Formation of the Digital Platform for Precision Farming with Mathematical Modeling

Victor Medennikov[0000-0002-4485-7132], Alexander Raikov 1[0000-002-6726-9619]

[1] Federal Research Center "Informatics and Control" of the Russian Academy of Sciences, Vavilova 44-2, 119333, Moscow, Russia
[2] V.A. Trapeznikov Institute of Control Sciences of the Russian Academy of Sciences 65 Profsoyuznaya street, 117997, Moscow, Russia
dommed@mail.ru, alexander.n.raikov@gmail.com

Abstract. The paper addresses the issue of development trends of precision farming technologies (PFT) in the world. PFT's rapid development's main motive is the improvement of geoinformation technologies, artificial intelligence, and other cutting-edge digital technologies. It is shown that these technologies are currently evolving from the digitalization of individual operations to the digitalization of an interconnected set of operations in crop production and related industries. The approach makes PFT available for small and large farms. The paper analyzes the problems of PFT implementation such as following: the lack of a clear strategy in this area, weakening of scientific researches, the dominance of the "task-based" approach of the development and implementation of digitalization systems, significant underutilization of traditional factors of increasing production efficiency in the industry, limited financial, labor, material and technical resources, poverty of most households. The paper discusses the scientific basis for designing an optimal digital platform for precision farming based on mathematical and ontological modeling. An analysis is made of the constituent modules of a promising digital platform of precision farming integrated into unified geographic information space. To demonstrate the possibility of forming a cloud service of the value chain, the concept of the single cloud Internet space for digital interaction of the logistic activities of agricultural production, processing, and marketing of its products is presented.

Keywords: Digital Platform, Precision Farming, Mathematical Modeling, Geographic Information System.

1 Introduction

An increasing number of countries are currently giving strategic priority to the digitalization factor of developing an effective interaction between the state, business, and population. Based on the acquired positive experience of countries' digital transformation, this process is becoming increasingly large-scale and dynamic. The digitalization of the economy has significantly affected agriculture, turning it into industrial production. For example, in 2018, in the UK, for the first time in the world, winter wheat has been grown in one hectare area without people's direct participation. A good harvest was obtained. Robotic agricultural machines and units carried out all technological operations from processing the soil to threshing the grain.

The upcoming digital era of agricultural industrialization in industrialized countries requires introducing the most modern information and communication technologies (ICT) in management and agricultural machinery in almost all production and auxiliary technologies. In digital technologies, countries see the main means of increasing the efficiency and quality of industrial products in the world against the background of exhaustion of other factors of its growth, which include: obtaining more productive varieties of cultivated plants, an invention of more energy-efficient agricultural mechanisms, the formation of optimal agricultural technology systems, the emergence of effective remedies and feeding plantations. Goldman Sachs Bank believes that digital technologies can increase industry productivity in the world by 70% by 2050.

At the same time, the leading technology is precision farming technology (PFT), which increases productivity to the degree that cannot compare with the appearance of tractors, chemical fertilizers, pesticides, herbicides, and genetically modified seeds and plants. Precision farming (PF) is the approach that utilizes cutting edge information technology to achieve the greatest improvement and efficiency in agricultural systems. This approach exploits modern information technology tools such as Global Positioning System (GPS), Geographical Information System (GIS), and Remote Sensing to improve farm management [1].

The essence of PFT is the integration of new agricultural technologies with the high-precision positioning based on remote sensing technologies (Earth remote sensing) and differentiated highly effective and environmentally friendly agricultural practices in the fields based on detailed information on the chemical and physical characteristics of each site. As a result of this integration, by creating optimal conditions for the growth and development of crops within environmental safety boundaries, digital PFT makes it possible to obtain the maximum number of products with requirements for quality, price, and safety.

This shows that agriculture has to combine a huge amount of heterogeneous, multidimensional, diversified information with appropriate technologies for its processing. As a result, PFT has evolved from the digitalization of individual operations to a complex of operations in crop production and the integration of operations in related industries. A significant reduction in the cost of digital technologies has propelled them to such a level that it has become possible to receive information about each operation with any agro-industrial facility and its surroundings with an accurate analysis of all actions' consequences. Accounting and monitoring the maximum possible number of agricultural processes become the main goal in developing a digitalization strategy for the world's largest agricultural and engineering companies.

