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**ROLE OF THE INFORMATION SYSTEM  
IN THE PROCESS OF DIGITAL TRANSFORMATION  
OF THE AGRICULTURAL ENTERPRISE**

**ABSTRACT**

of a dissertation for awarding the educational and scientific degree of "Doctor" under  
the doctoral program "Application of Computing in Economics"

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# **I. GENERAL CHARACTERISTICS OF THE DISSERTATION**

## **1. Relevance and significance of the studied problem**

Digital transformation is becoming a major factor for the sustainable and competitive development of agricultural enterprises. In the context of grain production, which is characterized by high resource intensity and the need for precise planning, the implementation of information systems becomes critical for optimizing processes and making management decisions.

The relevance of the topic is determined by the national and European strategic documents, which place the digitalization of agriculture among the top priorities. The Digital Transformation of Bulgaria 2020-2030 Strategy and the Bulgaria 2030 Program emphasize the need for modern technologies, reducing administrative burdens and increasing productivity. These guidelines are in line with international sustainable development goals and reflect the growing demands for transparency, efficiency and environmental sustainability.

Information systems occupy a key place in this process, as they integrate technologies, organizational processes and management practices, supporting analysis, planning and control in the agricultural enterprise. However, in Bulgarian grain farms, their application remains limited – basic solutions oriented towards document flow, finance and GIS, which often work in isolation, without integrated data and without analytical functionalities, prevail. This fragmentation hinders a full-fledged digital transformation and reduces the strategic value of the information collected.

The need for integrated systems that bring together data from field sources and support real-time management is becoming increasingly important. In the context of the Common Agricultural Policy, enhanced regulatory requirements and changing market conditions, the implementation of modern information solutions is becoming a critical factor for sustainable and competitive production.

The importance of the study is also reinforced by the need to develop digital skills and organizational capacity. Insufficient staff training and underestimation

of the complexity of implementation often limit the effectiveness of technological solutions. At the same time, the advent of artificial intelligence, machine learning and big data analysis is creating new opportunities for optimizing production processes and managing risk.

Thus, the role of the information system in the process of digital transformation is a topical and significant scientific problem, directly related to increasing the efficiency and sustainability of Bulgarian grain production enterprises.

## **2. Object and subject of the study**

**The object** of the dissertation is the process of digital transformation in the grain production enterprise.

**The subject** of the study is the flow of information systems on the process of digital transformation of the agricultural enterprise and the possibilities for their optimization through modern approaches and technologies.

## **3. Purpose and objectives of the study**

**The main goal** of the dissertation is to investigate the role of the information system in the process of digital transformation of the agricultural enterprise and to propose a model for optimization of this system to increase efficiency.

### **Tasks of the dissertation:**

- **In theoretical terms:**

- a) To define the concepts of "information system" and "digital transformation of business" and to build a conceptual framework for their application in agribusiness.
- b) To explore the need and role of digital transformation for the intelligent grain production enterprise, as well as the main approaches, technologies, challenges and trends in the digitalization of the agricultural sector.

- **In the practical and applied aspect:**

- c) To analyze the current state of digitalization and the application of modern information systems in grain production enterprises.
- d) To investigate the impact of digital transformation on grain production efficiency.
- e) To develop a model for digital transformation and optimization of information systems in order to increase the efficiency of the grain production enterprise.

#### **4. Research thesis**

The research thesis is that the evolution of information systems in agricultural enterprises from reporting to intelligent and analytical platforms is a determining prerequisite for the implementation of a full-fledged digital transformation of production and management processes.

#### **5. Restrictive conditions of the study**

The study is focused on enterprises mainly engaged in grain production, with an emphasis on specific processes in agribusiness. The scope includes analysis of information systems for production management, resources and data, as well as specialized agro-technological solutions. The study is limited mainly to the territory of Bulgaria, as theoretical comparisons with practices in the EU are made, without conducting detailed empirical studies.

#### **6. Research methods and methodology**

The study is based on a mixed methodological approach, combining quantitative and qualitative methods for analyzing the role of information systems in the digital transformation of grain production enterprises. Quantitative data were collected through surveys, and qualitative data – through interviews and expert consultations with representatives of the sector.

In the process of research, the methods of analysis and synthesis, comparison, induction and deduction, system and critical analysis, observation, modeling, expert evaluation, as well as tabular and graphical presentation of

information are used. Statistical analysis helps to justify and validate the results obtained.

Historical-theoretical and system analysis is applied in the study to trace the development of concepts and technological solutions in the agricultural sector and the transformation of information systems into intelligent management platforms. Through critical and comparative analysis, the main limitations and risks of digitalization have been identified, with statistical analysis, modeling and tabular presentation supporting the justification and validation of the results.

The practical orientation of the research is supported by the participation of the PhD student in the development and implementation of the information systems "Agrosystems", "Arendator-BG" and "Bank of Properties", which allows testing and validation of the main conclusions in compliance with the principles of data protection.

## **II. STRUCTURE AND CONTENT OF THE DISSERTATION**

The dissertation consists of 244 pages, of which: introduction (5 pages); exposition in three chapters (222 pages); conclusion (4 pages); references (13 pages) and appendices (12 pages). The main text contains 33 figures and 34 tables, the annexes contain another 15 figures. The list of references consists of 222 sources.

The structure of the exhibition is as follows:

### **LIST OF ABBREVIATIONS USED**

### **LIST OF FIGURES USED**

### **LIST OF TABLES USED**

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###### 1.1.2. Types of information systems applicable in the agricultural sector

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### III. MAIN CONTENT OF THE DISSERTATION

In the introduction of the dissertation, the actuality of the problem, object, subject, purpose, tasks of the development are clarified and the scientific thesis is presented, which should be proven.

## CHAPTER ONE INFORMATION SYSTEMS IN THE GRAIN PRODUCTION ENTERPRISE

Chapter One presents the theoretical framework of information systems (IS) and their role in the digital transformation of agricultural enterprises, with a focus on the grain production sector.

Paragraph 1.1. **Conceptual Framework of Information Systems in Agribusiness** outlines the main characteristics of IP as **an integrated set of technologies, data, organizational processes and human factor, and not as an independent technological tool**. It is summarized that in agricultural enterprises IP support planning, control and decision-making by structuring and transforming data into management and strategic information, which defines their role as a key management mechanism.

The types of IP applicable in agriculture are presented – geographic information systems, monitoring systems, integrated farm management systems, resource management systems, land relations IS, logistics systems and others, emphasizing that the real effect of digitalization is achieved through their integration, and not through fragmented implementation of individual solutions.

Special attention is paid to the concepts of precision agriculture, smart agriculture and digital agriculture. The role of IoT, cloud services, automation, BI, artificial intelligence and machine learning in optimizing agricultural production is emphasized, but also the limitation that technological development often outstrips the organizational readiness of enterprises for their effective use. risk management, cost reduction and yield increases.

It is understood that IP is a strategic resource for agricultural enterprises, and their importance is manifested not only in the automation of operations, but also in improving coordination between processes, resource management and increasing competitiveness.

Digital transformation is seen as a fundamental organizational change that goes beyond the implementation of technologies and includes process optimization, building new business models and developing digital competencies. In the agricultural sector, it is determined by the specific features of production – dependence on natural factors, seasonality, market instability and the need for precise planning and risk management, which is why information systems are established as a key element of a modern and sustainable grain production enterprise.

In paragraph 1.2. **Information systems in the grain production enterprise**, grain production is presented as a complex production system that requires a systematic and integrated approach to management.

The main components of the IS – hardware, software, databases, communication technologies and the human factor – are considered as interrelated elements providing real-time data collection, analysis and making operational and strategic decisions, the effect of which depends on the degree of consistency between the individual modules.

The structure of IP in grain production has been defined, which includes:

- Crop Development Monitoring System
- land management systems;
- systems for control and management of the machine and tractor fleet and resources;
- financial accounting and logistics systems;
- modules for planning, forecasting and reporting.

