The Development of Artificial Intelligence Technologies and Their Potential Applications in Supply Chain Management

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***Abstract*—The article under consideration here sets out to explore the practical applications of artificial intelligence technologies in the context of implementing digital ecosystems for the identification and traceability of goods within supply chains. The challenges associated with the modernisation of existing supply chain monitoring systems through the utilisation of AI technologies are emphasised. This text sets out the general requirements for a model of a digital ecosystem of supply chain support that uses the Internet of Things, a distributed registry (blockchain), artificial intelligence and other modern technologies. The issues of security and the need to prevent negative consequences of AI-based decisions by developing a model for assessing the risks of errors associated with the AI system as applied to the supply chain management process are highlighted.**

***Keywords*—artificial intelligence, ecosystem**

I. Introduction

Digitalisation, which has the potential to transform the modern rules of the market, is gradually transforming the competitive environment and society as a whole. At the same time, it necessitates a deep rethinking of established approaches to the creation of information and analytical systems, technologies and products.

These should be focused on the following:

1) providing situational management and decision-making support in the republican bodies of state power and public administration;
2) managing the processes of planning, production and sales of products in industry;
3) creating high-tech farms and processing enterprises that ensure the production of high-quality agricultural products, taking into account current market demands.
4) the optimisation of commodity transport flows, risk reduction and stock reduction in trade, logistics and transport;
5) the introduction of new high-tech tools for training specialists in the education system;
6) the implementation of educational and entertainment events using modern technologies in the field of culture.

In order to facilitate the advancement of these aforementioned domains, there is an imperative for the proactive development of contemporary digital information technologies, including but not limited to artificial intelligence, the Internet of Things, blockchain, robotics, unmanned transport, aerospace technologies, augmented reality technologies, and other associated fields.

Among the technologies previously mentioned, one of the most debated at present is undoubtedly Artificial Intelligence (AI).

The evolution of AI is influenced by related technologies and processes of big data formation, without which AI training is not directly possible. In this section, there is an escalation of developments focused on the integration of AI with the Internet of Things technologies. Modern automated systems endowed with artificial intelligence capabilities are adept at interpreting and analysing data received from IoT objects (e. g. sensors and other data sources) in real time, thereby enabling businesses to respond and manage operations with greater efficiency and precision. [1], [2] The practical application of such integrated solutions has been identified in a number of areas of the economy, but primarily in trade, transport and logistics.

Experts estimate that companies that have implemented AI to optimise deliveries can reduce logistics costs by up to 20% [3]. The integration of AI within the domain of logistics has been demonstrated to facilitate warehouse operations. Robotic assistants have been shown to facilitate the expeditious and systematic organisation of tasks, including picking, packing, and delivery. The utilisation of AI-powered tracking sensors and video cameras has the potential to facilitate real-time management, thereby leading to substantial losses and cost reductions. The process of inventory control gives rise to a substantial amount of new data, which, when analysed, can assist in the creation of accurate forecasts for the organisation of stock in warehouses. The delivery process is accelerated, and customer and partner interactions are enhanced.

It is important to note that, in general, supply chain business processes remain virtually unchanged (e. g. physical production of goods, transportation, etc.), however information about events related to these business processes and directly related to goods is subject to evolutionary changes. At present, GS1's approaches enable the execution of the conventional 5W model (i. e. what, who, why, when, where) [4] and the response to the query 'how' (in what state?) with respect to the designated object (i.e. goods, products). In recent years, the implementation of this approach has been constrained by technological limitations. However, contemporary digital technologies are now being incorporated into the process at an accelerated pace. GS1 standards facilitate the assurance of technological interaction between supply chain participants on a global scale, thereby enabling the creation of interoperable data exchange networks between digital objects. This is achieved by leveraging contemporary technologies, including the Internet of Things (IoT), distributed ledger (DLT), and artificial intelligence (AI), encompassing machine learning [5].

