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Decision-making models in information management systems of agro-industrial enterprises

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Abstract. The relevance of the stated subject is determined by the wide spread of information intelligent systems (IIS) in various spheres of modern science, technology and industry, and the need to develop and implement effective algorithms for decision-making based on IIS technologies in the agricultural sector of the economy of the Republic of Kazakhstan. The main objective of the study was to propose a model of managerial decision-making in the agrarian sector of Kazakhstan. The methodological

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approach here was based on the combination of methods of a comprehensive study of the key principles of decision-making in information management systems and an analytical study of the current prospects for the practical application of artificial intelligence technologies in the processes of enterprise management in the agro-industrial complex. Methods of analytical comparison and synthesis of data gathered during the study were also used. The findings obtained determine the main tasks of decision-making methods in the information networks of management of enterprises in the agricultural sector of the Republic of Kazakhstan, considering the current issues in this area and practical options for their resolution. The study revealed that, between 2000 and 2024, the average yield of all crops increased by 153%, with significant improvements observed in oilseeds, sunflower seeds, and potatoes. The study also observed a substantial increase in the use of information and communication technologies in Kazakhstan, with a nearly 3.5-fold rise in related expenditures. Furthermore, the research highlights the potential for automation in the agricultural sector, particularly in enhancing resource utilisation and boosting productivity. The practical significance of the findings lies in their implementation in the activities of enterprises in the agricultural sector to create effective management systems, leveraging artificial intelligence technologies. These developments will support the further modernisation of the sector, contributing to its economic sustainability and alignment with global trends in digital transformation

Keywords: artificial intelligence; information intelligent systems; agrarian sector; agriculture; management solutions; innovative technologies

INTRODUCTION

Ensuring the most effective development of the enterprise is an important task for managers of enterprises in modern conditions. This is primarily caused by the fact that this component is one of the main ones to ensure competitive advantages in the domestic and foreign markets. In Kazakhstan, agro-industrial enterprises are currently facing an increased need to optimise production processes to address the difficulties that are observed in the agricultural sector. In this regard, it remains relevant to research existing decision-making principles improvement ways. Problematics of the stated subject lies in the wide use of modern information technologies in various areas of social life, but also with the need to develop and practical implementation of artificial intelligence systems in the management of processes that take place in the activities of an agrarian enterprise. This study examines both theoretical and practical aspects of the use of modern information systems in management decision-making used by the enterprises of the agro-industrial complex of the Republic of Kazakhstan.

The environmental accounting and auditing model was considered in the framework of the research by B. Korabayev *et al.* (2024). They noted that the environmental accounting and auditing model formed in the state can have a significant impact on the financial results of industrial enterprises, and not only help the enterprise to effectively justify its costs and taxes but also receive certain benefits from the government related to the stimulation of environmental protection activities. However, this system should be designed to satisfy the needs of both the state, in terms of openness and reliability of the data obtained, and agrobusiness. A. Sumets (2020) considered a methodological approach to the evaluation of the management system of manufacturing enterprises. He pointed the peculiarities of the essence of the company's activity management within the framework of modern economic literature, describing the main elements of this system considering the specifics of its sphere of activity. Furthermore, an emphasis was made on what parameters to consider in the process of enterprise management, and what to strive for to achieve company maximum efficiency. Nevertheless, the scholar provided little empirical data (reports of enterprises, etc.) to show the calculation of such indicators in practice. In addition, the emphasis placed on the peculiarities of individual spheres of activity was rather superficial.

R. Gabdualiyeva *et al.* (2024) emphasised the digitalisation of the agricultural sector in Kazakhstan. The scientists noted that under current conditions farmers face quite a lot of obstacles, which digitalisation can partly help to solve. They also recommend optimising sowing and harvesting times, improving pest control methods, better irrigation and fertilisation of crops. However, scholars did not sufficiently consider the formation of management models, which are also an important part of both the digitalisation process and the improvement of the state of enterprises in the agricultural sector. G. Lukhmanova *et al.* (2019) also highlighted the innovative development of the agro-industrial complex of the Republic of Kazakhstan in modern conditions. They concluded that the country needs targeted modernisation of all components of the digitalisation complex in the country and suggested strengthening protectionism to ensure the development of innovation in the country in the long term. The peculiarities of strategic planning in agricultural production were studied by B. Myrzaliyev *et al.* (2023). They acknowledged that in the current conditions, the agricultural sector plays a huge role in the welfare of the Republic of Kazakhstan, in this regard, the development of long-term development

strategies in this area is relevant. Based on the peculiarities of the agricultural sector in Kazakhstan, scientists have developed certain advice on long-term planning.

The purpose of this study was to propose the model of decision-making in the agrarian sector of Kazakhstan.

MATERIALS AND METHODS

The study assessed selected statistical data that can indirectly characterise the quality of governance in the country, for which economic and statistical research methods, namely descriptive statistics, i.e. the direct collection and organisation of quantitative data, were used. Information from the official website of the organisation The World Bank (2024) on the ratio of expenditures on the development of innovative technologies to gross domestic product (GDP) was used for this purpose. The logic behind this indicator is that the more funds (compared to the level of GDP) are used for the development of the latest technologies, the more effective will be the management of information systems in the country. Innovative developments play the most important role in this context.

