioning, Production	The operation of the product and service
Technologies	Digital design and modeling (CAD/CAM, CAE, CPE, CAE, CAM, PDM, PLM), additive and hybrid technologies, CNC technologies, Smart Big Data	Industrial robots, MES and ICS systems, sensors, industrial Internet, Big Data, artificial intelligence, virtual reality	Enterprise management information systems in supply chains (ERP, CRM, SCM…)

Product	Digital prototype (DMU) "Digital Twin" Prototype or small batch	Serial product	In the supply chain, a prototype or small series, serial product

The digital economy could be defined as a special form of economy where reproduction processes have undergone digital transformations using information and communication technologies. But at the end of the last century, the following features of the modern “digital economy” were identified: management centralization, virtualization, digitalization, information transparency, integration, individualization, non-mediation, innovation, global scale, clustering and convergence.

For example, digital color-recognition technology has already changed the processes of paint distribution; cell phone technology, sensors, and speech recognition can speed up the process of making deals, modular design has changed the location of distribution centers, and the “whip effect” in the supply chains of Procter and Gamble and Nokia has brought to life MPICS (production planning and material control systems) and VMI (supplier inventory management). CSRP information systems (resource management synchronized with the client) require intensive information flow technologies both from the design and development stage to timely notify the market of new products, and in the opposite direction – to report the first market reaction of customers to the product being developed. Digital compatibility is also important. For example, the design of a car air conditioner module may differ from the production method and from service, like spare parts (Bitton et al., 2018; Cai et al., 2017; Jia & Guo, 2012; Schluse & Rossmann, 2016; Stark, 2015).

Theoretical Fundamentals

Some general principles of Industry 4.0 technologies are used to build low-cost and versatile, "lean" and "agile" supply chains. a special role in this is given to the “digital twin” technology (Al-Mudimigh, Zairi & Ahmed, 2004; Junge & Straube, 2020; Llopis-Albert, Rubio & Valero, 2021; Manavalan & Jayakrishna, 2019; Müller & Voigt, 2018; Reinartz, Wiegand & Imschloss, 2019; Rejeb et al., 2020; Toorajipour et al., 2021; Wiedenmann & Größler, 2019; Witkowski, 2017).

Currently, one of the most key strategic technology trends as of 2019 (Gartner group) is considered to be the digital twin technology [38]. We should consider it in more detail.

There are various definitions of a digital twin, here are some of them.

A real-time image of a physical object or process that helps optimize business metrics; a real-time image of a physical object or process that helps optimize business metrics; in the era of Industry 4.0, a digital twin is a virtual copy of a system that can interact with a physical twin in two-way mode, probably promising real-time replication and analysis of production systems. Supports operations such as monitoring, health support, management, optimization, and security; miniaturization and cost reduction make it possible to integrate information, communication and sensor technologies into any virtual product. Products are able to feel their state, as well as the environment. Together with the ability to process and exchange this data, this creates a digital twin – a comprehensive digital representation of the individual product that plays an integrating role in the fully digital product lifecycle (Campos et al., 2017; Jones et al., 2020; Tajima, 2007).

The CIRP encyclopedia of manufacturing engineering recently defined a "digital twin" – a digital representation of an active unique product (a real device, object, machine, service, or intangible asset) or a unique product-service system (a system consisting of a product and a corresponding service) that encompasses its selected characteristics, properties, conditions, and behavior through models, information, and data within a single or multiple phases of the lifecycle (Albukhitan, 2020).

The concept of a "digital twin" was first introduced by Michael Grieves during his work with John Vickers of NASA in 2003 at a lecture on the product lifecycle, which described it, starting with a digital twin of a prototype product at the beginning of the life cycle and gradually developing over the entire life cycle (Grieves, 2014). The vast majority of authors agree with this (Figure 2).

