Digital transformation modeling for agricultural land irrigation

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Abstract. The paper defines the importance of using software solutions to manage the process of agricultural land reclamation. Effective implementation of such a process ensures high yields of plant crops while preserving soil properties, ecosystem biodiversity and reducing the negative impact on the environment. This requires control and monitoring of numerous factors, most of which are random in nature. Designing a software product that provides constant and objective monitoring of the state of agricultural land is the purpose of this work. The use of system analysis methods made it possible to establish the key factors affecting the changes in the states of plants in their growing season, and based on this to formulate the functional possibilities of the intelligent system. Based on this, a functional model demonstrating the processes of transformation of data flows and control at each stage of functioning of the designed software product was developed. In addition, the main categories of users for whom the functional possibilities of the intelligent system are available have been defined.

1 Introduction

Crop yields depend on numerous factors that influence the development of plants throughout their growing season [1, 2]. They can be divided into three categories: natural (climatic conditions and soil characteristics), biological (seed quality and use of organic fertilizers) and anthropogenic (methods of soil cultivation, use of mineral fertilizers and protection products) [3]. Depending on natural factors, the most suitable crop is determined and appropriate measures are applied to increase its yield [4].

Not all lands in Russia are suitable for agricultural activity: most of the land is located in the Central Black Earth Region, the lands of the subarctic and arctic belt are not designed for farming [5]. As of 2024, the area of agricultural land amounted to 200,665.3 thousand hectares (53.51%), of which 118,605.4 thousand hectares of arable land (31.63%), 18,818.6 (5.02%) hayfields, 57,571.6 thousand hectares of pastures (15.35%) [6]. Such lands can be used for agricultural production, research purposes, farming, etc.

To improve soil, agro-climatic and hydrological conditions in order to obtain sustainable and high yields of agricultural crops, complexes of technical, organizational and economic measures are actively carried out [3]. Depending on the growth environment, irrigation or drainage of soils, control of surface runoff water, fortification of unstable ravines, changes in

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the chemical composition of soil can be carried out, which contributes to the creation of optimal heat, air and food conditions for the development of living organisms and reduce the negative impact on the corresponding natural ecosystems. At the same time, it is important that irrigation works for each type of agricultural plant are observed. Excess and insufficient water can reduce crop quality. For instance, under-watering of sugar beets leads to lower sugar content in root crops, while over-watering of potatoes leads to rhizoctoniosis and lower starch levels in the new crop.

Design and development of software solutions with artificial intelligence functions that make it possible to constantly control and monitor soil and agro-climatic conditions to achieve the goals set for crop growth is a topical objective of the Agriculture 4.0 concept. Such a concept is associated with the developmental stage of technological development of the agricultural industry in Russia, based on the introduction of “smart” solutions (for instance, the Internet of Things, the use of robots, “precision” farming), alternative technologies and biotechnology [7].

The purpose of the work is to model the processes that ensure the implementation of “smart” irrigation of cultivated agricultural works. This requires establishing the key objects and processes of reclamation works and the links between them; developing the main functional possibilities of the intelligent system and determining the list of user categories for which they are available; developing a functional model for dynamic description of the processes, the digital transformation of which is carried out.

The object of research is the process of vegetation of agricultural plants.

The subject of research is the process of agricultural land reclamation.

Theoretical significance of the research lies in the creation of a model of an integrated approach to the processes of growing agricultural crops, which can be used in works to improve soil productivity, plant resistance to climatic changes, diseases and other factors that negatively affect yields.

The practical significance of the research lies in the design of a tool to reduce labor costs for the implementation of processes of monitoring and control over the condition of agricultural land, to make decisions on the management of processes based on objective data and rationally use water resources.

2 Methods

The subject of the research is a system, the functioning of which is carried out according to the “black box” type. This means that the law of its functioning is not completely known, and there is only information about input and output data. Accordingly, for the accomplishment of the set objectives applicable to the type of system required the complex use of general scientific methods.

The method of system analysis made it possible to establish the behavior of the system and the factors influencing its change. As noted in works related to studying the content of complex systems, in the process of system analysis requires the use of decomposition and abstraction methods to determine its structure, synthesis and analysis in order to establish links and rules of interaction between objects and processes at each structural level [8-10].

The creation of a model makes it possible to represent the essential aspects of the process realization in a certain form regardless of the subject area [11-13]. The method of functional modeling was used to formalize the obtained results of system analysis. The methodology of functional modeling makes it possible to graphically represent processes in terms of object subordination [14, 15]. This approach made it possible to obtain logical relations between the functional possibilities of the intellectual system in reclamation works. The use of a universal graphical language to display the functional model made it possible to show a set of subprocesses that transform input data streams (arrows pointing to the left boundary of the block) with the help of certain mechanisms (arrows pointing to the lower boundary of the block) into output data streams (arrows coming out of the right boundary of the block). This transformation process occurs due to the presence of controls (arrows entering the upper boundary of the block).

3 Results

The following factors are considered when selecting an irrigation method:

1. Climatic: wind speed and direction, air temperature and humidity, and natural precipitation.
2. Soil: acidity level, water holding capacity and granulometric composition.
3. Hydrologic: presence and level of groundwater.
4. Geomorphologic: relief of the site (slope and its extent).
5. Economic: remoteness from water bodies used as an irrigation source, availability of specialized equipment in the farm.

To determine the quantitative characteristics of the listed factors requires the use of specialized instruments, which can be installed permanently or moved around the site during monitoring by a specialized specialist.