The need for integration between different systems is emphasized, as their fragmented functioning in practice limits the accuracy of data and makes it

difficult to make management decisions. An effective information system should be built as a single architecture that reflects the logic of the production process, and not as a set of isolated software solutions.

Particular attention is paid to **information systems for land management** (item 1.2.3), which represent the most specific element of IP in grain production for the Bulgarian conditions. The development of land data management systems after the restoration of ownership, the introduction of KBC, the passage through WGS84 and BGS2005, the functioning of many incompatible registers and systems (IMCO, CADIZ, IACS, etc.). Key problems have been identified:

- lack of a single digital database and synchronization between registers;
- discrepancies in coordinate systems and graphical models;
- inaccuracies in ownership, area and category data;
- limited access to ZEM files;
- difficulties in administrative procedures.

The analysis shows that the fragmentation of data and registers creates the need for specialized, adapted to the national specifics information systems to maintain up-to-date information on ownership, contracts, real use, rents and consolidation processes. The unique structure of land use in Bulgaria is emphasized, in which more than 80-90% of the land in grain production is rented. This makes land management structurally decisive for the efficiency of farms.

The complexity of the consolidation processes requiring a GIS environment, high accuracy of graphic data and constant updating is also analyzed.

As a result, it is substantiated that the information systems in the grain production plant should be built as an integrated, process-oriented and nationally specific architecture, since the implementation of standard solutions does not correspond to the complexity of production and land relations in Bulgaria. This

makes dedicated IP for land and resource management a key enabler for efficient, sustainable and competitive grain production.

In paragraph 1.3. **The main challenges and trends in the digitalization of the agricultural sector are analyzed.**

Technological, financial, infrastructural, organizational and regulatory barriers that slow down the implementation of digitalization processes are summarized. These include: high investment costs, low digital literacy, lack of standardised and compatible data, regulatory complexity and frequent changes in the regulatory framework, as well as difficulties in integrating between different platforms and registers. It is justified that additional constraints stem from the significant administrative burden, the incompatibility of the systems used and the risk of incorrect implementation due to insufficient training and inefficient use of digital solutions.

It is concluded that, despite the growing technological potential and the availability of modern digital solutions, the real digitalization of the agricultural sector remains limited, especially in small and medium-sized farms, which underlines the need for targeted policies, trainings and an integrated approach to the implementation of IP.

Item 1.3.2. and Table 1 summarize **the main trends in the development of digital technologies**, which are characterized by a high degree of integration and complexity and are used in grain production by combining with:

- autonomous equipment, drones, telemetry;
- big data analysis (BigData), forecasting, production optimization;
- digitalization of supply chains and e-commerce;
- green technologies and sustainable production;
- introduction of the concept of "Agriculture 4.0".

Table 1 - Opportunities for digitalization in the agricultural sector

Precision Agriculture	Smart agriculture	Digital Agriculture
<p>Includes the following technologies (but is not limited to)</p> <ul style="list-style-type: none"> <li>➤ Global Navigation System (GNSS) and Global Positioning System (GPS)</li> <li>➤ GIS</li> <li>➤ Variable Performance Management (VRT)</li> <li>➤ Wireless Sensor Networks (WNS)</li> <li>➤ Sensors, monitors and controllers for agricultural machinery</li> <li>➤ Software Systems, Mobile Devices and Communications</li> <li>➤ Big Data Analytics</li> </ul>	<p>It includes precision farming technologies integrated with:</p> <ul style="list-style-type: none"> <li>➤ Internet of Things</li> <li>➤ Artificial Intelligence</li> <li>➤ Smart control devices</li> <li>➤ Machine Learning</li> <li>➤ Automation and robotization</li> <li>➤ Communication technology</li> <li>➤ Unmanned technologies – satellite systems, drones, etc.</li> </ul>	<p>Includes smart farming technologies in addition to:</p> <ul style="list-style-type: none"> <li>➤ Physical products enhanced with additional non-physical services designed to transform data into value-added information.</li> <li>➤ Agricultural ecosystems with platforms combining data from several sources (field/farm and external)</li> <li>➤ Cooperation between different actors in the agri-food chain</li> </ul>

*Source: Adapted from [www.bgfarmer.bg](http://www.bgfarmer.bg) (DIGITIZATION: Agritech – the technologies that set the future | Bulgarian Farmer)*

It is concluded that trends clearly show that the future of the agricultural sector is linked to high-tech solutions, automation and integrated management platforms, but these trends have real value only when they are tailored to the needs and capacities of farms, as technological progress is sustainable only when it leads to practical benefits and better management.

Item 1.3.3. discusses **the regulatory frameworks and standards**. The main regulatory requirements related to the use of IP in agribusiness are presented:

- CAP regulations;
- Food Safety Standards (HASP);
- quality standards (ISO);
- GDPR and personal data protection requirements;
- national legislation on agricultural land, safety, investment, etc.

The need for IP to comply with regulatory requirements, to ensure traceability, quality and transparency is emphasized.

**The results of Chapter One form the theoretical basis of the dissertation and show that:**

- IP are a strategic factor for the effective and sustainable development of agricultural enterprises;
- Digital transformation in the agricultural sector is a complex, multifaceted process;
- Grain production has specific requirements that require specialized IP;
- Land management is a unique challenge for Bulgaria;
- Technology is rapidly advancing, but its deployment is limited by significant barriers;
- Integration, standardization and development of organizational competencies are needed;
- IP creates the basis for sustainable production, optimisation and competitiveness.

## CHAPTER TWO

### ANALYSIS OF THE OPPORTUNITIES AND ROLE OF MODERN TECHNOLOGIES IN THE DIGITAL TRANSFORMATION OF THE GRAIN PRODUCTION ENTERPRISE

In paragraph 2.1. **The current state of digitalization in grain production at national and international level is analyzed.**

The implemented technologies are tracked and the key factors that influence the digital transformation process are outlined. It has been concluded that IP is a critical element for the modernization of the sector, as they provide automated data collection, processing, dissemination and analysis that support real-time decision-making.

It is noted that the information system in grain production performs functions related to:

- integration of data from multiple sources (sensors, meteorology, economic indicators);
- processing and analysis to forecast market and production trends;
- dissemination of information to all participants;
- modelling scenarios and supporting management decisions.

In Chapter Two, it is proven that digitalization is no longer an additional option, but a necessity dictated by production dynamics, growing demands for quality, sustainability and transparency, dependence on subsidies and the need for high competitiveness.

The **result** of the empirical and statistical analysis is that digitalization in grain production in Bulgaria is characterized by accelerated positive dynamics, although at still lower levels compared to the EU average. In the period 2020-2024, there is an increase in the use of cloud services (up to 14.2%), solutions for big data analysis (up to 21.9%), which forms the technological basis for the implementation of complex digital solutions.

The use of artificial intelligence remains limited until 2023, but the period 2023-2025 recorded the highest growth rate, from 3.61% to 8.55% of enterprises, which indicates a shift from experimental to practical application of AI technologies, and in grain production this process is supported by a relatively widespread use of precision agriculture elements used by about 42% of farms.

An analysis has been carried out that at the global level, the United States and Canada are leaders with about 75% implementation of precision agriculture, while in the EU Germany, Denmark and the Netherlands occupy leading positions, and Bulgaria lags behind by 35-40% and, together with Romania, is among the last countries in digitalization. The regional analysis in Bulgaria shows a strong differentiation – the highest digitalization is observed in the North-Eastern region (70–80%), and the lowest in Southwestern Bulgaria (20–30%). These differences are mainly driven by the level of infrastructure, investment activity, human capital and farm size.

It is concluded that the main factors stimulating the implementation of innovations are: the pursuit of cost optimization, risk management and increasing competitiveness, as well as the availability of targeted European policies and financial mechanisms to support the digital transformation. The constraints are related to the shortage of qualified personnel and the lower level of digital skills, which underlines the key role of human capital in the sustainable technological development of the sector.