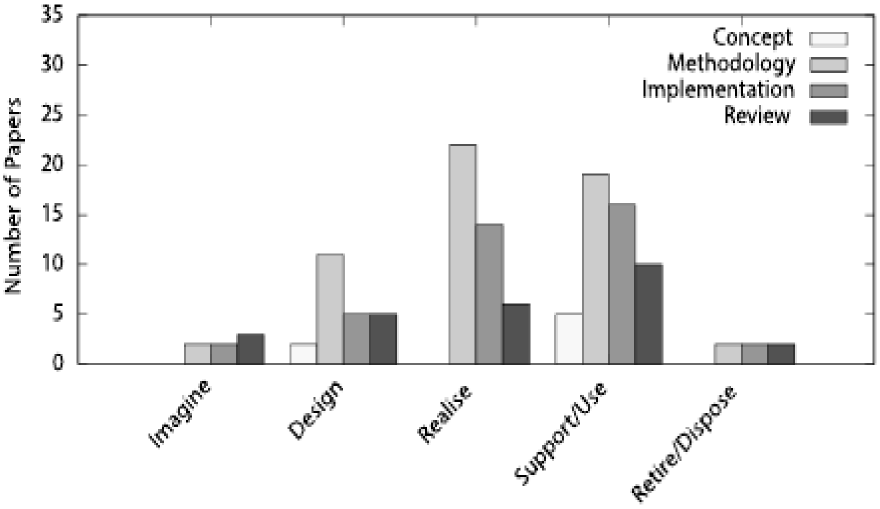

FIGURE 2
THE NUMBER OF PUBLICATIONS ABOUT THE “DIGITAL TWIN” RELATED TO DIFFERENT STAGES OF THE PRODUCT LIFECYCLE [38].

Grieves extends this definition by describing a “digital twin” as consisting of three components - a physical product, a virtual representation of this product, and bidirectional data connections that feed data from the physical to the virtual representation, as well as information and processes from the virtual representation to the physical. Virtual spaces themselves consist of any number of subspaces that allow you to perform certain virtual operations: modeling, testing, optimization, and so on. In a later paper (Grieves & Vickers, 2016), Grieves extends the concept of a digital twin to the entire product lifecycle - using the concepts of: a digital twin prototype, a digital twin instance, a generalized twin, and a digital twin environment. The digital environment of a twin is a virtual representation of the environment in which a physical product exists, and includes virtual methods such as modeling and evaluation. Digital copies - generalizations and environments are stored beyond the actual life of the physical product, which ends in the phase of disposal. This basic concept of a digital twin provides a system that connects physical entities with virtual counterparts, taking advantage of both the virtual and physical environment to take advantage of the entire system. Product information is obtained, stored, evaluated, and training is applied to improve the quality of both current and prospective products.

In 2018, Langle, et al., (2018) made a bibliographic analysis of 1687 articles of the journal. As a result, the top 30 keywords were selected, with the first three being "modeling", "schedule control" and "process planning". Regardless of the context, virtual methods such as "modeling", "simulation", "optimization", means of implementing changes in a physical entity (software management, numerical software management, metrology and data management methods, “RFID”, options for specific use cases, chain management, "supplier selection") are distinguished.

According to a generalization from several sources (Abramovici, Göbel & Savarino, 2017; Funk & Reinhart, 2017; Kritzinger et al., 2018), the digital twins model consists of the following characteristics, summarized in Table 2.

Table 2
CHARACTERISTICS OF THE CONCEPT OF “DIGITAL TWINS”