Russian agriculture lags far behind the pace of the digitalization of developed countries. One of the reasons is the absence of a clear national strategy in the agriculture area. There are a lot of factors affecting both the industry itself and its digitalization. A scientifically integrated approach to the industry's digital transformation based on mathematical modeling, taking into account financial, labor material, and technical resources, is required. This concerns the PFT, an integrator of a significant number of agricultural technologies, remote sensing, and geographic information systems.

Authors' papers [2, 3] represent results of the analysis of the experience of creating information systems in the agro-industrial complex of Russia within the framework of the Comprehensive Program of Scientific and Technological Progress of the Member States of the Council for Mutual Economic Assistance. In these papers, the conceptual approach to the digital transformation of agriculture using the necessary conditions for applying this approach is suggested. To develop this approach in this paper, a more detailed scientific elaboration of the PFT's dominant digital technology is given; the upper-level of the architecture of the unified digital agricultural platform created in the context of international standards is presented.

2 Review and Trends

The main motivator for the rapid development of PFT in recent years was the improvement of ICT, electron-optical surveying equipment, the formation of global positioning systems that can simultaneously determine the coordinates of a significant number of objects with high accuracy anywhere in the world. There are a lot of papers devoted to this issue.

For example, the paper [4] highlights that the PFT tools are gaining ground in sustainable agriculture policies. The authors suggest a model that describes different farms with different propensity to adopt precision farming tools. The paper marks two main limitations. The first one concerns the representativeness of the sample: farmers were selected during fairies devoted to PFTs. Secondly, the adoption rates vary widely among different kinds of PFT [5]. In this context, the authors considered precision farming tools as unique.

The paper [6] addresses the issue of influencing the trend of precision livestock farming on human-animal relationships. It is shown that introduction of this approach does not always depredate human-animal relationships. Farmers spend more time in front of the computer each day looking at digital data about the animals. But the paper does not describe the details of working with digital technology.

The paper [7] devoted the idea that sensory signals help make animal production decisions more effective and achieve significant animal husbandry and farming gains. Sensing technology can make animal farming more holistic, humane, environmentally friendly, centralized, large scale, and efficient. There are many types of machine learning algorithms. For getting the desired outcome of the animal welfare evaluation, the choice of features for data analysis has to be done. For example, from a set of 44 features, perhaps only five to seven features may be needed to yield highly accurate classification results. In real-time systems, large feature sets could be problematic due to computational complexity. The paper shows that the machine learning algorithm has to take into account the behavior of animals in different environments because it can show discrepancies in classification results, which can be due to differences in the animals or environmental characteristics.

Some innovative examples show the trend of using GIS in PFT for collecting, storing, processing, and displaying spatial data of a certain object or event on a map. The research work [8] presents a GIS approach for assessing the biogas production potential's spatial distribution by taking into account the seasonal variation of this production. The results proved that seasonal variations of the potential of non-lignocellulosic agricultural residues and municipal bio-waste could be neglected since the generated feedstocks have near-continuous generation during the whole year.

Different applications can extend GIS systems. For example, the article [9] presents the *r.landslide* system. This is a free and open-source add-on to the open-source GIS for landslide susceptibility mapping, written in Python. Land-use planning organs can use it as a support tool very agile and effective. This system could be intended to support early-warning systems for events that are triggered by rainfall.

The GIS using in various industries has led to the fact that such data currently occupy a predominant share of all stored data—over 80%, the bulk of Earth remote sensing data. Due to such properties, remote sensing and GIS technologies immediately found their widespread use in technologies of remote sensing throughout the world due to the obvious spatio-temporal nature of the agricultural activity.

Modern electron-optical equipment installed on various mobile (space, air, sea, transport, agricultural) and stationary devices has such a resolution that allows solving a significant range of problems in the field of agricultural production - from mapping the boundaries of individual land plots to the analysis of using intended to land and plant conditions over large areas. Thanks to special means of deciphering the vegetation cover's spectral characteristics, it became possible to calculate various vegetation indices that reflect the dynamics of crops' development, their biomass. The use of the dynamic data series of remote sensing data makes it possible to monitor the implementation of agricultural measures to identify the fields infected by pests and diseases in the dynamics and the damage caused to them due to natural disasters. Every year, the list of tasks to be solved is significantly replenished.