Data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2024a; 2024b; 2025) on the level of investment in agriculture in general, as well as the level of yields of individual crops, were also assessed. The importance of assessing the level of investment in agriculture is that the more funds are allocated for the development of this sphere, the more effective the management of internal processes in it should be. This can also be partially evidenced by crop yields (this study assessed cereals (including rice) and legumes, oilseeds, sunflower seeds, potatoes, open field vegetables, melons, and sugar beet). Thus, although yields are influenced by many factors, especially cultivation methods, the management of the enterprise also plays an important role in this context. Therefore, an assessment of this indicator may indicate an improvement in such processes within the company. The factors – external socio-economic conditions, internal financial and innovative capacities, and technology advancements – constituted the foundation for evaluating governance efficacy in the agriculture sector. The analysis was supplemented by schematic representations of management decision-making spheres, which contributed to the qualitative organisation of agricultural activities.

An expert survey was conducted to assess the qualitative factors influencing managerial decisions. The survey involved experts rating various factors on a scale from 0 to 10, with higher scores indicating a stronger positive influence on decision-making. This survey provided valuable data for computing weighted average assessments, which were incorporated into the decision-making models. The qualitative factors assessed by the experts were integrated with quantitative evaluations of key indicators, providing a comprehensive approach to decision analysis. Informed consent was obtained from all individuals included in this study. All procedures performed in the study were in accordance with the ethical standards of the institutional research committee and with the Helsinki Declaration (1964) and its later amendments.

The system analysis of decision-making principles allowed the formation of a unified system of analysing the relationship between the problems of activity of agricultural enterprises and possible practical solutions. The study utilised formulas for normalisation and weighted averaging of expert evaluations for qualitative decision-making. These mathematical models allowed for a more structured and objective analysis of decision options, improving the accuracy and effectiveness of management strategies. An analytical study of the real prospects of introducing artificial intelligence technologies in the management of agro-industrial enterprises of Kazakhstan made it possible to identify the problems facing information intelligent systems. The study was conducted in the conditions of Kazakhstan, taking into account the peculiarities of the country's economic development, especially in the agricultural sector. This particular model was used in the work, since it allows to improve the ability to use information systems to form more effective conclusions of management decisions. It also improves resource utilisation, productivity, workplace safety and supply chain efficiency.

The modelling method was also used within the framework of the research. It was used to build a system in the area of managerial decision-making when using information intelligent systems in the agro-industrial complex. The depiction of this model was made using the graphical method. Systematisation was used to evaluate the analysed factors within a single system where they interact with each other. The generalisation method was used to simplify the process of data analysis in the study. The descriptive method was used to characterise the individual data in the paper, assessing their main characteristics. The historical method was used to evaluate past quantitative data of changes in the parameters characterising the quality of management at enterprises. The comparison was used to assess the dynamics of individual countries (in the context of expenditures on research and development) to understand what the situation in Kazakhstan is. The abstract-logical method was used to make assumptions about what the actual model of information management at agrarian enterprises should be.

RESULTS

There are a number of issues in the development of the agro-industrial complex of the Republic of Kazakhstan that require immediate resolution in the context of a modern market economy (Smagulova *et al.*, 2022; Tkacheva *et al.*, 2024). Such issues include insufficient material and technical support, weak control over the

available natural, labour, and material resources along with their irrational use, and insufficient cooperation of small non-commodity enterprises into larger, commodity ones. Other concerns involve unsatisfactory processing of raw materials in agriculture and inadequate control over this process, an excessive number of intermediaries in the supply chain of agricultural products to the end consumer, and limited implementation of advanced scientific, technical, and software developments in agricultural production. Additionally, the economic mechanisms for attracting investment funds and state support measures to the agro-industrial complex remain underdeveloped.

One of the most effective and timely options for solving these current problems is the introduction of information intelligent systems for managing processes within these enterprises. The tasks assigned to such systems, currently being implemented in the agro-industrial complex of Kazakhstan, can be roughly divided into two main areas: monitoring the management processes of enterprises in this sector and making decisions to optimise the management process at any stage. The use of intelligent information management systems in agricultural enterprises is primarily driven by the need to transform the very structure of agricultural activities. This transformation includes an increase in the volume of agricultural production, coupled with improved organisation of management activities. When appropriate automated management systems and optimal information management tools are chosen, labour productivity at an agricultural enterprise can increase significantly compared to manual management. Another key aspect is the qualitative improvement of agricultural production safety and the enhancement of working conditions within agricultural enterprises.

The introduction of automated systems for managing the activities of an agricultural enterprise is especially effective when it comes to harmful agricultural production associated with the use of pesticides, pesticides, various chemical fertilisers, along with waste products of cattle or poultry farms. The automation of the agricultural sector also offers the prospect of significantly reducing occupational morbidity and injury in the agricultural sector, and of cutting the cost of rehabilitation and workplace health and safety measures. To date, one of the most significant problems in the development of enterprises in the agricultural sector of the economy of the Republic of Kazakhstan is the mismatch between the level of management and the technologies used by enterprises to meet the requirements of a modern market economy. One of the key requirements for economic management technology in the agribusiness sector under market conditions is the development of effective tools for this purpose, which include methods, algorithms, models, and information bases (Binu & Rajakumar, 2021; Srivastav *et al*., 2022). Figure 1 provides a schematic representation of the main areas of management decision-making when implementing intelligent management information systems in an agricultural enterprise.