Characteristics of the “digital twin”	Content
Physical entity/twin	A “real” object, such as a vehicle, component, product, system, or model.
Virtual entity/twin	A computer representation of a physical artifact, such as a vehicle, component, product, system, or model. In accordance with the concept of M. Greaves, several virtual entities are present in a digital twin, each of which has a specific purpose, such as planning, health monitoring, etc.
Physical environment	Measurable “real”, the physical environment that a physical object is located in. “Real space”, “real world”, and “factories” are all examples of terms used in the literature. Aspects of these environments are measured and entered into the virtual twin environment to accurately reflect the virtual environment, which is used for modeling, optimization, and / or decision making. Achieving this requires the inclusion of all appropriate parameters, such as the weather, regional holidays, or the schedule of home games of a sports team
Virtual environment	Any number of virtual “worlds” or simulation models that reproduce the state of the physical environment and are designed for a specific use case. For example, health monitoring, optimization of the production schedule. The virtual environment exists within the digital world and is a mirror of the physical environment obtained through physical metrology (*i.e.* sensors) in key dimensions - from the physical to the virtual, "virtual space", "virtual world", "data model".
State	The current value of all parameters of the physical or virtual object / environment. Taking the state into account, the virtual twin in comparison with the physical twin gains functionality, for example, real-time state estimation, as well as representation and prediction of past, current and future states.
Metrology and Accuracy	A set of parameters passed between physical and virtual entities, their accuracy and level of abstraction.
Intensity of “twinning” (replication)	The act of syncing between two entities and the speed at which synchronization occurs. The change that occurs in a physical or virtual entity is measured before being implemented in an equivalent virtual / physical double, and when both states are identical, the entities ‘twin'. The combination of both compounds allows you to optimize the continuous cycle as much as possible, physical states are predicted in the virtual environment and optimized for a specific purpose. In other words, the virtual optimization process becomes executed by using the current state of the physical / virtual object, after determining the optimal set of virtual parameters that extend further to the physical counterpart. The physical twin responds to the change, and the

	loop repeats to update the virtual twin's state to match the measured physical state. For example, an assembly line that automatically sets up scheduling to counteract production losses when a faulty batch of components is detected.
The link between physical-virtual twinning	Connecting from a physical environment to a virtual one. It consists of physical metrology and virtual implementation stages. Physical-virtual connections are the means by which the state of an individual is transmitted and implemented in a virtual environment - that is, updating virtual parameters, that is, they reflect the values of physical parameters. These include IOT sensors, web services, 5G, or customer requirements.
The link between the virtual-physical double	Connecting from a virtual to a physical environment. It consists of virtual metrology and physical implementation stages. Examples of this in practice include changes in display readings, product life cycles, process control parameters, machine parameters, and production management. The value of a virtual physical connection is that, when combined with a physical and virtual connection, it closes the loop between the hypotheses generated in the virtual environment and the actual consequences implemented in the physical environment. In fact, a digital twin, with a physically-virtual and virtual-physical connection, can put forward hypotheses, and then execute, test and correct them in a continuous process of adaptation and improving the cycle. It is this continuous loop that can distinguish the digital twin from traditional modeling methods, where hypothesis testing is a much more complex and time-consuming task.
Integration between virtual objects	There is still a step to take to better understand the interaction of virtual entities – for example, balancing the need to deliver products by the deadline with predicted future failures, each of which can be managed by separate digital twins.
Technical performance	Technology used in implementing the digital twin, such as the Internet of things.
Intended benefits	Perceived benefits achieved by implementing a digital twin, such as improved design, behavior, structure, manufacturability, compliance, and so on.
Physical process	Physical goals and processes that an individual participates in, such as a production line.
Virtual processes	Computational methods used in the virtual world, such as optimization, forecasting, modeling, analysis, integrated, multiphysical, multiscale, and probabilistic modeling.
Examples of using digital twin applications, such as cost reduction, service improvement, and decision support.	The vast majority of the identified use cases are related to manufacturing, with some specific examples related to "Industry 4.0", smart factories/productions, and training. Other use cases include, for example: product design (bicycle, pump, or automobile wiring), model engineering, smart cars, agriculture, and human health and the agricultural supply chain. For example, modeling, simulation, and optimization are all virtual processes and are located on the virtual side of the loop. Smart cars and farms are physical objects and are therefore placed on the physical side of the cycle. The main research here is related to data management and methods of using it - simulation, modeling, and optimization. The requirements for a digital twin at each stage of the lifecycle are not yet fully understood. The main focus is on using existing technologies. [10]