The types of software solutions applicable in grain production **are analyzed**, and three main groups are distinguished:

- IP for land management;
- State IP for agribusiness management;
- Production and operating systems;

The information systems for land management **are studied in detail**, which are identified as a **unique requirement for Bulgarian conditions**, conditioned

by: fragmented ownership; high share of leased land (80–90% in grain production); the need for annual consolidation and complex rental relationships.

Key systems have been identified, including: "**Agrosystems**", "**Arendator-BG**", "**Cadis**", "**Property Bank**", "**Agro Office**", as well as specialized GIS modules for consolidation.

The development of land relations management systems is traced, which moves from local DOS applications to complex ERP/GIS platforms integrating satellite maps, graphic layers and automated reports.

The significant dependence between agrotechnical activities and the quality characteristics of the land is emphasized (Fig. 1), and it has been established that the applied cultivation methods and the preparations used have a direct impact on the soil indicators, agrochemical condition, category and even the permanent use of agricultural properties. It is summarized that these amendments are important both for land users oriented towards achieving certain yields and for land owners interested in the long-term preservation of its value, which was also taken into account in the development of the proposed model in Chapter Three.

State IP for agribusiness management **is analyzed**. It has been established that the Bulgarian administration maintains a significant number of unrelated IS, including: ISACS, LIPS, IMCO 3, ISMS of the Ministry of Agriculture, Cadastre, SEU of the SFA, PPP, EUSO, ISAMM, the control systems of the BFSA, subsidy systems, etc. The analysis shows that these systems function mainly in isolation, and the lack of integration between them is identified as a significant barrier to effective data management. administrative procedures and processes for digitalization of agribusiness.

Production and operational systems for the digitalization of grain production processes through the application of established technological solutions are analyzed. Platforms for management and analysis of data on plant development, as well as specialized software for precision agriculture have been identified.

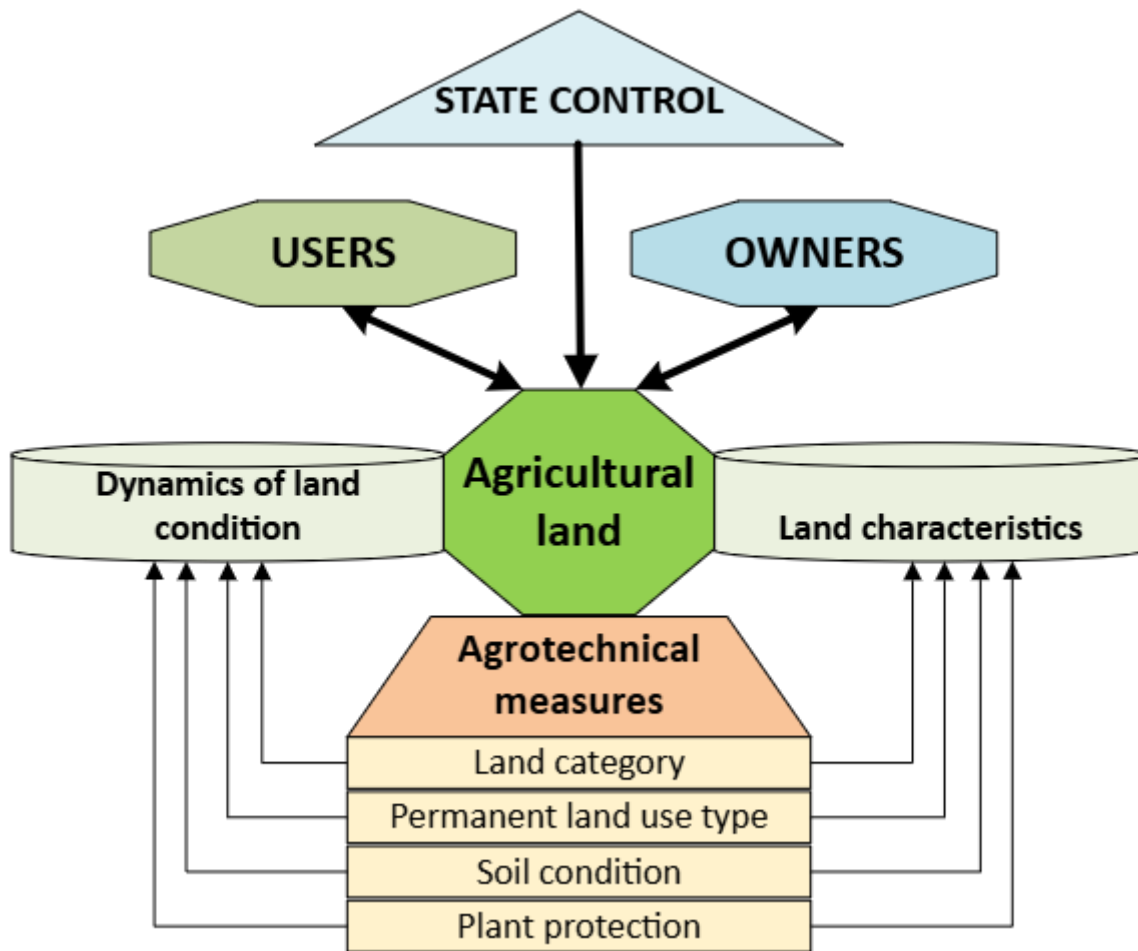


Figure 1. – Impact of agrotechnical measures on the quality of agricultural land, yields and stakeholders;

*Source: Author's image*

The use of resource management platforms and ERP solutions such as Agrosystems, FarmERP and Farm 360, as well as the implementation of SCADA systems for silo management, LITS and others has been established.

Sales management platforms are also considered, taking into account that web platforms and social networks are widely used in Bulgaria for the realization of production.

Additionally, intelligent management systems **based on real-time data collection devices, educational platforms and resources, information exchange platforms, weather monitoring systems, as well as reporting and quality management systems** have been identified.

It is summarized that these platforms support key activities in grain production, including agro-processing planning, management of agricultural machinery, resource control, crop monitoring, yield analysis, as well as ensuring traceability and logistics along the production and sales chain.

In paragraph 2.2. **modern information technologies applicable in grain production enterprises are analyzed.**

These are IoT, sensors and communication technologies, GIS, GPS and drone technologies, artificial intelligence and machine learning, specialized ERP and CRM systems.

The role of IoT and sensor systems **in grain production has been analyzed in detail**, and it has been found that they allow:

- Continuous monitoring of soil, moisture, temperature and nutrients;
- automated irrigation management;
- early detection and diagnosis of diseases;
- performing predictive analyses of production and climate risk.

The main communication protocols are reviewed and evaluated: LoRaWAN, NB-IoT, Zigbee, WiFi, GSM/4G/5G, BLE, MQTT, and their applicability to the scale, environment and goals of the farms is assessed.

It is summarized as a key result that IoT technologies represent the foundation of precision agriculture, building a continuous cycle: "**monitoring - diagnostics - decision - action**".

An in-depth technological overview of **GIS, GPS and drone technologies** as the main components of modern precision agriculture in grain production is presented.

It has been established that **GIS** is used for mapping and spatial analysis of agricultural land, integration of graphical and tabular data, analysis of yields and cultivability, property management and contractual relations, as well as for crop planning. The role of GIS as a key technological basis of Bulgarian land and management systems in the conditions of precision agriculture is emphasized.

The analysis shows that **GPS and GNSS** systems (GLONASS, Galileo, BeiDou) provide positioning with an accuracy of up to 2 cm when using RTK correction. Their main applications have been identified: for automatic control of agricultural machinery, precise sowing and fertilization, as well as the creation of yield maps, which leads to an increase in efficiency and a reduction in resource costs.

It has been found that **drone technologies** are applied for aerial photography and NDVI analysis, diagnosis of diseases and nutritional stress, identification of problem areas, as well as for low-volume treatments and spraying. It is summarized that the use of drones leads to a significant reduction in costs, operating time and production risks.

**The penetration of artificial intelligence (AI) and machine learning (ML)** in the agricultural sector has been studied, and it has been found that they are applied to:

- forecasting yields based on historical and sensory data;
- diagnosis of diseases by image analysis;
- smart irrigation and fertilizer optimization;
- Modeling productivity;
- automation in operations;
- Building "digital twins" of farms.