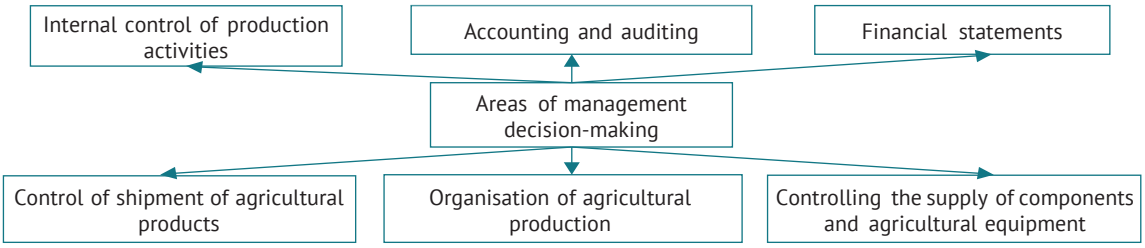

Figure 1. *Areas of management decision-making when using information intelligent systems in the agricultural sector*
Source: *compiled by the authors*

Decision-making models in agribusiness management information systems are divided into two main classes. The first class focuses on planning and ensuring the production activities of agricultural enterprises. This includes accounting for the supply of components and agricultural equipment, organising agricultural production processes, controlling the quality of finished products, and managing their shipment to the final consumer. The second class pertains to planning and ensuring the financial activities of agricultural enterprises. It covers the organisation and control of financial reporting, as well as accounting and auditing.

The closest to solving the problems of organising agricultural activities and production should be considered mathematical methods for processing data on economic parameters, through which the degree of informativeness of the presented parameters and the level of impact of extreme factors are determined (Caixeta *et al*., 2022; Kumar *et al*., 2022). However, these decision-making techniques, which are implemented separately and with no apparent correlation, do not fully equip the agribusiness sector with the capacity to manage successfully in a market environment (Huang *et al*., 2021; Deebak & Al-Turjman, 2022). The final quantitative characteristics based on the results of the analysis of identified indicators do not always contain objective information or reflect the direction of entropy fluctuations of individual indicators or the entire farm correctly. A schematic diagram of intelligent information management and processing system is shown in Figure 2.

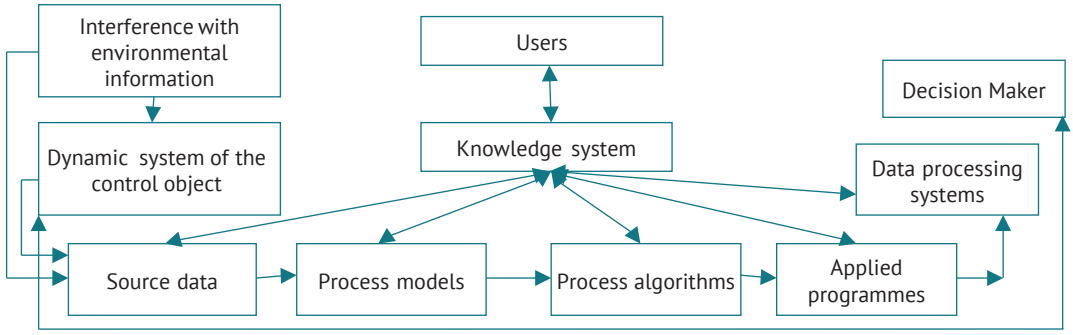

Figure 2. *Information intelligent control and data processing system*
Note: *LPD is linear, programme distribution*
Source: *compiled by the authors*

The data presented in Figure 2 suggest that the accurate formulation of the task of comprehensive application of mathematical methods of decision-making in information management systems involves a sufficient number of algorithms and data processing systems, and software packages for the implementation of the task. The situation is complicated by the fact that until recently, information technologies for managing the activities of agricultural enterprises in Kazakhstan were almost completely absent, due to the lack of an objective demand regarding their use, given the near absence of competition between enterprises in the agricultural sector. Agricultural production worldwide and in Kazakhstan in particular is considered to be among the low investment-attractive economic sectors. The total volume of investment in Kazakhstan was set at KZT 18 trillion (The volume of investments…, 2024). Attracting investment into this economic sector requires the formation of attractive investment projects. Leasing and investment credit can be sources of investment funds for agriculture (Abbad, 2021; Tkacheva, *et al*., 2024).

Any managerial decision-making should be based on the analysis of certain factors, both quantitative and qualitative. Quantitative decisions rely on statistical data, while qualitative decisions are based on expert opinions. Additionally, key factors can be identified for each decision, and these factors may vary. However, certain benchmarks should be given priority. The external environment includes socio-economic, technological, market situation, and climatic factors. The internal environment encompasses the financial and economic features of the enterprise, the level of innovation development, competitive advantages, and the level of strategic management.