Concurrently, AI can be employed for more intricate tasks, such as supply chain network design, supplier selection, and demand planning. Consequently, such solutions have the potential to facilitate more efficient, sustainable, and environmentally sound supply chains. However, it should be noted that AI tools currently provide more of a predictive component to assist in decision making. That is to say, AI can take over some, but not all, tasks, as it does not involve autonomous decision making.

II. **Goals, objectives and principles of creating**

The primary objective of the development and subsequent operation of a digital traceability ecosystem based on AI technologies is to create a comprehensive system for supply chain participants, enabling the use of modern international standards and best practices aimed at ensuring the interoperability of digital platforms being developed and evolving, including cross-border ones, in the context of the ongoing digital transformation of the economy.

The utilisation of AI has the potential to facilitate the transformation of traceability technologies into a flexible, interconnected digital infrastructure, capable of supporting multiple virtual, non-linear supply chains. Consequently, virtual supply chains will supersede traditional fixed linear supply chains. Such approaches involve new options for information flows that enable faster order fulfilment, such as real-time order fulfilment, predicting potential risks and making decisions that minimise losses.

The process of transitioning towards a technologically mature digital supply chain can be conceptualised as a sequence of four distinct stages. The initial stage involves the establishment of data visibility within the supply chain. Subsequent stages entail the development of predictive analytics and a directive supply chain. Ultimately, the objective is to achieve a self-learning supply chain. As companies progress along the maturity curve, their reliance on manual management will be superseded by autonomous management, resulting in substantial efficiency gains and cost savings. There is now a strong focus on end-to-end supply chain visibility to help companies better manage constraints in the chain. At this stage of maturity, supply chain visibility is being established by various system integrators, including ERP systems. It is evident that businesses are able to obtain a comprehensive perspective on the movement of products through the supply chain by leveraging these types of solutions. The majority of contemporary enterprises are currently at the initial stage of digital supply chain maturity.

The subsequent stage of development (second) involves the development of predictive analytics. At this stage, predictive analytical algorithms based on big data, such as IoT sensor data, weather data, traffic levels on routes, restrictions and other related data, should be used to anticipate (predict) possible risks, respectively. This will enable the prediction of where problems may arise in the supply chain in the future. To illustrate this point, predictive analytics can be utilised to analyse data such as weather forecasts and port congestion, thereby enabling the assessment of the impact on in-transit shipping and the identification of potential delays in shipments.

The subsequent (third) stage of digital supply chain development should be a directive supply chain, powered by the application of machine learning technologies. At this stage, intelligent systems will be capable of predicting potential supply chain problems and suggesting an action plan to solve them. This technology has already been incorporated into the most advanced software solutions, in which directive analytics utilise historical data from planners. For instance, in the event of a shipment being predicted to arrive late, the software can provide a number of potential solutions, including the rescheduling of resources or the procurement of goods from an alternative supplier. The system will then recommend the most appropriate solution.

The final (fourth) stage of digital supply chain maturity should be a self-learning supply chain made possible by 'deep machine learning'. The capacity to deliver such software solutions will confer a substantial competitive advantage on both companies and software solution providers. At this stage of its development, AI is also being used for predictive analytics, taking into account an archive of data on similar deliveries under similar conditions. This helps to identify delivery problems (congestion, delays, damage, insurance, etc.) before they occur. Concurrently, AI technologies have the capacity to expeditiously and precisely analyse voluminous data in terms of demand and associated metrics. This can assist in the generation of forecasts for future sales. This approach serves to reduce the likelihood of stock formation and optimises the work of enterprises, taking into account the current and forecasted market situation for a particular period.

III. Problem Statement

The advent of contemporary digital technologies, underpinned by artificial intelligence (AI), has led to the facilitation of real-time monitoring of material flow traceability within supply chains. This development has been instrumental in the enhancement and progression of efficient logistics systems for cargo delivery, including in the context of international traffic. AI systems are capable of analysing vast quantities of data, including information on traffic situations, weather conditions, traffic congestion and delivery times. It is evident that, in consideration of the data presented, the utilisation of artificial intelligence results in the generation of optimal routes, thereby leading to a reduction in journey times, fuel consumption, and vehicle wear and tear. By leveraging data from sensors and connected devices to provide real-time insights into operations, companies can achieve cost reductions, address transport challenges and enhance productivity.