Digital twin across the entire product life cycle	Research is largely focused on the final phases of the product lifecycle, with most papers presenting methodologies followed by implementation reports. And there are relatively few papers that focus on the basic concept of the digital twin or the consideration of the digital twin for the entire lifecycle, while there are a relatively large number of presented methodologies and implementations of the digital twin for specific use cases. Gaps exist in the study of the applicability of digital twins to earlier stages of the product lifecycle and the recycling stage, as well as key concepts of digital twins, as in in general, and in specific phases of the life cycle. Sometimes benefits are shown as results, such as reducing costs, risks, and design time, encouraging innovation, overall reliability, and quality of decision-making, particularly during the design and development and disposal stages. [38]

Negri, et al., (2017) offered a systematic review of the literature on the concept of the digital twin, tracing the origin of the term to the aerospace industry. Pointing to a wide range of applications and benefits, the authors found that studies on the matter are still in the early stages. Furthermore, (Cimino, Negri & Fumagalli, 2019) explored the applications of digital twins and manufacturing, discovering a certain gap between the implementations of the concept and its descriptions in literature.

The similarity between the concepts of "digital twin" and advanced control systems, predictive control models, computer-integrated production, virtual production systems, predictive management based on models, advanced control systems and performance monitoring are examples of well-established research areas that preceded the emergence of the term digital twin (Tao & Zhang, 2017; Wagner et al., 2017; Yang, Yoshida & Takakuwa, 2017; Zhang, Zhang & Yan, 2018).

RESULTS

Simulation Procedures And Digital Twinning Methods

Thus, digital twins are models of idealization (and idealization is, in general, the main method of theoretical research). It is important to understand that the twin is not a substitute for the real object, but only allows considering it “shadows”, projections, that is, from the sides of interest to the researcher, in order to then transfer the knowledge gained to the real object in the form of directed management actions.

Simulation remains the central method of working in a virtual twin environment. In general, the use of modeling methods is not a new practice, but currently the use of computer technology, the use of various simulation models based on a direct description of the object of reality, which makes it possible to test its behavior in various modes, is being developed due to low cost, low risk, visibility, proximity to the described object, multiple statistical verification functions, etc. In combination with the above simulation models, the use of optimization methods remains an important resource. The use of optimization models (and simulation models are also referred to as optimization models) is a certain assumption regarding the object under study, goals, approaches, and criteria for managing them.

Simulation procedures and digital twinning methods are based on modern principles of supply chain design. Using the study of modern trends, principles, the western methodological approaches in construction supply chains we propose the following proposed methodological framework, the principles of finding the "ideal" supply chain: the use of theoretically "idealized" objects, the consideration of logistics facilities as a system of nodes and connections in the process of material flow, the preferable use of quantitative indicators, orientation not as much on costs as on the criterion of added value, the use of modeling, particularly simulation, use of logistics systems automation tools, consideration of inventory as a key element of the system, centralization of logistics systems management using strategic planning.

In our opinion, the properties of the digital economy could also relate to the features of the building supply chains in industry 4.0 – Supply Chain Management 4.0 (Table 3).

Table 3
FEATURES OF THE MODERN ECONOMY, TECHNICAL AND ECONOMIC METHODS AND TECHNOLOGIES OF SCM 4.0.

Supply chain issues and challenges	**Features of the modern economy**	**Using principles in logistics**	**Methods, techniques, methodological approaches, techniques from the experience of leading companies**	
Influence of the nature of demand on the chain strategy	Centralization Virtualization of economic objects	Consolidation of distribution centers	Reconfiguration of the logistics structure Using inter-company integration systems	Segmentation of wholesale customers based on logistics
The "bullwhip effect" on optimal chain structure	Digitalization of information	Combining the structures of material flows on the principle of value increment	Construction of MPC systems based on "dyads"	Placement of warehouses in transportation hubs and points of consumption
Concepts of "lean"and "agile" in the development of a logistics strategy and chain integration	Integration	Information transparency on the material flow (MP) route	Reconfiguration and optimization of the material flow structure in the supply chain	Reducing number of warehouses in the supply chain
	Splitting market agents by function	Development of MP hubs in the global market	System management policy modeling	Consolidation of procurement
	Refusal to intermediate	Moving assembly hubs down the chain	Designing the supply chain material flow based on MPC systems	Establishing close relationships with intermediaries
	Innovation	Inclusion of outsourcing hubs in the MP structure.	Intra-company optimization of the material flow structure	Partnership and trust
	Globalization	Information outsourcing	System analysis of material flow in production	Defining a replenishment policy in warehouse systems