Nevertheless, as already mentioned, these are only guidelines that can be relied upon in forming the factors on the basis of which conclusions will be formed, whereas in reality they may be quite different and only indirectly related to those proposed above. As already mentioned, factors can be both quantitative and qualitative, and their analysis will differ significantly depending on the type. To commence, the peculiarities of analysing qualitative factors must be taken into account. It should be assumed that the number of factors X1, X2, … Xn has been determined; regarding their influence on the management decision, a survey of experts was conducted, in which they could rate each of the factors on a scale from 0 to 10. If the factor has a positive influence on the factor, you high score indicates a stronger interaction, compared to others; if the factor has a negative influence, the high score indicates a lower influence on this factor. Thus, authors obtain the sum of m expert evaluations for each of n factors. The weighted average assessment of experts can be calculated by finding the arithmetic mean, namely by using the formula (1):

$$X_n = \frac{(E_1+E_2+E_3 \ldots E_m)}{m}, \quad (1)$$

where X_n – value of the factor with index n; E_1, E_2, E_3, E_m – corresponding estimates of the factor's influence on the managerial decision; m – number of experts that take part in the survey.

It is also worth noting that if one wishes to give a greater role to the evaluation of individual experts, a slightly different model can be proposed. Within its framework, it can be proposed to use weighted assessments for each expert's decision. The main thing is that in the end the sum of indices for each expert's assessment should equal 100%. In the case of quantitative assessments, it is worth applying approaches to normalise the data, bringing it to a uniform value. This paper proposes an approach in which the most favourable value of a quantitative indicator is determined at the level of 10 and the least favourable at the level of 0. An example of such an indicator is Net Present Value (NPV) when implementing a project in an enterprise. Thus, to determine the value of the indicator Xn it is worth making the following calculation (2-4):

$$X_n = \frac{K_m - K_{min}}{\left(\frac{K_{min}+K_{max}}{(x_{max}-x_{max})}\right)} + X_{min}, \quad (2)$$

$$X_{min} = \frac{G}{(n+1)}, \quad (3)$$

$$X_{max} = G - \frac{G}{(n+1)}, \quad (4)$$

where X_n – value of factor with index n; k_m – quantitative value of factor m; k_{min} – quantitative score of factor with minimum value; k_{max} – quantitative score of factor with maximum value; G – maximum possible score that can be obtained within the framework of this evaluation (within the framework of this paper it is at the level of 10); X_{min} – score for the indicator with minimum value; X_{max} – score for the indicator with maximum value.

Thus, a normalisation can be carried out which will produce a uniformly distributed series of scores from 0 to 10.As a consequence of estimating in this way,the following matrix of scores can be obtained, as shown below (5):

$$\begin{matrix} X_{11} & X_{12} & \cdots & X_{1m} \\ X_{21} & X_{22} & \cdots & X_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ X_{n1} & X_{n2} & \cdots & X_{mn}, \end{matrix} \quad (5)$$

where X_{mn} – values of n factors with m options for solving the management problem.

In this case, each of the options for solving the management problem is actually a vector, as it is shown below (6, 7):

$$\begin{bmatrix} X_{11} \\ X_{21} \\ \cdots \\ X_{n1} \end{bmatrix} \begin{bmatrix} X_{12} \\ X_{22} \\ \cdots \\ X_{n2} \end{bmatrix} \begin{bmatrix} \cdots \\ \cdots \\ \cdots \end{bmatrix} \begin{bmatrix} X_{1m} \\ X_{2m} \\ \cdots \\ X_{mn}, \end{bmatrix} \quad (6)$$

where L_m – length of vector m; X_m – value of factor with initial n for the variant of solution of management problem m.

$$L_m = \sqrt{(X_1^2 + X_2^2 + \cdots + X_n^2)}, \quad (7)$$

where L_m – length of vector m; X_m – value of factor with initial n for the variant of solution of management problem m.

Thus, at the end, n vectors with different lengths can be defined: the longer the vector is, the more effective the solution to a problem is considered to be. It is worth paying attention to the fact that in this case it is also possible to determine weight coefficients for each of the factors when analysing management problems, but it is worth paying attention to the fact that the sum of coefficients should be equal to 1. In addition, this leads to the possibility of additional errors due to the existence of the human factor. This can be graphically depicted as follows (assuming that only three factors are considered). As can be seen from Figure 3, it is not always obvious which of the options for solving a management problem is more favourable; the assessment is even more difficult when there are actually many more options.

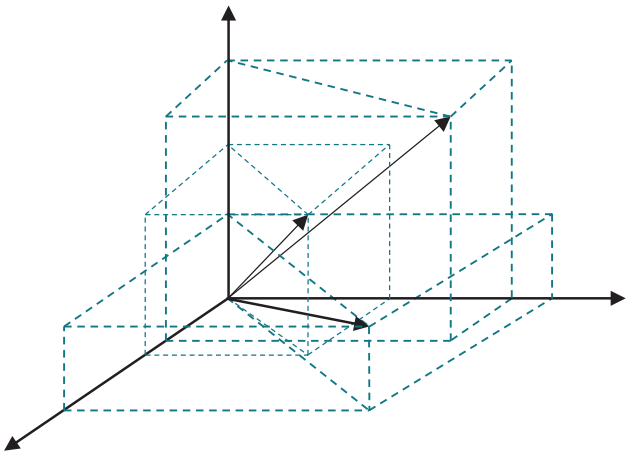

***Figure 3**. Example of vectors image in space*
***Source:** compiled by the authors*

Managerial decisions should be evaluated based on the model proposed above (with randomly assigned values, provided as an example). It is to be assumed that there are 4 factors that were evaluated using assessments from 5 experts, and there are 4 factors that can be evaluated quantitatively for each option of managerial decisions. There are 3 such decisions. For each of the factors in the context of each managerial decision the impact of experts was assessed. During the assessment the following results were obtained (Table 1).