J'son & Partners Consulting presents the research results devoted to the world market of cloud platforms of the Internet of Things (IoT) for agriculture in Russia [10]. This company believes that two specialized platforms are gradually formed in agriculture: agrarian data aggregator platforms; otherwise, platforms for primary data collection and accumulation (information resources) and application platforms. These two platforms must be integrated with the intensive mutual exchange of data. At the same time, data analysis is carried out in both platforms, and applications in the form of automation of production management using information resources are solved only in application platforms. It is also argued that such symbiosis is possible only through the development of appropriate cloud platforms and services since only such cloud technology makes them available for enterprises of all sizes and not just for some of the largest farms. The appearance of these services, including those available for small farms, will significantly increase the industry's efficiency and reduce the risks of activity for all participants in the value chain: suppliers of resources, consumers of products, and transport companies. This chain's main element is cloud platforms and applications for crop production and universal logistics platforms and applications that form 86% of the total amount of information consumed. The massive use of such a cloud service in the agricultural business is only planned.

This company also believes that using the two types of technologies of the above-mentioned cloud platforms in the supply chain (wholesale companies, logistics, retail chains) will provide an opportunity to switch to direct sales, in which the manufacturer traces the final consumer, the volume and structure of his demand, and through the use of mathematical models, in particular, artificial intelligence and predictive analytics, it produces exactly the products that the consumer needs and at the right time, and delivery control is realized by automatic exchange of information between participants in the supply chain and minimizes the use of warehouse and logistics infrastructure resellers. Such an approach makes it possible to exclude any unnecessary intermediaries from the chain, which now account for up to 80% of the cost in the retail price of goods. It is believed that in total, these two factors can increase the volume of agricultural products consumption in Russia by 1.5 times in monetary terms. Simultaneously, the decrease in retail prices will be compensated by an increase in the volume of consumption of goods. AS a result, the margin of agricultural producers' business even grows with a decrease in risks. Due to this, the fleet of tractors in the industry may increase by 300 thousand units, combines will increase by 200 thousand units, and the use of fertilizers can grow nine times.

Agriculture, in terms of the production process, looks and is usually described as a system of its interrelated elements in the form of production resources. To produce a certain type of product with required qualitative and quantitative characteristics, strict proportions between the system's elements (resources) must be observed due to the general and specific requirements of the planned products' production technologies. Deviations from technological requirements for the quality and quantity of one of the resources entail certain changes in using other resources, which ultimately leads to the products' quantitative and qualitative consequences. With the awareness of the importance of the digital economy, as one of the resources, along with the material, human and financial ones, most affecting the economy, their rational use becomes very obvious in conditions of their limited number. Therefore, depending on the resource base, the state of agricultural machinery, and personnel's education, each country chooses its own approach to the industry's digitalization, choosing individual digital technologies. So, in the USA, already 40-50% of farms use PFT technologies, which is about 40% of the world's market. Monitoring of US farms has shown that the following PFT services are most popular: rapid soil analysis (90% of farms); yield monitoring and mapping, space navigation technology (80%); dosed fertilizer application based on technological maps (60%); images from spacecraft, vegetative indices of cultures (30%) [11].

In the European Union, almost all countries are beginning to use PFT, while Germany is the PFT leader. Significant experiments are planned with PFT in Asia: China and India. In Germany, the Atfarm digital service is currently being tested. The Atfarm is a cloud-based service in the field of PFT developed by the Norwegian company Yara for dosed plant nutrition based on plant health data collected using Yara N-Sensor equipment [12]. This service helps farmers to apply nitrogen fertilizers using satellite remote sensing data at each specific site. The Yara N-Sensor is equipment allowing to determine the requirements of plants for nitrogen. It moves during the fields with dosing of fertilizer application on a plot of 20x20m in size. Although the Yara N-Sensor costs about 25,000 euros, which is extremely expensive for Russia, it gives the most accurate recommendations of all methods and does not depend on the weather. Most technologies based on satellites and Unmanned Aerial Vehicles (UAV) depend on the region's cloudiness.

3 Problems of Introducing PFT in Russia

Precision farming is defined as a system consisting of interconnected subsystems: differentiated production technologies in crop production, a software and hardware complex for high-precision positioning of technological operations of the production process, a set of technical and agro-chemical means meeting the quality and quantity requirements. Therefore, the use of PFT should occur using an integrated approach. It requires the appropriate integration of information systems and information resources. However, today in Russia's agriculture, a task-oriented approach to the design and development of information systems (it is also called patchwork, island informatization) prevails, when they either order independently or purchase individual software systems that are ready from various manufacturers and are neither connected ontologically, nor functionally, nor informational. It was still possible to put up with this situation before the digital age due. But now, in the era of total digitalization of the economy, the low level of penetration of informatization into the enterprise management system, the haphazard introduction of ICT leads to huge losses.