The thesis that AI and ML are emerging as the next leading driver of the digital transformation of agricultural enterprises is emphasized.

The application of ERP and CRM systems in agribusiness **has been studied.**

The analysis shows that ERP systems function as a critical digital infrastructure for the modern management of agricultural enterprises, covering financial accounting activities, human resources, management of material stocks, equipment and machinery and tractor park, as well as planning, implementation

and reporting of agrotechnical measures, in compliance with the requirements for control and traceability of plant protection products.

It has been established that in the structure of ERP and CRM systems in grain production, a particularly important place is occupied by the administration of rents, contracts and land relations.

The specifics of ERP applications in the agricultural sector, related to the seasonality of production, high administrative and reporting requirements, the need for integration with subsidy systems and regulatory mechanisms, as well as the need for reliable analytical information for management decision-making, are emphasized.

It is summarized that the critical factors for the successful implementation of ERP systems include active support from the management, adequate training and qualification of the staff, correct configuration according to the specifics of the farm and clear intra-organizational communication.

It has been found that CRM systems are adapted to agribusiness through functionalities for managing relations with landlords and cooperators, managing sales, customers and logistics, as well as ensuring traceability of production and batches along the supply chain.

In paragraph 2.3. **The impact of digital transformation on grain production efficiency has been studied.**

The analysis shows that digital transformation is directly related to increasing production efficiency through more precise resource management, automation of core activities and the use of real-time data. It has been found that the application of precision agriculture, IoT technologies, GPS and drones contributes to reducing costs, limiting losses and improving the quality of agrotechnical treatments. Information systems provide a higher level of control, traceability and document flow, and analytical tools support the processes of forecasting, risk management and production optimization.

As a result of the analysis, the key production and management processes in grain production, subject to digitalization, are summarized. Figure 2 presents the main processes that are identified as an object of digital transformation in the sector.

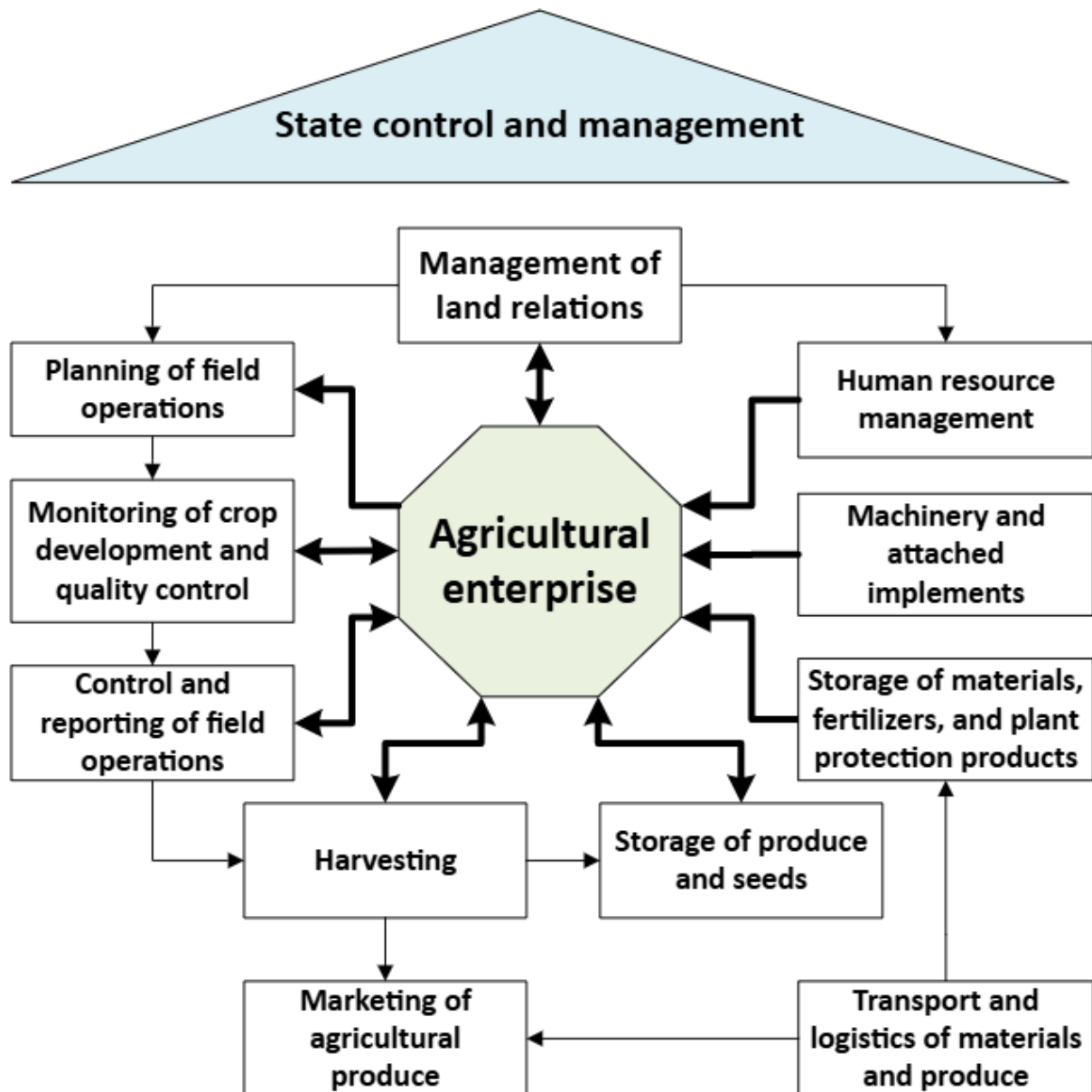


Figure 2 – Main processes in agribusiness subject to digitization

*Source: author's image*

**The results of the second chapter of the dissertation and prove that:**

- Digitalization is a strategic factor for the competitiveness of grain production.

- Bulgaria lags far behind the EU and world leaders.
- IC, GIS, GPS, IoT, drones, and AI are the foundation of modern agriculture.
- The lack of integration between state systems is a key limitation.
- Software solutions for land relations are a unique need for Bulgarian farms, but also an administrative burden.
- ERP/CRM systems are critical for sustainable transformation.
- The human factor remains the most significant barrier – low skills, lack of training, conservative attitudes.
- Regional differences show the need for targeted state policy.
- The potential is very high, but it requires investment, education and an integrated digital environment.

## **CHAPTER THREE**

### **MODEL FOR DIGITAL TRANSFORMATION OF THE GRAIN PRODUCTION ENTERPRISE**

Paragraph 3.1. presents **the methodological approach for building a model for digital transformation in grain production.**

It combines managerial, technological and organizational components in a complete architecture, adapted to the Bulgarian specifics of land relations, seasonality and regulatory requirements. At the heart of the development is the understanding that digitalization is not a set of isolated tools, but **a consistent, managed process**, the effectiveness of which depends on flexibility, scalability and the ability to integrate with existing infrastructure and practices. The methodological scheme of the model is illustrated in Figure 3.

The model is presented as **a modular, multi-layered system** that provides sustainable resource management, process optimization and transparent document

flow, moreover, in a highly dynamic environment and fragmented land use structure.