***Table 1**. Example of assessment of qualitative factors of influence on the management problem in the context of management decisions*

Management decision 1						Average
Indicator	**Expert 1**	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	
Factor 1	9	8	8	3	10	7.6
Factor 2	7	7	3	1	9	5.4
Factor 3	10	8	6	2	8	6.8
Factor 4	4	4	7	1	8	4.8
Management decision 2						**Average**
Indicator	**Expert 1**	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	
Factor 1	0	10	4	4	1	3.8

Table 1. Continued

Management decision 2						Average
Indicator	**Expert 1**	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	
Factor 2	5	4	9	1	9	5.6
Factor 3	3	0	2	8	1	2.8
Factor 4	9	6	7	7	7	7.2
Management decision 3						**Average**
Indicator	**Expert 1**	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	
Factor 1	4	6	2	1	1	2.8
Factor 2	4	3	3	2	9	4.2
Factor 3	0	5	4	6	5	4
Factor 4	8	2	9	8	4	6.2

Source: *compiled by the authors*

According to Table 1, due to the different estimates of the influence of factors for different management problems, it is possible to obtain indicators that differ significantly between the different management solutions. Authors will also conduct an impact assessment for the quantitative factors as well, as shown in Table 2.

Thus, authors get 3 vectors with 8 values, for each of which it is worth calculating the length (Table 3).

Table 2*. The obtained results of the influence of quantitative factors within the framework of individual management decisions*

Estimation of in-kind indicators			
Indicator	**Management decision 1**	**Management decision 2**	**Management decision 3**
Factor 5	175	590	855
Factor 6	491	263	811
Factor 7	822	471	262
Factor 8	532	602	375
Evaluation of indicators in terms of scores			
Indicator	**Management decision 1**	**Management decision 2**	**Management decision 3**
Factor 5	2.5	5.55	7.5
Factor 6	4.58	2.5	7.5
Factor 7	7.5	4.37	2.5
Factor 8	5.96	7.5	2.5

Source: *compiled by the authors*

Table 3*. Final results of calculating the effectiveness of management decisions*

Indicator	**Management decision 1**	**Management decision 2**	**Management decision 3**
Factor 1	7.6	3.8	2.8
Factor 2	5.4	5.6	4.2
Factor 3	6.8	2.8	4
Factor 4	4.8	7.2	6.2
Factor 5	2.5	5.55	7.5
Factor 6	4.58	2.5	7.5
Factor 7	7.5	4.37	2.5
Factor 8	5.96	7.5	2.5
L	16.59	14.76	14.32

Source: *compiled by the authors*

As can be seen from Table 3, within the selected data the most effective is the use of management decision 1. Thus, the proposed methodology allows to determine which of the methods is more effective for

enterprises, and therefore the hypothesis can be considered confirmed. The application of decision-making techniques in information intelligent systems for managing agro-industrial enterprises is aimed at solving several key tasks (Galanakis, 2021; Yessilbayeva *et al.*, 2025). These include developing effective mechanisms to enhance the competitiveness of agricultural enterprises in a real market economy and identifying key trends in the development of integration processes within the agricultural sector. Additionally, it involves outlining the main priorities for agricultural sector development in the context of national food security and identifying prospects for strategies to increase the competitiveness of agricultural enterprises.

Further objectives include conducting an objective analysis of existing agricultural production management methods using forecasting techniques and analysing business processes within individual enterprises in the sector. Another critical task is developing an effective system for managerial decision-making at all levels and in all areas of an agricultural enterprise to ensure an appropriate level of management. Lastly, the creation of an information-analytical system using mathematical models is essential for making accurate forecasts of financial, economic, and production indicators in agricultural production.

Prospects of the practical introduction of artificial intelligence technologies in the processes of enterprise management of the agrarian sector of the economy in Kazakhstan are largely determined by both real problems of this industry, and options for their practical resolution, in the context of the realities of economic development of the country. The practical effectiveness of any management decision-making models used by agricultural enterprises in Kazakhstan can be supported by real improvements in their functioning, manifested in an increase in agricultural production, improved labour safety of employees of enterprises, and their stable functioning regardless of changes in the current economic situation and various negative external factors.

In reality, managerial decision-making is closely linked to the development of innovations. This is related to the fact that companies actively involved in innovation discover new opportunities to improve business processes and create new products. In addition, decision-making processes include analysing technological trends, risk management, and supporting an innovative culture, stimulating creativity and initiative among employees. Integration of innovation into the business model includes assessing the impact on current processes and possible changes in strategy. Thus, innovation and decision-making complement each other, creating the basis for sustainable development and competitiveness of the company. In this regard, by assessing the level of innovation spending in a country, it is possible to partly infer the extent to which the effectiveness of decision-making in the country is increasing (Fig. 4).