In the case of stationary instruments, the indicators are taken at fixed intervals and transmitted to an intelligent system for storage and processing. If the installation of devices is temporary, i.e., during the monitoring of the growing crop, the indicators are entered into the system by the specialist who performs this process (user with the role "Agronomist"). In this case, the indicators can be obtained by manual or visual measurement. Accordingly, in the functional model, such data are "objective control data" (Fig. 1).

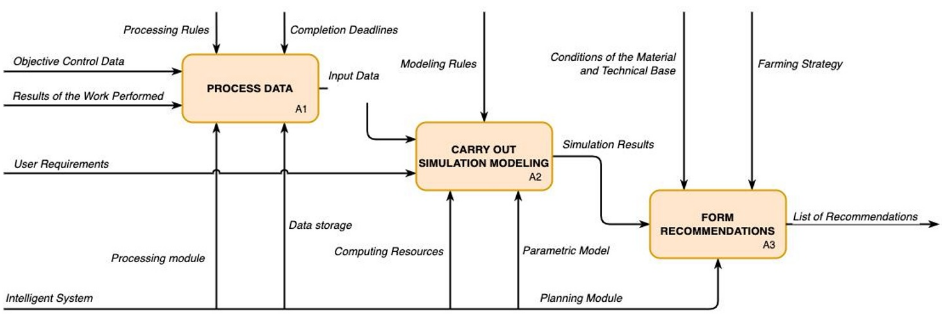

Fig. 1. Functional model of agricultural land reclamation management process.

"Objective control data" must be processed by the intelligent system software module to make it suitable for further use in the digital environment (process A1). In addition to such data, data obtained on the activities performed (for instance, fertilization, harrowing, weeding, perching) should also be available. If the list of activities has been planned and entered into the organization's digital ecosystem, then a response from the employee responsible for the activity (user with the role "Worker") or supervising the activity (user with the role "Agronomist") is required to retrieve information about the activity. In case of unscheduled works, it will be necessary to manually add information about them. This objective is realized by the specialist who made the decision to carry out the work (user with the role "Principal Engineer"). Their confirmation is performed in the same way as for planned works.

After all the transformations, the data can be used in the program module that forecasts changes in the states of the process of growing agricultural plants (subprocess A2). For its full implementation, it requires information about the goals to be achieved at different stages of the process (for instance, maximum yield, saving certain resources). These are entered into the system by the user with the role of "Principal Engineer".

Based on all objective and subjective factors, changes in the cultivation process are modeled and the corresponding result is formed. Implementation of the process is possible with the use of simulation methods, making it possible to recreate the behavior of the system on the basis of specified parameters over a certain time interval. Such methods are actively used in complex dynamic systems for which it is labor-intensive or impossible to assess the effectiveness of the adopted management decisions due to the occurrence of irreversible changes in the research object and long observation periods (for instance, this is characteristic of transport [12, 16], economic [17] systems, natural ecosystems [15, 18]). The result of subprocess A2 is the information that should be used to form a list of works to obtain the planned result.

The list of recommendations is formed as a result of subprocess A3 and become available to the user with the role "Principal Engineer". After confirming or changing the list of objectives, they are distributed by the "Principal Engineer" in manual mode or automatically by the intelligent system to available users of the farm (roles "Agronomist" and "Worker"). To implement the described functions, resources of the planning module are required. It should be noted that the received recommendations are dynamic and can change depending on the actual work performed and received data of objective control of the research object.

In this case, the data from the list of recommended works can be transformed by the intelligent system into the flow of control of technological processes of the farm. This is possible if the farm has automated or robotic irrigation complexes. With their help, for instance, it is possible to control water supply in in-soil or drip irrigation systems [1, 4].

4 Discussion

As noted in works related to the design of software solutions, at the first stages it is required to establish requirements for the product functional possibilities based on the needs of potential users and the current state of the problem area processes [1, 9, 19]. The use of the system analysis method made it possible to obtain a description of the process of agricultural land reclamation and factors affecting changes in its states. Evaluation of the obtained results made it possible to establish potential problems that can occur when the technologies of the corresponding process are violated.

After identifying the problems, the authors of developments usually create a description of the possibilities of the future software product functionality with the definition of user roles, based on which access to the digital system resources will be realized [8, 10, 17, 20]. At the same time, different modeling methodologies are used to visualize the obtained results. The choice of methodology is justified by the authors of the objectives of the created model, which may include the demonstration of the system architecture, its reaction to changes in the states of internal processes or external influences [14, 15, 21]. The methodology of functional modeling chosen in this research corresponds to this concept, as it makes it possible to show the sequence of system operations, the transformation of control flows and the resources required for this. At the same time, ready-made models or software developments can be used as resources. The developed software product model can be integrated into the existing digital ecosystem of a farm, or it can be an independent object.

5 Conclusions

Modern achievements of science and technology in agriculture make it possible to minimize, and in some cases neutralize, adverse effects of climatic factors on crop yields. This requires a complex of organizational and technical works, the composition of which depends on numerous factors, monitoring and control of which is impossible without the use of specialized hardware and software. This approach ensures the competitiveness of farms in the market of agricultural products.

Introduction of "smart" technologies into agricultural processes provides a balance between sustainable development of the industry and the use of natural resources. It provides an approach of careful and rational use of natural resources that reduces the negative impact on the environment and preserves its biodiversity.

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