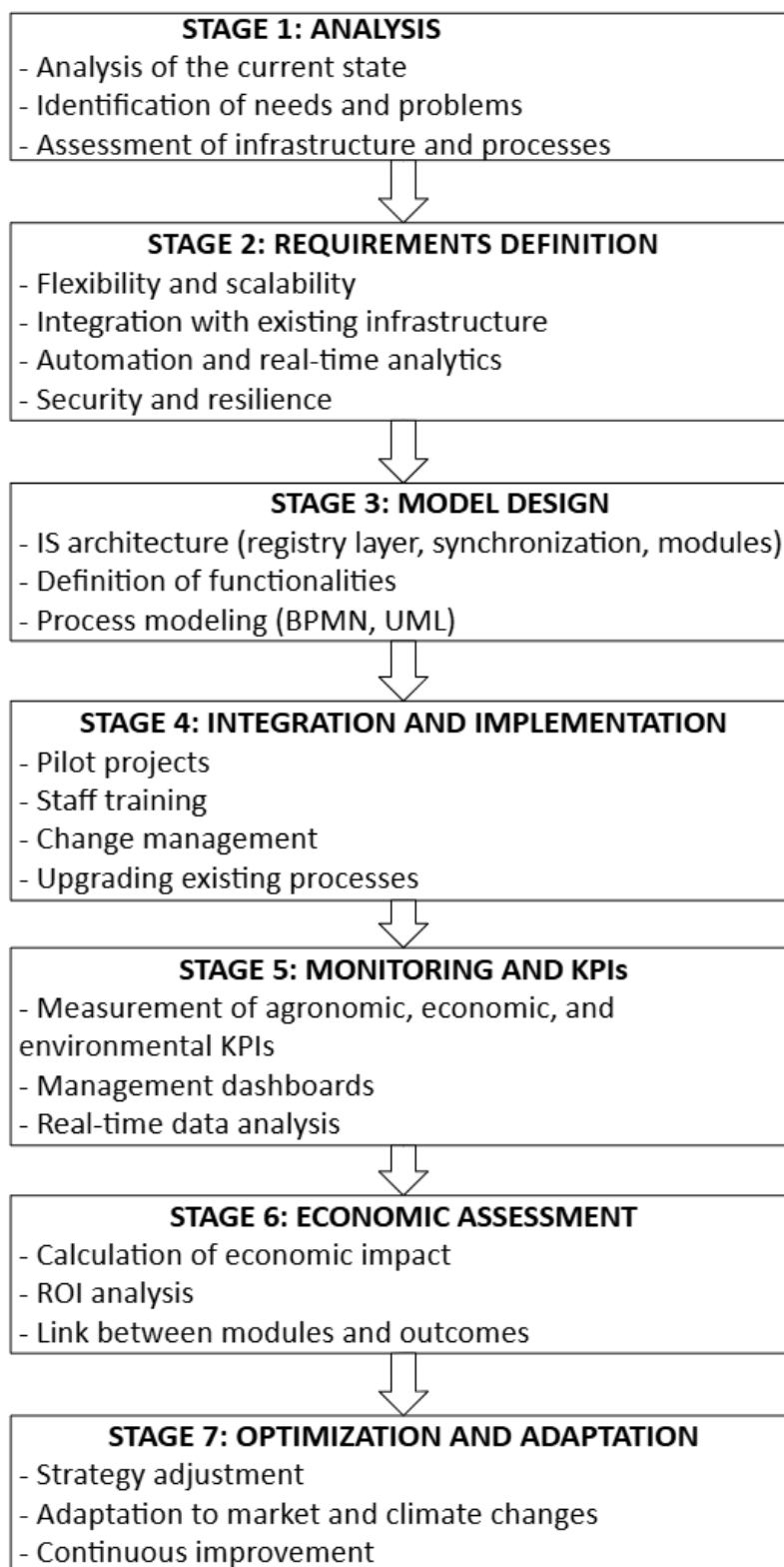


Figure 3. Methodological scheme of the model for digital transformation of a grain production enterprise; *Source: author's interpretation*

A significant contribution in this paragraph is the formulation of a **system of key performance indicators (KPIs)** - agronomic, economic, environmental and operational, which turn the proposed model into a **management tool** with a measurable effect. Table 2 shows the relationship between the individual modules of the model and the projected economic results.

Table 2. Model of economic performance by module

module	Actions	Economic effect
<b>Land consolidation</b>	<ul style="list-style-type: none"> <li>- consolidated (enlarged) plots;</li> <li>- fixed routes and handlings;</li> <li>- Lower consumption of fuel, seeds, preparations</li> </ul>	3–7 BGN / decare
<b>Land rents</b>	<ul style="list-style-type: none"> <li>- Automatic Accrual</li> <li>- Elimination of errors</li> <li>- less administrative costs</li> </ul>	1–2 BGN / decare
<b>“Operations” – Agro task planner</b>	<ul style="list-style-type: none"> <li>- precise treatment;</li> <li>- reduced use of plant protection products;</li> <li>- solely by transferring information from the GIS to the tractor and by changing the processing sequence from “straddle cultivation → row cultivation” to “row cultivation” followed by “final straddle cultivation,”</li> </ul> <p>material savings of 6–8% are achieved.</p>	3–6 BGN / decare
<b>Production monitoring and real-time analysis</b>	<ul style="list-style-type: none"> <li>- early detection of diseases</li> <li>- optimal fertilization</li> <li>- optimal irrigation</li> </ul>	An increase in yield of 40–120 kg per decare (dka), at an average wheat price of BGN 330 per tonne, corresponds to an economic gain of approximately BGN 6 per decare.
<b>Control and monitoring</b>	<ul style="list-style-type: none"> <li>- fewer penalties</li> <li>- more accurate reporting</li> <li>- better compliance with regulations</li> </ul>	indirect but significant

*Source: author's summary*

The dependencies presented in Table 2 show that KPIs are validated not only as an assessment tool, but also as an **active management mechanism**, allowing the formulation of objectives and timely implementation of corrective measures in short operational cycles.

The financial-economic effect is detailed by modules in the model (Figure 4, oriented to wheat production). For a farm with a size of 10,000 decares, an average direct effect of ~BGN 170,000 has been calculated, without taking into account indirect benefits such as reduced penalties, limitation of data errors and prevented lost profits. **financial performance and risk management**, which is key during seasonal peaks and short time "windows" for the implementation of agrotechnical operations.

Paragraph 3.2. presents a **conceptual model for digital transformation of the grain production enterprise**.