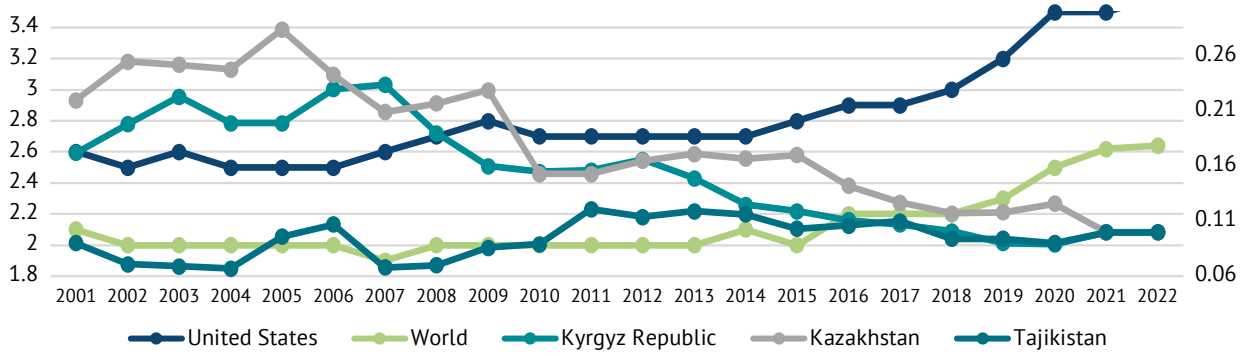

***Figure 4**. Research and development expenditure in selected countries from 2001 to 2022, %*
***Source:** compiled by the authors based on The World Bank (2024)*

As can be seen in Figure 4, the level of innovation expenditure in Kazakhstan relative to GDP is gradually decreasing. The value in the country in 2001 was 0.22%, while in 2022 it was 0.1%, which is on par with Kyrgyzstan and Tajikistan. Compared to the world average, such values remain quite low. Although the country defines innovation as one of the most important strategic goals in its development, the data show that the ratio of costs to the latest technologies is only getting lower, which may be a bad factor, indicating, among other things, the insufficient pace of development of decision-making methods. Such dynamics are primarily caused by the rapid GDP growth rate in the country as a whole, which outstrips the growth of innovation costs. Nevertheless, it can be argued that the public authorities pay insufficient attention to the development of innovations in the country. The change in Tajikistan, on the other hand, is uniform. For developed countries, in particular the United States of America, the dynamics are upward, as is the global average, which is different from Kazakhstan's trends. Another component that can influence the effectiveness of management in agriculture is the level of investment (Fig. 5).

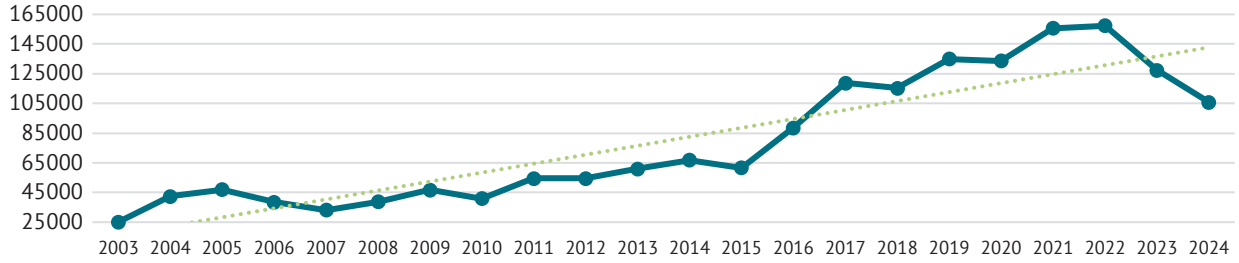

***Figure 5**. Level of investments in agriculture adjusted for inflation (in 2003 prices) in the period from 2003 to 2024, million tenge*

***Source:** compiled by the authors based on Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2024a)*

As can be seen from Figure 5, the level of investment in agriculture in Kazakhstan has been experiencing fluctuations in recent years. After a period of steady growth until 2022, there is now a noticeable decrease in investments in 2023 and 2024, indicating a decline rather than gradual improvement in this sector. Another indicator worth considering is the yield level (which characterises productivity) (Table 4).