It is important to acknowledge that the implementation of AI technologies is concomitant with an elevated degree of risk. This thesis has been noted on multiple occasions in the reports of the participants of the 34th session of the Working Group on Standardisation, Policy and Regulatory Cooperation (WG.6) of the UN Economic Commission for Europe, which was held from 26-28 August 2024. [4]. In particular, the resolution of the meeting on the regulation of products and services with embedded AI or other digital technologies states the following: "When establishing objectives for AI regulation, it is imperative to recognise that the attainment of zero risk is an unattainable ideal.

In this regard, the United Nations Economic Commission for Europe (UNECE) has issued a recommendation for the conduct of risk assessments and the selection of appropriate conformity assessment methods. For instance, certain medical devices are equipped with sophisticated diagnostic systems that incorporate artificial intelligence. Despite the capacity of such medical devices to facilitate algorithmic decision-making processes, concerns regarding liability and the potential risks to patients have led to the recommendation that human involvement in the decision-making process should be incorporated wherever feasible. The necessity of mandatory human control and intervention for specific industrial equipment that incorporates human operators and programmable robots managed by AI systems should be contemplated. It is recommended that analogous approaches be formulated for other AI applications, including the automation of supply chain traceability processes [11].

It is important to acknowledge the complexity inherent in evaluating and identifying the algorithms embedded within these technologies. This is due to the fact that the methods and logics underpinning the outcomes are often not readily apparent. This element of uncertainty in technological systems is typically addressed through the implementation of a series of meticulously designed tests conducted under diverse conditions. However, it should be noted that these tests may not always prove adequate in identifying all the unknown characteristics of the system, thereby resulting in a residual risk. It is incumbent upon the regulators and distributors of such products to ensure that residual risks do not exceed an acceptable level of risk and to disclose them.

In circumstances where the potential for error associated with an AI system is deemed to be significant, it is imperative for humans to play a pivotal role in the decision-making process. It is imperative that AI systems do not possess the capability to override human control commands [3].

In view of the aforementioned points, the following tasks must be addressed:

- The establishment of requirements for automation objects, where the implementation of AI can yield substantial outcomes.
- The formalisation of the primary supply chain traceability processes, which can be enhanced through the integration of AI technologies.
- The development of a model for the digital ecosystem of supply chain support, utilising Internet of Things, distributed registry (blockchain), AI, and other contemporary technologies.
- The development of a model for the assessment of the risks of error associated with the AI system as applied to the supply chain management process is the primary objective of this study.
- The development and validation of a prototype of a digital ecosystem of supply chain support based on modern technologies is a secondary objective.

IV. Proposed approaches to the realisation of the digital ecosystem

Supply chains are complex systems, and the manner in which they are organised, transparent, flexible and scalable directly affects their success. Digitalisation is leading to the emergence of digital ecosystems for supply chain product identification and traceability, with the aim of ensuring integrity, transparency, monitoring, management and control for the entire product lifecycle. This includes the sourcing, manufacturing, warehousing, distribution and delivery of products to end consumers [3].

The digital ecosystem of supply chain identification and traceability involves the management of substantial volumes of both structured and unstructured data, the establishment of integration processes, and the coordination of logistics between supply chain actors across organisational boundaries. In addition, the design and implementation of modern integrated systems is necessary for the automatic, efficient, and secure processing of incoming orders for cargo delivery, thereby ensuring the availability of goods to intermediate and final consumers. On this basis, the formation of requirements for automation objects should be based on the analysis of a set of GS1 international standards, existing large-scale systems of goods traceability in supply chains, opportunities for their further modernisation and highlighting the main tasks where the use of modern technologies allows for significant effects to be obtained.

In terms of formalising the main processes of traceability and ensuring information interaction between the components of the digital ecosystem of traceability in supply chains, it is proposed to identify the following main architectural components, as presented in Figure [4].