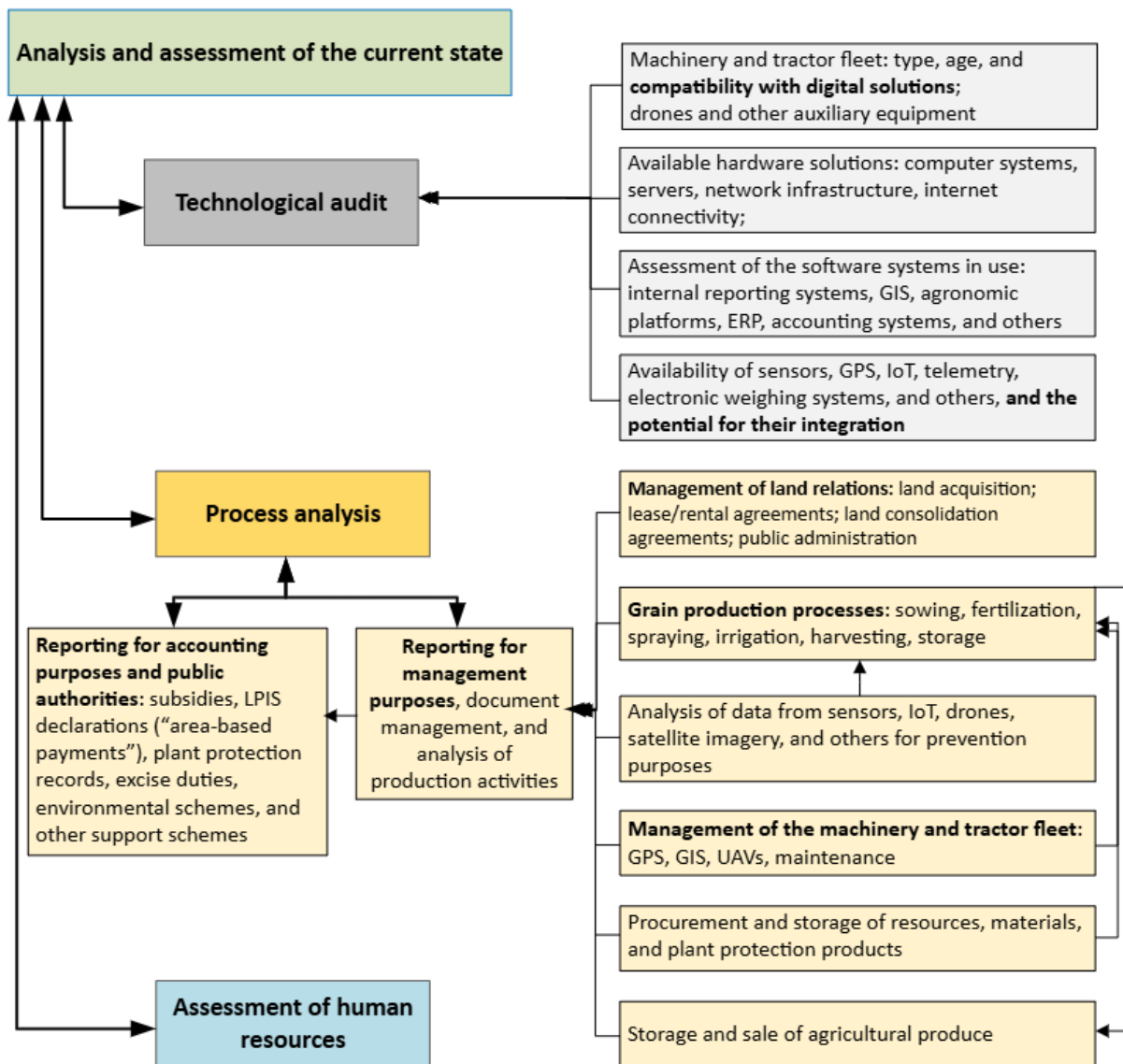


Figure 4 - Phase Analysis and assessment of the current state

Source: author's image

The developed approach begins with baseline diagnostics, including: technological audit of equipment, software and IoT solutions, analysis of production and management processes, as well as assessment of digital competencies and attitudes towards change. This phase has been found to ensure the realistic definition of needs and the selection of appropriate technological solutions (Figure 4).

The next stages include planning the digital transformation through the formulation of SMART goals, prioritization and resource provision, as well as the design of phased implementation. The use of **pilot tests** is envisaged, which allow validation of solutions in a limited scope before scaling them up. , which are identified as the main driver of the adoption, effective use and sustainability of the implemented digital systems. The process culminates in **monitoring, evaluation and optimization**, in which key performance indicators (KPIs) are used to measure effects and to make real-time adjustments to the strategy.

The significance of the proposed model is justified by a system of key requirements ensuring its applicability and sustainability:

- First of all, there is **flexibility in** terms of adaptability to different farm scales, levels of technological maturity, agri-environmental conditions and regulatory frameworks, achieved through modularity, standardised interfaces and 'lightweight' integrations.
- **Scalability** allows capacity expansion through cloud services, automation, and subscription models without disproportionate increases in costs and complexity.
- **The integration ensures** compatibility with the available physical and information infrastructure, including ERP, accounting systems, GIS, machines, and navigation technologies, while complying with API compatibility requirements, data standards, cybersecurity, and backup.

The architecture of the information system has been developed as **multi-layered** (Figure 5), and it is substantiated that it is this approach that provides structural clarity and a consistent flow of data - from the field to management decisions.

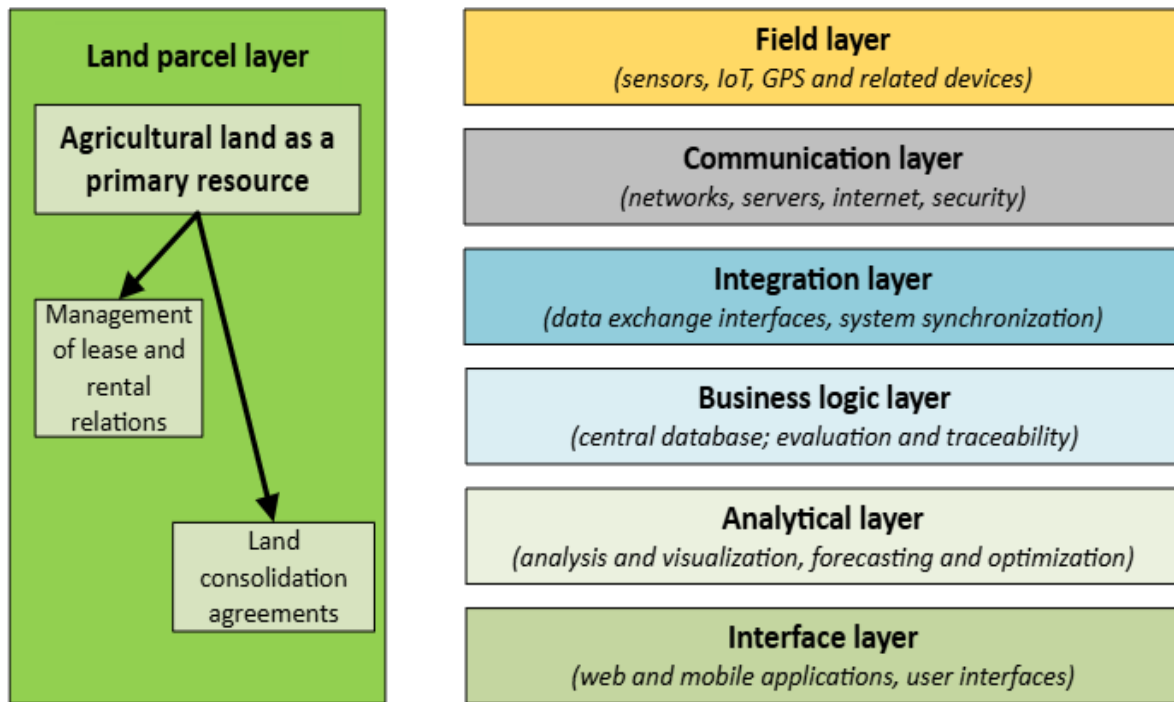


Fig. 5 – IP architecture – multi-layer structure

*Source: author's image*

1. **The land layer** has been identified as strategic and unique to the Bulgarian conditions, as fragmented ownership, annual consolidation agreements and "per area" support require **a dynamic and reliable foundation**. It has been established that this layer determines the geographical configuration of the farm and the logic of planning and accountability.
2. **The field layer** is defined as the primary source of primary data, collecting information from IoT sensors (moisture, temperature, nutrients), weather stations, GPS/telemetry, drones, and machine sensors, thus providing a fact-based basis for analysis and automation.
3. **The communication layer** is designed to provide reliable and energy-efficient data transfer, through technologies such as LoRaWAN, NBIoT,

WiFi and 5G, minimum traffic protocols (MQTT, etc.) and agricultural standards (ISOBUS/ ISO 11783), ensuring sustainable exchange and low energy intensity for remote locations.

4. **The integration layer (middleware)** is justified as key to connecting subsystems, through API Gateway, ETL processes and an event-based architecture (Event Bus), which allows for real-time responses to anomalies such as diseases, deviations in sensory data and crop risk.
5. **The core of the system – business logic and the central database (CBD)** is implemented through an FMIS platform integrated with ERP/CRM/GIS/IoT solutions. It has been established that this architecture allows for effective management of crops, resources, inventory, contracts and rents, finances, traceability and administrative references, as the CBD provides historical data, security, access control and upgradability.
6. **The analytical layer** is structured on **Big Data repositories** and **AI/ML models** used for yield forecasting, early risk warning, and fertilization and spraying optimization, with BI tools supporting visualization and scenario planning.
7. **The interface layer** has been developed with a focus on operational management, through web and mobile applications with role-based access, alarms, geovisualizations and dashboards, which provides "real-time" management and effective field control.

To move from concept to practical application, the technological path is structured in five stages (T1–T5): data digitization (IoT, GPS, GIS); automation and operational integration (FMIS, ERP/CRM, intelligent irrigation, sectional control); analysis and decision support (AI/ML, forecasting and optimization); external connectivity and ecosystem exchange (API, interaction with partners and institutions, blockchain for traceability); smart and sustainable agriculture (autonomous machines, circular economy and green indicators). This stepping

reflects a logical evolution, from basic digital registers to an integrated, self-regulating risk and performance management system.