This is also true concerning the PFT. So, the first experiments of their use in Russia's agrarian production show their non-integrated, fragmentary use of individual technologies with filling heterogeneous information that differs in a structure during sending from one farm to another. In connection with the mass introduction of information systems and individual technologies of PFT, only in the last two years, the heads of information departments of agricultural companies began to pay keen attention to the weak unification of primary accounting, patchwork computerization of business, the introduction of software systems, databases, the absence of a unified system of reference information.

At the end of 2019, a draft concept of the national platform “Digital Agriculture of Russia” was developed. It provides a list of sub-platforms, the composition of which is determined from a task-based approach. The sub-platforms included: a sub-platform for collecting agricultural statistics, a sub-platform for providing information support and services, a sub-platform for digital land use and land devices, a sub-platform for storing and disseminating information materials, a sub-platform for traceability of agricultural products, a sub-platform for agro-meteorological forecasting, a multi-factor service operational monitoring, diagnostics and proactive modeling of the development of crop diseases. Such an approach to the digital platform (CPU) of agriculture, such as combining these sub-platforms, excludes their integration on a truly integrated unified CPU agribusiness.

However, the concept says almost nothing about the transformation of national agricultural management technology. The problems of forming a unified educational environment, which should play a tripartite role, are almost not addressed: support for scientific research, raising the level of education, an effective system of transfer of scientific and educational knowledge to the economy due to unlimited access to knowledge not only to traditional users in the person of scientists, students, and teachers but also to prospective applicants and employers, government agencies, producers, business, management, other categories of the population. Such a unified information space of scientific and educational resources should remove the contradictions between the volumes of accumulated knowledge and their effective use, as well as a tool to improve the quality of human capital, its assessment, and the impact on the socio-economic situation in the industry.

The number of companies offering various individual solutions in precision farming based on GIS technologies is growing. Since these technologies are implemented in fragmented form, GIS is also capturing only individual aspects of the processes. Moreover, the logical database structures are incomplete subsets of the ideal unified informational scheme of plant growing [13], which poses a threat to the future integration of agricultural information resources into a promising digital platform for the use of GIS. In this situation, following a task-oriented approach, the potential number of information systems in crop production that may appear in the absence of their integration may be assessed. We think that about 150 topical tasks are to be solved in crop production for 20 crops, about 20 different technological operations are performed with each crop, and the number of regions is 80. Then, we can potentially get 4,800,000 information systems. From an analysis of the calculation results based on a mathematical model of scenarios of possible options for informatization of the agricultural industry, it becomes clear that with this approach, without abandoning task-oriented technologies for designing digital systems for standard and automated design with state support, the maximum possible level of the digital transformation of the industry will not exceed 17%, according to our estimates.

Also, there are a significant number of other problems in the implementation of PFT technologies. Thus, the supply of expensive and high-tech machinery and equipment will have a delayed effect due to, on the one hand, its high cost and lack of sufficient financial resources for most households; on the other hand, a significant amount of existing equipment, but unsuitable, for the most part, PFT. PFT's containment is affected by the almost complete absence of domestic manufacture of communication devices, sensors, and actuators necessary to install on agricultural machinery for automatic control of PFT technological processes. For example, a Yara N-Sensor device [12], mounted on a tractor to measure the culture requirement for nitrogen when the tractor is moving across the field and varying the dose of fertilizing on a 20x20 m plot, costs about 25,000 euros, and the MTZ 80.1 tractor is almost three times cheaper—from 800,000 rubles. Manufacturers of Kirovets tractors without smart electronics currently have big problems with the sale due to the huge price for farms of about 7 million rubles. Due to the much more difficult to master PFT technologies compared to existing technologies in the country, there is a big drawback and trained staff.

4 The Approach to Design a Digital PFT

The most advanced approach to the design of digital systems is currently considered an architectural approach. This approach determines the overall structure and organization of life cycles and the life history of the "enterprise" [14, 15]. An enterprise here is understood in a broad sense; for example, an enterprise may be a system for managing the industry, the economic sector, or the state. So, the user of this approach has found its application in the federal authorities of the United States, the construction of the electronic government of India, and so on.