The Digital Traceability Ecosystem is primarily supported by data from multiple transactional systems, including ERP, CRM, SRM and WMS [2], [12]. These systems facilitate the transfer of data on suppliers, customers, scheduled production resources, warehouse balances, and delivery schedules. Thereafter, the data is transferred through the corporate data bus to the messaging layer in accordance with the publish-subscribe model (pub/sub - publisher-subscriber – a messaging template in which messages are divided into classes and do not contain information about their subscribers (subscriber). Further templates can be used to build machine learning models in real time, for example, in order to categorise new products and upload information about them to a digital platform) [8], [10].

At the level of visualisation and decision-making, data are accessed by all stakeholders in the process, ensuring its efficiency and transparency. These stakeholders include suppliers, customers, and managers of production, warehouse, distribution of goods and/or services. It is at this level that operational, tactical and strategic management is performed, and that decision support is formed based on data analysis. These decisions may pertain to alterations in production schedules, optimisation of warehouse stock levels, the selection of suppliers and customers, and other related matters. It is imperative to acknowledge that all such decisions, made at this level, exert a direct influence on the order plans and records of customers and suppliers, consequently prompting alterations to the corresponding plans and records residing within the source systems.

In order to develop a model for assessing the risks of errors associated with the AI system, it is necessary to develop algorithms for monitoring decisions made using AI as applied to the supply chain management process. It is imperative that security policies are implemented with the primary objective of identifying and preventing potentially hazardous decisions that are made with the utilisation of AI, with a particular focus on its application in predictive analytics tasks. One possible variant of such a model could be the formation of 'AI decision sandboxes'. The purpose of the sandbox would be to allow the modelling of the consequences of proposed AI supply chain management actions before an agreed decision is made. At present, such decisions are insufficiently studied and require elaboration.

In order to develop and test a prototype of a digital ecosystem for supply chain support based on modern technologies, it is recommended that a set of existing systems for product monitoring and traceability be considered. The development of these systems should be ensured through re-engineering. The integration of novel technologies (e.g. the Internet of Things, distributed registry, AI) into existing systems should be economically viable and offer the potential for substantial impact.

A. *Practical implementation*

In the Republic of Belarus, components of Digital Ecosystems of traceability of individual groups of goods (products) that meet international and national standards [5], [6] exist and are developing at the level of business and at the level of the state.

These components include:

- Interdepartmental distributed information system 'Bank of electronic passports of goods' (http://epass.by/) [14]. A comprehensive information system that was developed to harmonize the existing procedures in trade, transport and logistics in Belarus with international rules and standards:
  - contains product descriptions in the format which complies with the international standards of eCommerce;
  - is a source of reliable product information provided by manufacturers and suppliers; creates conditions allowing to shorten the list of documents accompanying goods to points of sale;
  - facilitates the acceleration of commodity flows in supply chains and increases their transparency through the use of e-document management.

  ePass application areas: trade, supply of raw materials and products, market analysis, logistics, control of distribution, quality and safety of goods.
  The system includes the information resource (https://epass.by) which contains descriptions of goods in a format that meets international standards. This allows participants of trade and transport operations to create and exchange electronic messages.

Figure 1. Basic model of interaction of architectural components of the digital ecosystem of traceability in supply chains

Product descriptions come from primary sources (manufacturers and importers). The descriptions are further transmitted to supply chain participants to be used in business process automation systems. This data capture algorithm makes it possible to:

- eliminate the expenses of multiple manual entry of product data into information systems;
- avoid errors and ensure uniformity of product data throughout the supply chain;
- automatically manage information about documents confirming quality and safety of goods and provide it to consumers.

- State information system of identification, registration, traceability of animals and products of animal origin (https://www.aits.by/) [15]. AITS is a system designated for state regulation and management in the field of identifcation, registration, traceability of farm animals (bovines, horses, pigs, goats, sheep) of all forms of ownership, livestock facilities, as well as identification and traceability of products of animal origin. A prerequisite for building safe and secure food supply chains is to adopt uniform national and international rules for identification, registration and traceability of farm animals and, basing on these rules, to develop technologies for traceability of products of animal origin.