	Customer orientation	Inter-company integration systems and MP management	Predictive (predictive) planning and MP management	Developing chain management technology and unified information system

The Optimizing Model as the Algorithmic Foundation of the Digital Twinning Methods in Logistics

Digitalization of information flows in logistics tasks opens up new prospects for the application of scientifically based business methods. The basis of logistics is the spatial movement of goods and cargo by means of all types of transport, which is due to significant time costs. But unlike material flows, counter financial flows, thanks to such tools as online payments, smart contracts, instantly provide a system for exchanging and distributing information data between all business participants (Barykin et al., 2020, 2021; Shmatko et al., 2021). This allows us to apply mathematical models based on the formalization of the relationship of counterparties. The peculiarity is concluded in the long-term physical execution of contracts based on transactions carried out and paid for at the initial moment of time.

The leaders of the modern logistics business are multinational 3PL companies (Tjahjono et al., 2017). Since they work on the principles of outsourcing, it is digitalization in the field of transportation that has given rise to a trend for deep integration of their activities into the business schemes of producers and consumers of products, goods and services. Logistics companies, thanks to the development of digital transport platforms and the implementation of the concept of digital transport corridors, have now moved out of the role of executors of orders for freight forwarding services.

The globalization of the economy, as well as the consolidation of commercial activities into network structures, has become a real trend generated by digital algorithms, both in trade and in the provision of a wide range of services.

PROBLEM STATEMENT

The task of this study arose in the course of practical activities of Huawei. This company is a leader in the development and mass production of telecommunications, data storage systems and equipment for high-speed data exchange networks. Huawei cooperates with hundreds of suppliers of raw materials, components, and semi-finished products around the world. A separate logistics division of the company focused on the European market of manufacturers. Since not all countries are members of the Euro area, settlements with numerous partners are made in national fiat currencies. Due to the instability of both the economic system of individual countries and the global economy as a whole, currency parities experience significant volatility. This makes it very difficult to optimize the planning of purchases, which are mainly conducted using currencies such as the Euro, the British Pound, the Swiss Franc, the Swedish Krona, the Hungarian Forint and the Czech Koruna.

The authors try to develop a formalized description of the logistics operator's activities to ensure the procurement process using several types of currencies, and select the criterion of economic efficiency. The researchers take as a basis a digital data stream about currency parity; use it as arguments for a mathematical model. The goal of the task is to find the optimal criterion of economic efficiency and get recommendations for building a logistics cycle for the selected planning horizon of the Huawei enterprise.

A Formalized Description

The current currency parity is changing, and thanks to the online data flow from exchange platforms, it is possible to program an algorithm for optimizing the profit obtained on the information about the current values of transactions denominated in national fiat money (table 4). The number of possible transactions in different currencies is equal. As a rule, it is quite large and the aggregation of contract indicators of procurement and transport operations related to one region is used.

Table 4
COUNTERPARTY CURRENCY TYPE AND VARIANTS OF CONTRACTUAL INTERACTION

Counterparty currency type			**Variants of contractual interaction**		
1	**Resident currency**	**Contract scope**	**Contract 1**	**...**	**Contract n**
2	USD	z_1	$q_{11}(z_1)$	...	$q_{1n}(z_1)$
3	EUR	z_2	$q_{21}(z_2)$	...	$q_{2n}(z_2)$
4	GBR	z_3	$q_{31}(z_3)$	...	$q_{3n}(z_3)$
5	CHF	z_4	$q_{41}(z_4)$	...	$q_{4n}(z_4)$
6	SEK	z_5	$q_{51}(z_5)$	...	$q_{5n}(z_5)$
7	HUF	z_6	$q_{61}(z_6)$	...	$q_{6n}(z_6)$
8	CZK	z_7	$q_{71}(z_7)$	...	$q_{7n}(z_7)$

The authors could determine the main resident currency, for example z_1 , which leads to the criterion of economic efficiency of the entire set of transactions, and formulate the problem statement as follows.