The architectural approach began to take shape a long time ago. Back in the 60-80s of the last century, CODASYL (COnference on DAta SYstems Language) made a significant contribution abroad. We can recall the ANSI-SPARC 1975 standards. In domestic practice, A.I. Kitov and V.M. Glushkov made a great scientific contribution to solve this issue when creating a nationwide automated system to collect and process information. The 100th anniversary of the former is celebrated this year [16]. In Russia, the conceptual issues of designing a unified digital agricultural platform, including the PFT sub-platform strategy creating (Fig. 1), were worked out due to the optimal integration of information systems [17, 18]. So, an economic-mathematical model was developed for the formation of a digital platform for economic management, which allows calculating the optimal digital platform in agriculture.

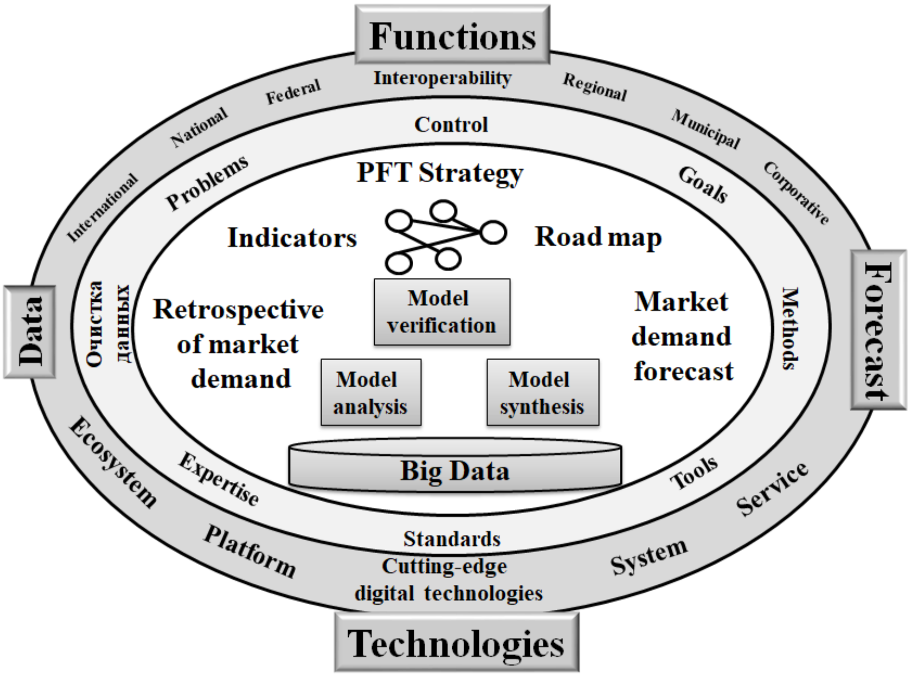

Fig. 1. The upper-level of the architecture of the unified digital agricultural platform

A digital platform is a business model for providing the possibility of an algorithmized exchange of information and values between a huge number of market participants by conducting transactions in a single information environment, leading to lower costs due to digital technologies and changes in the division of labor. It includes a collection of ordered digital data based on ontological modeling; mathematical algorithms, methods and models of their processing, and software and hardware tools for collecting, storing, processing, and transmitting data and knowledge optimally integrated into a unified information management system designed to manage the target subject area with the organization of rational digital interaction of stakeholders.

The model constructed by the authors made it possible to distinguish many digital sub-platforms, one of which is a cloud service for collecting and storing operational primary accounting information of all enterprises in the Unified Database of Primary Information (UDPI) in the following form: type and object of operation, place of implementation, subject of implementation, date and time interval conducting, means of production involved, the volume and type of resource consumed. The second is also a cloud service of a Unified Database of Technological Accounting of all enterprises (UDTA). The ontological information model of crop production, based on them, is common for all agricultural enterprises in Russia (a standard for information resources) with 240 functional management tasks with a single description of algorithms for most agricultural organizations (a standard for applications). Similar work was done for all sectors of agricultural production and 19 types of processing enterprises.