AITS creates and keeps up-to-date databases and functional components for the identification and traceability of products of animal origin in supply chains, allowing to trace them from farm to fork and fork to farm in a "one step forward, one step back" manner.

AITS enables animal traceability in Belarus basing on national and international standards (GS1 global standards) for animal identification and registration.

The core of the AITS system uses modern international zootechnical and veterinary reference sources, global standards for identification, traceability and electronic data interchange, and has a flexible customization system. This allows it not only to be quickly tailored for the identification of different animal species, but also to take into account changes and differences in legislation, ensuring that the system can be quickly set up and implemented in other countries. This creates conditions for the development of effective traceability information technologies at the national, inter-agency and corporate level.

The aforementioned components of digital ecosystems of traceability of certain groups of goods (products) can be modernised through the implementation of contemporary technologies, including AI. In consideration of the significance of the implementation of these solutions for the nation's economic advancement, the re-engineering of these systems can be undertaken within the ambit of state-sponsored programmes, with the active participation of the most accomplished scientific and practical organisations within the country. In the domain of AI, it is imperative to consider priority markets and technologies in a holistic manner, with a view to identifying the most promising projects at the nexus of these areas.

The primary objective at present is to generate demand for the utilisation of AI technologies and to establish an environment conducive to the establishment of fundamentally novel technological enterprises based on novel combinations of AI technologies [3]. In order to address this challenge, it is imperative to establish a state programme on AI, within which a long-term strategy for the development of AI in Belarus can be articulated. This strategy should be focused on leveraging the existing backlog, while also fostering collaboration among scientific, design organisations and universities to create unified and promising solutions. The following links will facilitate the effective promotion of the nation's pressing sustainable development priorities and the introduction of solutions in new global markets for AI technologies and tools.

B. Conclusion

Supply chains are intricate systems, and the efficacy of their organisation, transparency, flexibility, and scalability directly impacts their development success. The application of AI technologies is leading to the emergence of digital ecosystems and their creation in the field of supply chains. The purpose of these ecosystems is to ensure integrity, transparency, monitoring, management and control for the entire product lifecycle. This includes the selection of suppliers, production, warehousing, distribution and delivery to the end consumer [7], [9].

The solution to the problem of modernising existing supply chain monitoring systems through the use of AI technologies provides an opportunity to obtain a significant effect through the implementation of predictive analytics approaches in the real sector of the economy. The execution of such a task can be achieved through the implementation of a digital ecosystem model for supply chain monitoring, which utilises the Internet of Things, distributed ledger technology (blockchain), artificial intelligence, and other contemporary technologies. The implementation of such an ecosystem should, in principle, provide opportunities to prevent negative consequences from AI-based decisions. One such opportunity would be the development of a model for assessing the risks of errors associated with the AI system as applied to the supply chain management process.

The utilisation of AI technologies is poised to further modernise a plethora of business processes, encompassing not only supply chains but also all phases of the product life cycle. Specifically, SCM based on artificial intelligence has the capacity to address the following tasks: modelling and simulation, optimisation, forecasting and risk analysis, decision support, inventory management, marketing and transportation.

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О РАЗВИТИИ ТЕХНОЛОГИЙ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА И ПЕРСПЕКТИВАХ ИХ ПРИМЕНЕНИЯ В УПРАВЛЕНИИ ЦЕПЯМИ ПОСТАВОК

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В статье рассмотрены вопросы практического применения технологий искусственного интеллекта для реализации цифровых экосистем идентификации и прослеживаемости товаров в цепях поставок. Освещены проблемы решения задач модернизации действующих систем мониторинга цепей поставок за счет применения технологий искусственного интеллекта. Описаны общие требования к модели цифровой экосистемы сопровождения цепи поставок с использованием технологий Интернета вещей, распределенного реестра (блокчейн), искусственного интеллекта и других современных технологий. Отмечены вопросы безопасности и необходимости предотвращения негативных последствий от решений, принимаемых на основе технологий искусственного интеллекта, за счет разработки модели оценки рисков ошибок, связанных с системой искусственного интеллекта применительно к процессу управления цепями поставок.

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