Since transactions and financial flows are conducted in real time, it is necessary to find the maximum of the criterion at the current time R: $R^* = \max_{z_j}(R)$

$$\boldsymbol{R = \sum_{i=1}^{n} w_i\, q_{1i}(w_1)}$$

Changing the size of contracts w_j для $j = 1, 2,..., n$. In this case, the conditions are imposed: $\sum_{i=1}^{n} w_i\, q_{ji}(w_j) \geq 0$ $\forall > 1$. Further, based on the limitation w_j ˜ possible investments for each type of contract transactions, a set of additional conditions is introduced: $w_j \leq \tilde{w}_j \quad \forall\, j$.

To solve this problem, we use the dynamic programming method. The search for the optimal solution is conducted for all $q_{ji}(z_i)$, reduced to a matrix Q , by vector W $=\{w_1, w_2,..., w_n\}$.

Let's make the corresponding Bellman equation:

$$S_k(W) = \max\left[\sum_{i=1}^{n} w_v\, q_{1i}(w_1) + S_{k-1}(W)\right]$$

and we will rewrite it taking into account a limited number of contracts in the form of a system of equations:

$$S_0(W) = \sum_{i=1}^{n} w_{i0}\, q_{1i}(w_{10});$$

$$\Phi_{12}(W) = S_2(W) = \max\left[\sum_{i=1}^{n} w_{i1}\, q_{1i}(w^* - w_{11}) + S_0(W)\right];$$

Etc. until:

$$\Phi_{12\ldots n}(W) = S_n(W) = \max\left[\sum_{i=1}^{n} w_{i\,n-1}\, q_{1i}(w^* - w_{1n-1}) + \Phi_{12\ldots n-1}(W)\right].$$

The result of the calculations will be a vector $W^* = \left\{ w_1^*, w_2^*, \ldots, w_n^* \right\}$ optimal distribution of contracts for logistics activities.

Example of the Calculation

The data for the calculation according to the above algorithm is obtained from reports on purchases of materials, components and semi-finished products in the European Union. At the same time, extensive purchases are provided for different items. This creates several closed cycles in the balance of financial flows, which can be calculated precisely due to the use of a dynamic model. The consolidated data on purchases in various countries are entered in the matrix elements Q. The US dollar is designated as the resident currency. The parity of currency pairs was received in real time. The values of the vector obtained in the optimal mode

$$W^* = \left\{6490.32; 1980; 44000; 17000; 955; 192; 27.46; 1884; 276; 231.47\right\}$$

Which corresponds at the moment to a matrix Q that has the form:

$$Q = \begin{vmatrix} 72.6 & 34.3 & 22.8 & 461.2 & 216.4 & -1 & -1 & 0 & 21.54 & -1 \\ -1 & 0 & 0 & 0 & 0 & 4.17 & 0 & 3.02 & 0 & 0 \\ 0 & -1 & 11.7 & 0 & 21.5 & 0 & 2.35 & 76.8 & 10.3 & 0 \\ 7.2 & 0 & -1 & 0 & 0 & 0 & 0 & -1 & 33.84 & 0 \\ 1.06 & 2.2 & 3.74 & -1 & 0 & 0 & 0 & 19.3 & 0 & 2.91 \\ 0 & 0 & 7.22 & 0 & -1 & 0 & 11.56 & 0 & 21.85 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1.2 & 0 & -1 & 1.05 \end{vmatrix}$$

When calculating the constraint vector $\tilde{W}$ was set as:

$$\tilde{W}=\{7900;1980;44000;17000;955;192;89;1884;276;240\}\ .$$

As can be seen from the comparison, not all the marginal opportunities were realized, since the volumes for the part of the contracts: $\tilde{w}_1, \tilde{w}_7, \tilde{w}_{10}$ allow you to increase purchases. However, it is the vector W^* It should be considered by the management of the Huawei enterprise as a starting point for correcting procurement planning in the conditions of changing parity of the currencies selected for calculation.