Thus, a digital platform is simulated, integrating primary accounting information and technology databases in a single cloud environment. It is formed based on a unified system for collecting, storing, and analyzing primary accounting, technological, and statistical information, interfaced both with each other and with a unified system of classifiers, reference books, standards, representing registers of almost all material, intellectual and human resources of the agro-industrial complex.

The presented digital platform is acquiring special significance when remote sensing and GIS technologies begin to be actively introduced in such a relatively young agricultural production field as precision farming, which requires a combination of a large amount of data and technologies. Fig. 2 presents the working schema of a promising digital sub-platform of PFT in agriculture, which uses the possibility of Unified Geographically Distributed Information System of Earth Re-mote Sensing from space (UGDIS ERS).

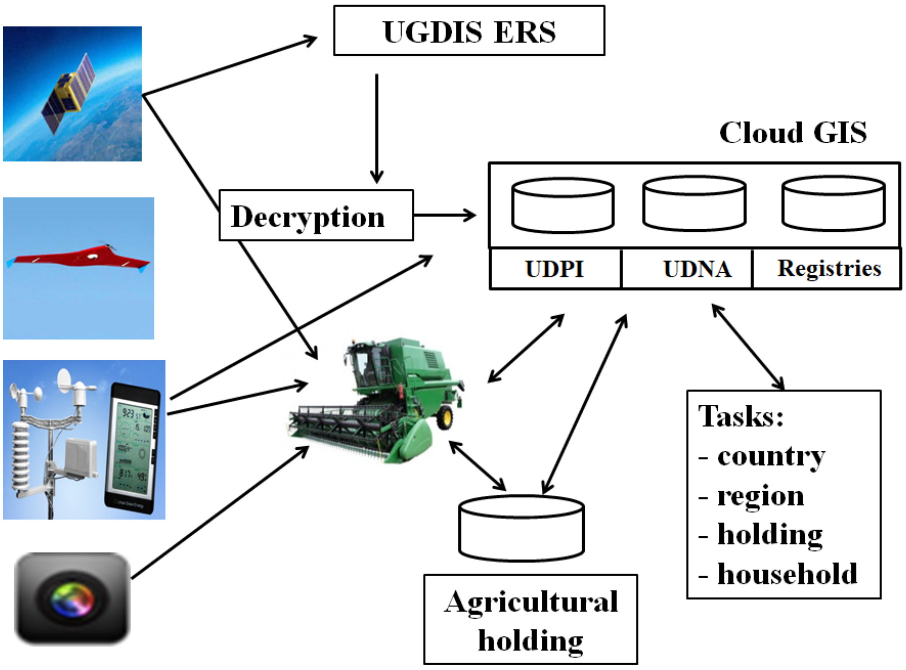

Fig. 2. The working schema of the digital sub-platform of PFT in agriculture

Consider the individual elements of this digital sub-platform PFT. All remote sensing data are currently in the heterogeneous databases collected and stored in various ground-based departmental complexes and centers. Data is often transmitted to customers in the form of images, which need to be independently and labor-intensively decrypted. The most effective way to get ready-made images for commodity producers would be forming a unified cloud GIS remote sensing with a special unified body for their decryption in the industry with free transfer of ready-made solutions to users. Now, there are hopes for this—UGDIS ERS is being created with the integration of all remote sensing information into a unified geographic information space of the country with an expiration date of 2025. The work is carried out following plans of the development concept of the UGDIS ERS. Of course, it would be desirable to create the same center for decrypting images both from drones that are gaining popularity, as well as from stationary remote sensing masts, which would lead to a decrease in the cost of introducing PFT and increasing the efficiency of using these devices.

Remote sensing information after decryption in the created centers should be collected in a cloud GIS (CGIS), which also collects information on technological and primary accounting, data on all material, intellectual and human resources of the industry. An example of this approach is the European Union Unified Administrative Management System (UAMS), which receives and stores information about lands and their users. Further, information obtained from sources other than those indicated above and from gadgets, ground-based sensors, and sensors installed on agricultural machinery are collected in a CGIS. At the same time, part of it is transmitted directly to communication equipment back to the equipment. Thus, the CGIS will collect all data on all employees' technological and accounting operations at each site throughout the year. It will be possible to track all movements of products, materials, and any equipment.