***Table 4**. Yield level of individual crops in Kazakhstan in the period from 2000 to 2024, quintals/ha*

Year	Cereals (including rice) and legumes (in weight after cultivation)	Oilseeds	Sunflower seeds (in weight after processing)	Potatoes	Outdoor vegetables	Gourds	Sugar beet (in weight after processing)
2000	9.4	3.9	4	106	153	119	154
2001	12.2	5.7	6	133	166	127	173
2002	11.5	6.3	5.9	139	172	135	207
2003	10.8	7.1	6.8	139	177	144.5	210.4
2004	8.8	6.2	5.9	134	186	153.2	197.4
2005	10	7	6.3	150	196	159.3	209.2
2006	11.7	6.6	5.9	153.6	201	167.1	240.8
2007	13.3	7.2	5.9	155.8	211	171.7	248.9
2008	10.1	5.5	4.1	143.7	204	158.9	204.3
2009	12.6	6.5	5.7	160	218.7	161.1	182.9
2010	8	5	4.4	143	214.4	177	174.3
2011	16.9	6.7	4.6	167.2	222.9	186.1	188.2
2012	8.6	6.1	5.9	165.9	234	206.8	168.2
2013	11.6	8	7	181.5	238.7	212.4	267.7
2014	11.7	7.8	6.7	184.3	243	217.1	240.6
2015	12.7	8.1	7.6	185.5	245.8	221	232.5
2016	13.5	9.6	9.3	190.4	250	221.4	285.5
2017	13.4	9.7	10.2	194.2	253.7	224.2	274.4
2018	13.5	9.7	10	197.9	257.3	224.2	305.3
2019	12.3	9.3	10.3	203.4	260.5	234.6	324.5
2020	12.8	9.5	11.3	206.7	265.9	238.8	323.2
2021	10.4	8.3	11	207.4	268	252.7	275.5
2022	13.8	9.1	12	205.4	271.3	255.6	341.4
2023	10.3	8.8	11	220.1	271.9	260.3	379.0
2024	15.2	12.2	14.6	219.1	284.2	253.2	507.3
Change, quintals/ha	5.8	8.3	10.6	113.1	131.2	134.2	343.3
Change, %	62	213	265	107	86	113	223

***Source:** compiled by the authors based on Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2025)*

As can be seen from Table 4, yields of all crops in Kazakhstan have increased, with an average yield increase of 153% between 2000 and 2024. This may partly indicate that the overall management efficiency of the industry is increasing. The scale of use of information and communication technologies can be assessed using individual statistical data provided in Table 5.

***Table 5**. Selected data characterising the use of information and communication technologies in Kazakhstan in the period from 2008 to 2023*

Years	2008	2009	2010	2011	2012	2013	2014	2015
Share of organisations using computers, %	76.6	69.8	62.7	65.2	66.9	66.2	58.1	66.3
Share of organisations with access to the Internet, %	55.5	54.2	52.9	55.4	58.4	60.7	52.4	61.2
Share of organisations with Internet resources, %	7.4	7.6	24.8	20.4	5.8	26.2	19.3	20.5
Share of organisations receiving orders for goods and services via the Internet, %	14.1	13	13	4.7	4.5	6.7	7.1	11.5
Share of organisations ordering goods and services via the Internet, %	14.9	15	15.7	3.6	3.9	5.9	7.7	15.3
Total costs for information and communication technologies, billion tenge	78.2	126.6	147.5	214.2	309.8	220.8	237.1	375.6
Total costs for information and communication technologies, taking into account inflation, billion tenge	71.4	108.7	117.3	158.5	216.2	146.9	146.7	204.7
Years	**2016**	**2017**	**2018**	**2019***	**2020***	**2021***	**2022***	**2023**
Share of organisations using computers, %	73.7	70.7	77.7	83	83.9	80.2	75.9	81.4
Share of organisations with access to the Internet, %	69.4	67.7	75.1	80.4	81.6	78.2	79.1	79.1
Share of organisations with Internet resources, %	18.5	21.7	22.3	18.9	17.9	17.6	25.6	26.5
Share of organisations receiving orders for goods and services via the Internet, %	4.4	1.5	1.6	5.4	7.4	8.5	9.3	10.6
Share of organisations ordering goods and services via the Internet, %	6.6	6.1	4.9	8.2	7.9	10.1	11	12.9
Total costs for information and communication technologies, billion tenge	269.5	349.9	305.2	337.7	388.9	443.1	589.9	918.3
Total costs for information and communication technologies, taking into account inflation, billion tenge	135.6	164.2	135.9	142.6	153	160.7	177.7	263

***Note:** * – for the first five indicators, the values were calculated until 2019 without taking into account government institutions, and from 2019 – together with them*

***Source:** compiled by the authors based on Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2024b)*

As can be seen from Table 5, different parameters have shown varying trends over time. According to the available data, the number of organisations using computers increased by 7.7 percentage points, while the number of organisations using the Internet to receive or place orders for goods or services rose by 5.5 and 4.9 percentage points, respectively. On the other hand, the share of organisations with Internet resources has remained relatively stable with a slight increase of 6.1 percentage points, while the portion of organisations with access to the Internet saw a significant rise of 14.6 percentage points. Additionally, the total costs for information technology have increased approximately 3.5 times. These changes indicate that the use of information and communication technologies in the country is steadily increasing. However, despite these positive trends, the level of Internet usage for business activities remains relatively modest. The upward trend in information technology spending among enterprises is a promising sign. All this suggests the potential for further positive development in this sector in the future. Although there is no specific data on the implementation of digital technologies in the agricultural sector, it is reasonable to assume that their share is still limited.

DISCUSSION

Taking into account the information analysed above regarding the formation of management information systems in agriculture, authors can offer separate recommendations aimed at shaping public policy in this area. So, it is worth increasing the share of budget expenditures on investing in infrastructure, which provides agriculture with the necessary tools and technologies. Also important is work on the legislative framework, which should be carried out towards the introduction of stricter rules and oversight mechanisms to ensure the sustainable and efficient use of natural, labour and material resources in the agricultural sector. In general, any government programs that could encourage enterprises to form and improve the quality of internal management systems are also an important component of the development of this area. The introduction of such components into the

country's public policy is a fundamental principle for ensuring high-quality implementation of information systems in agricultural enterprises.