DISCUSSION

The proposed algorithm fundamentally changes the approach to the organization of procurement and the choice of logistics solutions. Since a direct link to the exchange platforms gives not only current currency parities, but also spot prices for a number of products used in the activities of such large manufacturers as Huawei, further research is planned to solve the following problems:

1. Consider, in addition to the European region, the Asian and Middle Eastern regions separately. At the same time, for example, work with China is conducted using cross-rates of the Yuan, and with Japan, alternatives to the US dollar and the Yen are considered.
2. Include in the calculation of functions $q_{ji}(z_i)$ discount-a factor determined by the time of transfer of material logistics flows, since, unlike financial flows, there will be factors due to the time of capital freeze.
3. To work out a variant of the algorithm that provides for the construction of predictive analytics of changes in the criterion of economic efficiency. This approach will simplify the calculations, since it is possible to linearize the problem directly at each moment, based on the incoming data of exchange trading. But this requires a recalculation of the dynamics of changes in the criterion R^* and the choice of the data extrapolation method.

The difference between technical and economic approaches is shown by the example of different criteria in the tasks when developing the maximum power of a steam hammer, or when approving a bridge construction project. We also see that new, "more advanced" technologies are not always necessary included in economic practice for reasons of "switching costs", according to the concept of alternativeness. The engineering approach often ignores cost measures and does not take into account the full range of factors of production, such as time-capital factors, economic uncertainty, and risks of various kinds.

The technical and economic approach is a manifestation of the convergence of information in the "knowledge economy" based on modularity and cluster interaction, with a focus on achieving economic efficiency goals. Therefore, having different levels of hierarchy, they are also in an interpenetrating and mutually conditioning relationship. As a rule, advanced products, production and supply chains present a combination of achievements at all levels: robotics, additive technologies, digital twins, artificial intelligence, and big data; modular product design and modular process design, mass personalization, entrepreneurial combinatory.

CONCLUSIONS

An important challenge of our time is the ability to rationally identify and combine the technical capabilities and needs of society in innovative developments with the production of various digital products, where economic knowledge becomes an instrument of competition and a strategic guideline for the development of the digital economy. Since it is necessary to combine the knowledge of different specialists, the function of organizing material flows becomes important. It is concluded that the problems of production and supply chains in the digital economy require a comprehensive, technical and economic approach. The important role of combining the knowledge of different specialists in function of organizing material flows is shown. The theory of material flow (logistics) should be based on profound knowledge in the field of economic theory, with active use of the concept of SCM 4.0.

In accordance with the principles of "scientific management", the flow-forms of organizations (holdings, virtual, network organizations, "supply chains", etc.) will be further developed, and the organizing elements – systems, processes, structures, and methods-will be further developed. Collaboration and collective creativity are an important component of Industry 4.0. The rejection of the hierarchical model of enterprises and firms, where limited access to information prevailed, as well as the limiting and dynamism of rent sources, the development of differentiation — leads to dynamic, "flow" forms of organization. The problem of the digital logistics - to master the skills of organizing and optimizing transformed economic flows in economic systems, to determine the conditions of their functioning, to identify the laws according to which the formation and change of forms of their organization occur. It is necessary to create new models of supply ("market supply"), translate models into digital format, digital organizational forms of flow processes, considering them as a basis for breakthrough innovations and building advanced logistics systems.

Simulation and digital twin are optimization procedures, of optimal management, important and promising technical procedures for Industry 4.0. This helps to reduce the role of classical advantages based on a variety of rents — in favor of consumer qualities of the product and technological rents. In general, using the methods of Industry 4.0 will increase the rational use of resources, the economy will become more transparent, predictable, and its development will be rapid and systematic.

Author Contributions

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Conflict of Interest

The authors confirm that there is no conflict of interests to declare for this publication.

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