**Automation** has been identified as a key mechanism for transforming data into productivity through GPS navigation and autopilots to limit overlaps, intelligent irrigation according to soil and weather data, automated harvesters with yield monitoring, the use of drones for monitoring and precise treatments. As a result, a reduction in resource load (fuels, fertilizers, preparations), shortening production cycles, reducing errors and freeing up human resources for analytical and management activities.

Additional value has been reported through data security assurance – encryption, access control, redundancy, GDPR compliance, the use of AI to detect anomalies, and targeted staff training, which is seen as a key condition for trust, reputation, and institutional compatibility.

Chapter Three addresses **the Bulgarian specifics** through an analysis of land relations characterized by fragmented ownership, annual consolidation agreements (different arable fields) and the need for synchronization with the CAP, which defines the land layer as critical for the validity of all subsequent data in the model architecture.

A diagram of the pattern is visualized in Figure 6.

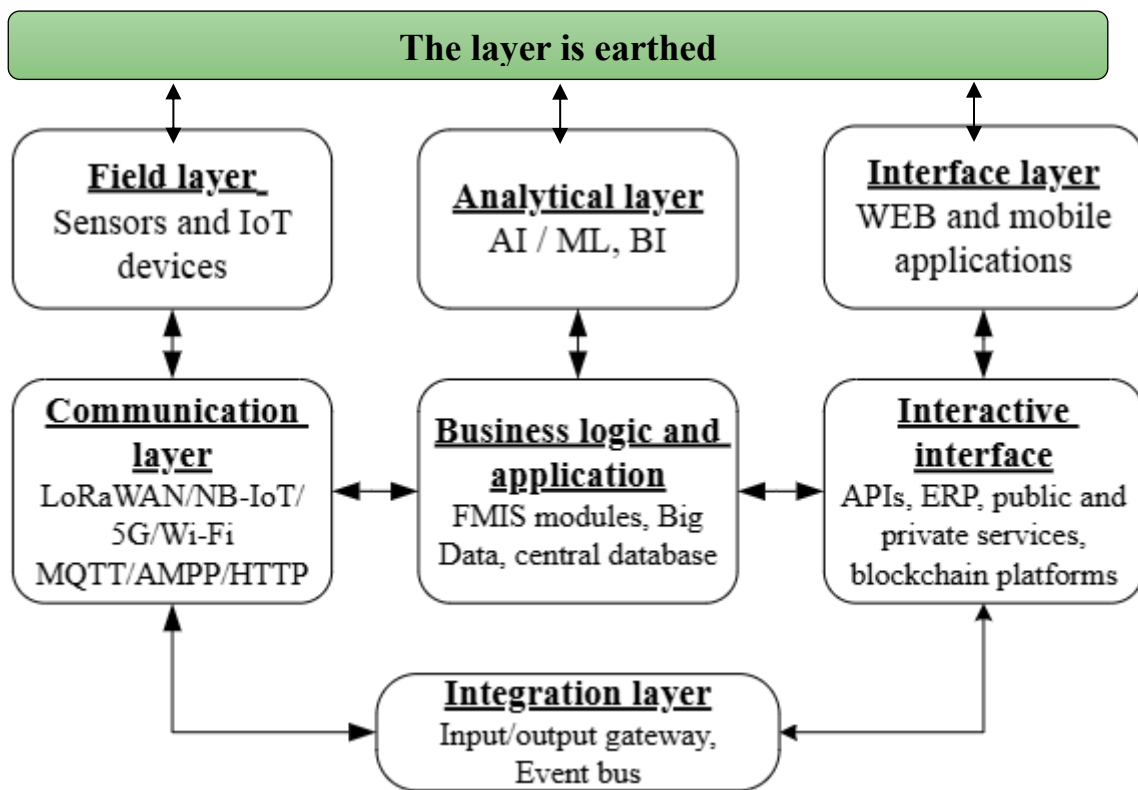


Figure 6. – Diagram of the model; *Source: author's image*

In paragraph 3.3, an **evaluation and validation of the proposed model** has been carried out through an empirical study of **more than 100 grain production enterprises**, of which **25** have been analyzed in depth.

The data document a **transition from predominantly Excel-based and poorly integrated processes to the implementation of specialized systems** (Agrosystems, ArendatorBG, Cadiz, Trimble, John Deere, Topcon, etc.), which leads to measurable effects: 10–20% reduction in fertilizer and preparation costs; 5–10% increase in yields; elimination of drawing errors, shortening of reporting and administrative cycles, and improved coordination and traceability. that the use of IoT outside the machine and tractor fleet remains limited, despite its significant potential to reduce losses, and integration with ERP/CRM systems continues to be a challenge due to seasonality, land relations and regulatory dynamics, which requires **phased deployment and locally adapted solutions**.

A key organizational conclusion is that the human factor and innovation culture are decisive for the success of digital transformation. Effective deployment requires targeted training, role-oriented interfaces, staff participation in pilot projects and the use of KPI incentives, and deployments should be planned according to the short time windows between agro-technical campaigns.

In its entirety, the third chapter proves the applicability of a practically validated model in which the architecture provides integration and a continuous flow of data, the methodology guarantees a phased and controlled implementation, the KPI system makes the effects measurable, and empirical studies prove the feasibility and applicability in Bulgarian conditions. The result is a smart and sustainable grain production enterprise, capable of managing resources and risk efficiently and using data as a strategic asset for long-term competitiveness.

The results of the third chapter of the dissertation show that:

- **The developed model is implemented as an integrated and modular system** that combines managerial, technological and organizational elements and functions as a multi-layer architecture (ground, field, communication, integration, business logic/CBD, analytical, interface layer), which guarantees a sustainable flow of data and manageability of the digital transformation process.
- **The model takes into account as a leading factor the Bulgarian specificity**, in which the "land layer" is fundamental due to fragmented ownership, annual consolidation processes with changes in the cultivated fields and support "per area". The model explicitly addresses the double registers (company and state), the campaign nature of the processes and the need for synchronization and control checks.
- **A step-by-step methodology validated in real business conditions is proposed**, including baseline analysis → planning/KPIs → pilot projects → full implementation → monitoring/optimization. The pilot approach

reduces risk, accelerates staff acceptance and allows adaptation to the specific conditions of the farms.

- **The implemented system of KPIs ensures measurability and manageability of the effects** through clearly defined agronomic, economic, environmental and operational indicators. Typical results have been registered, expressed in increasing yields, reducing the cost of fuels, fertilizers and preparations, reducing the time for document turnover, reducing reporting errors, increasing the return on investment (ROI in the range of 8–18%).
- **Automation has been proven to transform available data into productivity**, with the use of GPS navigation, autopilots, sectional inventory control, smart irrigation, drones and electronic scales reducing overlaps, losses and human errors and freeing up resources for analytical and management activities.
- **The AI/ML-based analytics layer has been identified as a strategic tool**, providing predictive yield and risk models, intervention optimization, dashboards, and real-time decisions, creating the foundation for a "digital twin" of the farm.
- **ERP / CRM / FMIS solutions function as a connecting management layer**, integrating production, financial and regulatory processes, including management of rents and consolidations, plant protection logs and administrative reports, and through the correct configuration the discrepancies between the calendar (accounting) and agricultural years are overcome.
- **The empirical validation covers a wide range of farms** - over 100, of which 25 were analyzed in depth, such as the application of technologies of TRIMBLE, John Deere, TOPCON and software platforms such as Agrosystems, ArendatorBG, CADIS, etc. leads to a 10-20% reduction in the fertilizer and preparations used, a 5-10% increase in yields,

elimination of drawing errors and a significant facilitation and acceleration of reporting processes.