As noted in Section 1, the improvement of PFT based on GIS and remote sensing will allow the formation of a cloud service for all participants in the value chain, which dramatically increases their activities' efficiency. Based on the results of calculations with the economic and mathematical model for the formation of the digital platform of the agro-industrial complex in the form of the unified database of primary accounting and the unified database of technological accounting, it can be obtained by integrating them the Unified space for digital interaction (USDI) of logistics activity (Fig. 3). The implementation of this scheme is based on a mathematical model for optimizing all participants' logistics activities in the supply chain.

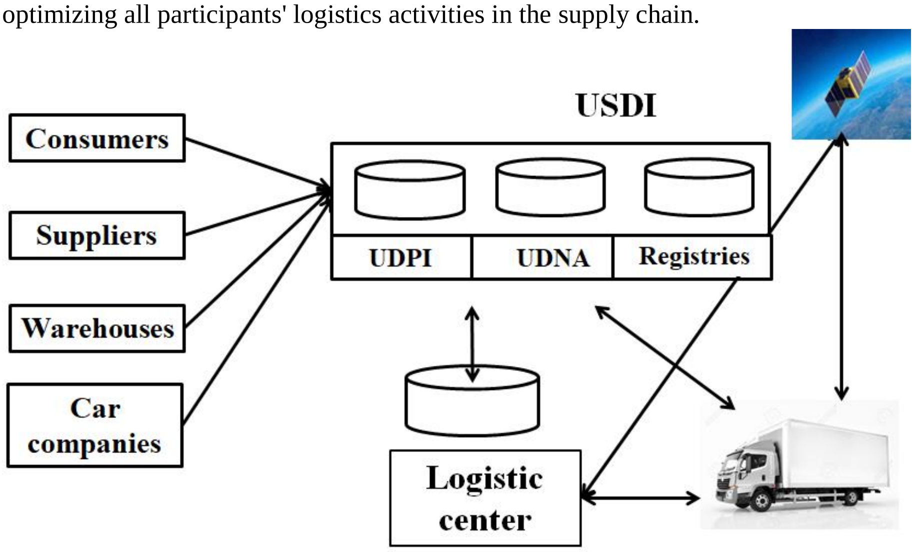

Fig. 3. Unified space for digital interaction

The digital platform, based on PFT, GIS, and remote sensing technologies, will create the operational management system. It will be a tool for economic analysis based on mathematical modeling, artificial intelligence, internet of thing, predictive logic, and big data in various sections at any level of management from the site to the federal center.

Since remote sensing and GIS technologies began to be actively applied in many other sectors of the economy besides agriculture, such as cartography, ecology, forestry, land management, geology, logistics, construction, oil and gas transportation systems, weather and climate, oceanology, etc. they will gradually acquire the status of infrastructure technologies [19]. In this case, with their competent integration, these technologies will soon have to play in the digital economy the same key role that electric networks, railway infrastructure, telegraph and telephone communications, etc. played in due time.

5 Conclusions

It has long been known that any innovation requires the fulfillment of three conditions: a “social order” must be formed, an appropriate technical level must be achieved for translating the innovation into practice, and the threshold of the socio-educational level of potential performers and consumers of innovation must be exceeded. Since these conditions are not fully ensured in Russia, the solution seems to be to use a proven approach, including the development of the most advanced remote sensing technologies at several reference objects of different levels of management (from the enterprise to the region), the supply of modern software and hardware for remote sensing in combination with a variety of technological equipment and machines involved in the production process of industries, the mass introduction across the country.

The consistent implementation of the promising PFT digital sub-platform based on reference objects will create the conditions for turning it into a set of scientifically-based infrastructure technologies for the entire agricultural sector. This integrated approach will significantly reduce the costs of implementing PFT, remote sensing, and GIS technologies with a significant increase in the efficiency of their use.