- **The economic effect is quantified by modules**, including consolidation (3-7 BGN/ha), rents (1-2 BGN/ha), agro-tasker (3-6 BGN/ha), monitoring/analysis (+40-120 kg/ha); and for a farm of 10 000 decares, approximately BGN 170 thousand is achieved without including indirect benefits.
- **The role of the human factor and organizational culture has been confirmed as critical**, and effective digital transformation is the result of targeted training, role-oriented interfaces, internal incentives (incl. KPIs, avoidance of sanctions), realistically planned deadlines and conscious management of integration complexity.
- **Security and regulatory compliance are implemented as a strategic component**, through encryption, access control, redundancy, GDPR compliance, the use of AI for anomaly detection and clear data governance policies, which is a prerequisite for trust, transparent reporting and institutional integration.
- **Specific guidelines for future development have been formulated**, including the expansion of IoT beyond the machine and tractor park; complete integration with external platforms and state IP; development of predictive analytics and mobile solutions; environmental monitoring and further development of the land management model (e.g. through the Property Bank platform).

## **CONCLUSION:**

The study offers a comprehensive model for digital transformation of the grain production enterprises, based on the integration between information systems, technological solutions and organizational changes. The analysis of theoretical concepts and existing practices shows that digitalization is a key factor in the modernization of the agricultural sector and for the transition to more efficient, sustainable and transparent management of production processes. The model is structured in such a way as to take into account the specifics of Bulgarian land relations, the fragmented structure of land and the high dependence on state regulation, which makes it applicable in the real economic environment.

The developed architecture of the information system is multi-layered – it includes ground, field, communication, integration, management, analytical and interface layers. This structure ensures a reliable flow of data, integration between the different subsystems and the possibility of automating key agrotechnical and administrative activities. Technological components (IoT, GPS and telemetry, GIS, drones, analytical platforms) are complemented by management modules (ERP, CRM, FMIS), which allows real-time decision-making, resource optimization and higher transparency of processes.

The validation of the model was carried out through an analysis of more than 100 enterprises, of which 25 were examined in detail. Practical results confirm that the implementation of integrated information systems leads to a significant reduction in the cost of fuels, fertilizers and preparations, an increase in yields, a reduction in reporting time and a reduction in errors. The data shows that automation and real-time analysis improve the efficiency of agrotechnical operations, and the system of KPI indicators turns digital strategy into a manageable and measurable process.

In conclusion, the proposed concept proves that digital transformation in grain production is most successful when it is implemented through an integrated

model combining flexible architecture, phased implementation, standardized data and active staff participation. The model ensures sustainable development and competitiveness of enterprises, while increasing the efficiency of the use of the key production resource - land.

## **PRACTICAL GUIDELINES**

### **1. Step-by-step and targeted deployment of digital technologies**

It is recommended that enterprises implement digital transformation in stages, starting with a diagnostic analysis of the available equipment, software and organizational processes, followed by the introduction of basic modules (land register, contracts, consolidation, technological maps), and gradually upgrading to automation, telemetry, precision processing and analytical solutions. The step-by-step approach reduces risk, allows adaptation and ensures a higher quality of integration.

### **2. Standardize and centralize data**

It is recommended to build centralized databases compatible with government systems and with all internal company modules, including ERP, CRM, FMIS. Standardized data formats and automatic exchange via APIs reduce errors, limit duplication and increase management transparency.

### **3. Active use of IoT, GPS, and drones for monitoring and control**

Practice shows that sensors, telemetry, and drones provide early detection of problems, better operations planning, and resource optimization. It is recommended to implement soil and climate IoT stations, GPS navigations with precise control, as well as routine use of drones for crop monitoring, treatment, and damage assessment. This significantly reduces the cost of fertilizers, preparations and fuel.

### **4. Building a management model based on KPIs**

Enterprises should implement a system of key indicators (yields, costs for fertilizers and preparations, efficiency of equipment, time for operations, errors in

reporting) to be monitored regularly through BI dashboards. This allows for real-time decision-making, comparison between seasons, crops and BgDD, and a clear definition of improvement goals.

### **5. Improving the management of land relations**

It is recommended that enterprises fully digitize the processes related to contracts, rents, consolidation and valuation of properties. The use of specialized GIS systems and automatic checks reduces the risk of errors, increases the accuracy of registers and facilitates communication with state systems (IACS, SES). The implementation of a platform of the "Property Bank" type can significantly increase transparency and sustainability.

### **6. Human Capital Development and Organizational Culture**

Digital transformation cannot be successful without targeted training, internal instruction, role interfaces and staff incentives. Regular training of drivers, agronomists and administrative employees is recommended, as well as the introduction of clear procedures for working with the systems, especially in agro-campaign periods.

### **7. Automation of critical processes**

Enterprises should prioritize the automation of processes that are sensitive to time and human error: precision processing, RW logging, chain of custody, warehouse control and electronic yield reporting. Electronic scales, automated material distribution and satellite control provide significant effects on quality and efficiency.

### **8. Improving integration with government systems**

It is of particular importance for businesses to maintain up-to-date and correct information corresponding to state and other registers in order to reduce administrative errors and the risk of sanctions. Maximum use of automated reports, data imports/exports and non-compliance checks is recommended.

### **9. Establishment of internal security and compliance policies**

Businesses should adopt policies on cybersecurity, archiving, access control and processing of personal data to ensure the protection of sensitive information and compliance with the regulatory framework. The inclusion of AI anomaly detection systems increases resilience and prevents losses.

#### **10. Promoting sustainable practices in agricultural production**

The use of environmentally oriented technologies is recommended: smart irrigation, optimization of fertilizers and preparations, inclusion of renewable energy sources, carbon footprint monitoring and waste management. These practices lead to savings, reduced environmental impact and easier participation in European programmes.

#### IV. REFERENCE SCIENTIFIC CONTRIBUTIONS TO THE DISSERTATION

The following research contributions **are presented in the dissertation:**

In theoretical aspect:

1. The concepts of "information system" and "digital transformation of business" are defined and a conceptual framework for the application of information systems in agribusiness has been developed, taking into account the approaches, technologies and limitations to the digitalization of the agricultural sector.
2. The role of digital transformation for the intelligent grain production enterprise is investigated through a systematized model for the use of key modern technologies and their integration into the architecture of the information system, supported by an empirical analysis of digitalization in grain production.

In the practical and applied aspect:

3. The level of digitalization and the use of modern information systems in grain production enterprises is analyzed, validated in over 100 Bulgarian enterprises and compared with international good practices.
4. A system of key indicators (KPIs) has been defined, allowing for quantification of effects and identification of economic benefits from the implementation of digital solutions.
5. Developed and tested, integrated author's model for digital transformation of the information systems of a grain production enterprise, applicable in Bulgarian practice, with multi-layer architecture and a specific "ground layer", for real-time control and predictive control.

6. A conceptual model for land relations management using AI has been created for a "Property Bank" platform. Applied and management solutions for digital transformation and recommendations for automation, change management and efficiency increase are proposed.

## V. LIST OF PUBLICATIONS RELATED TO THE DISSERTATION

### 1. **Report: DIGITAL SOLUTIONS FOR THE ADMINISTRATION OF LAND MANAGEMENT PROCESSES IN THE REPUBLIC OF BULGARIA**

Authors: Nikolova Marina, Chernaeva Penka, Chernaev Petar

Conference proceedings: „Innovative development of agricultural business and rural areas“, IDARA, 28-29 IX 2023 г., София, УНСС.

### 2. **Report "Photovoltaic Culture" – Digitalization or Rural Development?"**

Author: eng. Penka Chernaeva

Collection of Papers from the Round Table on "Theory and Practice for Sustainable Management and Development of Rural Territories in Bulgaria" – 31.05.2024

### 3. **Article on "Artificial Intelligence: Assistant or Threat to "Middle Management" in the Implementation of Information Systems for Agribusiness Management"**

Author: eng. Penka Chernaeva

Annual Almanac "Scientific Research of PhD Students", 2024

### 4. **Related article „Role of digital land management solutions in rural areas of the Republic of Bulgaria“**

Authors: Nikolova Marina, Chernaeva Penka

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