References

1. Kannan, B., Rajasekar, M., Jayalakshmi, K., Thiyagarajan, G., Selvakumar, S., and Rajendran V. (eds): Protected cultivation and precision farming technologies, TNAU, India, 297 p. (2019).
2. Medennikov, V.I.: Ot konzepzii k praktitscheckoj realisazii edinoj zivrowoj platvormy agropromyschlennogo komplekca (From concept to practical implementation of a single digital platform for the agro-industrial complex). Mezhdunarodnyj cel'cko-chosjajctwennyj zhurnal, № 5(377), 77-81 (2020), https://doi.org/10.24411/2587-6740-2020-15099.
3. Medennikov V.I.: Zivrowaja platvorma uprawlenija cel'ckim chosjajctwom (Digital Agriculture Management Platform). Cbornik III nazional'noj (wceroccijckoj) nautschnoj konverenzii c mezhdunarodnym utschactiem «Teorija i praktika cowremennoj agrarnoj nauki». Nowocibirck, IZ NGAU «Solotoj koloc», 846-851 (2020).
4. Vecchio, Y., De Rosa, M., Adinolfi, F., Bartoli, L., Masi, M.: Adoption of precision farming tools: A context-related analysis, Land Use Policy, vol. 94, 104481 (2020), https://doi.org/10.1016/j.landusepol.2020.104481.
5. Lowenberg-De Boer, J., Erickson, B.: Setting the record straight on precision agriculture adoption. Agron. J. 111(4), 1552–1569 (2019), https://doi.org/10.2134/agronj2018.12.0779.
6. Kling-Eveillarda, F., Allain, C., Boivin, X., Courboulay, V., Créach, P., Philibertf, A., Ramonet, Y., Hostiouh, N.: Farmers’ representations of the effects of precision livestock farming on human-animal relationships, Livestock Science, vol. 238, 104057 (2020), https://doi.org/10.1016/j.livsci.2020.104057.
7. Neethirajan, S.: The role of sensors, big data and machine learning in modern animal farming, Sensing and Bio-Sensing Research, vol. 29, 100367 (2020), https://doi.org/10.1016/j.sbsr.2020.100367

8. Lovrak, A., Pukšec, T., Duić, N.: A Geographical Information System (GIS) based approach for assessing the spatial distribution and seasonal variation of biogas production potential from agricultural residues and municipal bio waste, Applied Energy, vol. 267, 115010 (2020), https://doi.org/10.1016/j.apenergy.2020.115010.
9. Bragagnolo, L., Silva, R.V., Grzybowski, J.M.V.: Landslide susceptibility mapping with r. landslide: A free open-source GIS-integrated tool based on Artificial Neural Networks. Environmental Modelling & Software, vol. 123, 104565 (2020), https://doi.org/10.1016/j.envsoft.2019.104565
10. Analysis of the market of cloud IoT platforms and applications for digital agriculture in the world and prospects in Russia. J'son & Partners Consulting. URL: https://json.tv/en/ict_telecom_analytics_view/analysis-of-the-market-of-cloud-iot-platforms-and-applications-for-digital-agriculture-in-the-world-and-prospects-in-russia (2018), last accessed 2020/05/04.
11. Kulba, V., Medennikov, V., Butrova, E.: Methodical approaches to agricultural risk estimate in forecasting the economic effect of applying data of the Earth's remote sensing. IEEE Xplore Digital Library. 12th International Conference "Management of large-scale system development" (MLSD). Moscow, Russia (2019), https://doi.org/10.1109/mlsd.2019.8911084
12. Atfarm. URL: www.at.farm. last accessed 2020/05/04.
13. Ereshko, F.I., Medennikov, V.I., Muratova, L.G.: Modeling of a digital platform in agriculture. IEEE Xplore Digital Library. 11th International Conference Management of Large-Scale System Development (MLSD), Moscow, Russia (2018), https://doi.org/10.1109/MLSD.2018.8551894.
14. The TOGAF Standard, Version 9.2 Overview: URL: https://www.opengroup.org/togaf, last accessed 2020/05/04.
15. ArchiMate 3.1 Specification, a Standard of The Open Group: URL: https://pubs.opengroup.org/architecture/archimate3-doc/, last accessed 2020/05/04.
16. Peters, B.: How not to network a nation: The Uneasy History of the Soviet Internet. The MIT Press, 313 p. (2016).
17. Ereshko, F.I., Kulba, V.V., Medennikov, V.I.: Digital platforms clastering model // 12th International Conference Management of Large-Scale System Development (MLSD), Moscow, Russia (2019), https://doi.org/10.1109/MLSD.2019.8911012.
18. Raikov, A., Abrosimov, V.: Import countries ranking with econometric and artificial intelligence methods. 3d International Conference Digital Transformation and Global Society, DTGS, St. Petersburg, Russia, Revised Selected Papers, Part I. 402-414 (2018), https://doi.org/10.1007/978-3-030-02843-5_32
19. David, P.A.: The dynamo and the computer: an historical perspective on the modern productivity paradox, The American Economic Review, American Economic Association, 80(2):355-361 (1990).