In general, the model proposed in the work can solve a fairly large number of difficulties in the country. It explains the relationship between identified problems and potential mechanisms for solving them through strategic measures, in particular the implementation of information systems. This is primarily due to the fact that the economic sector of Kazakhstan itself is faced with systemic inefficiency, which includes insufficient material and technical support, weak resource management and limited cooperation between enterprises (Manatovna *et al.*, 2023). This inefficiency results in low productivity, resulting in a mismatch between the sector's development and the demands of a modern market economy. The model shown in the work allows you to create a structure for the formation of management decisions, use innovative technologies, programs and algorithms to form them, which makes the process faster and more accurate. Thus, its use makes it possible to increase the level of efficiency of applied management decisions, and therefore improve the quality of the company's functioning as a whole.

X. Pantazi *et al.* (2019), who investigated the application of intelligent analysis systems in agricultural activities, concluded that the artificial intelligence and data fusion techniques currently used in the agricultural industry for production control and crop monitoring have shown to be highly effective. The authors point out that neural networks and sensors with an artificial intelligence architecture make it possible to qualitatively identify trends in climatic conditions that negatively affect crop prospects. The need to apply the devices described competently to achieve the desired result is also stressed. The findings of the researchers can be accepted in the context of this study with the caveat that they should only be considered true if the equipment listed by the authors is adequately controlled.

At the same time, M. Khan *et al.* (2022), reviewing the prospects for the practical use of machine learning technologies in agriculture, argue that artificial intelligence technologies can only improve agricultural production and increase its economic efficiency only if they are used competently. Accordingly, since artificial intelligence methods are used to increase yields through optimal planting, fertilisation, irrigation, and harvesting, they are only part of a complex picture that should also consider economic investments and their optimised returns. The performance of machine learning models improves over time as various mathematical and statistical models are tested (Karaiev *et al.*, 2021). The conclusions in the context of the findings of this study seem questionable, due to the difficulty of controlling the level of return on investment invested in the development of agriculture in a particular region when it is not properly used.

P. Sharma *et al.* (2022), investigating the problematic aspects of bioinformatics in agriculture, came to a joint conclusion that echoes the findings of the researchers described above. The authors point out that the introduction of innovative processes in the agricultural sector will only be effective if they are properly implemented. They also draw attention to the fact that the application of artificial intelligence technologies in crop quality improvement management requires a high degree of competence from all parts of the chain involved, from the system designers to the direct performers of the tasks assigned. These findings show no clear contradiction with the results of this investigation, supporting and further extending it. R. Poonia *et al.* (2022), studying some problematic aspects of the use of artificial intelligence systems in agriculture, concluded that the success of such systems is largely related to the efficient use of information stored in databases of computer systems. Researchers note that managing artificial intelligence software databases requires the use of a special software learning algorithm to ensure high efficiency in solving the tasks at hand. Sustainable agriculture data determine the prospects for the sector and the possibilities for quality solutions to the challenges faced by agricultural enterprises at any stage of their existence (Yzakanov *et al.*, 2024). The conclusions can be challenged on the grounds that any algorithm requires an appropriate level of use, which implies quality training for the service personnel.

On the other hand, the subject raised is being further developed by G. Kaur *et al.* (2020) in a collaborative study on the application of artificial intelligence to the Internet of Things solutions. Researchers point out that to achieve a sustainable result, the introduction of artificial intelligence technologies in any sphere of everyday life requires a special algorithm that accounts for all features of the behaviour of an information intelligent system in a constantly changing external environment. According to a group of scientists, agriculture is an unstable environment with constantly changing external conditions, so the introduction of artificial intelligence systems in this environment involves constant monitoring of the nature of changes occurring at different stages of the system's functioning. These conclusions are fully in line with the author's findings. The results are consistent with those obtained in this study, presented in the case of the mathematical model for managerial decision-making.

The study by S. Kim and G. Deka (2021) examined the application of hardware accelerator systems and artificial intelligence in machine learning, assessing the prospects for their implementation in various branches of science and technology. The authors conclude that the development of deep neural networks and machine learning have opened vast prospects for many industries and economies. Special attention is paid to the fact that the transition of agriculture to the application of

artificial intelligence technology is possible only if the infrastructure of agricultural enterprises is sufficiently prepared for the implementation of new innovations (Zelisko *et al.*, 2024). Otherwise, it will not be possible to achieve high performance in the management of agricultural enterprises and increase the volume of agricultural output. These conclusions are fully in line with the author's findings. The results are consistent with those of this study, while also revealing new aspects of the problem under investigation.

Notably, the study by P. Srivastava and G. Tsakiris (2020) devoted to the consideration of challenges in the application of artificial intelligence systems in the management of water resources of agricultural enterprises, concluded that the effectiveness of their practical application depends to a large extent on the training of the personnel of these enterprises. Artificial intelligence can now effectively manage the water supply to irrigate fields or garden plots, whereas volume control and water delivery can be fully automated (Shahini *et al.*, 2023). The ultimate impact of such a system is determined by operator training, controlling the sequence in which commands are executed and the nature of changes to the underlying data. In the context of assessing the role of the information system operator (user), the findings mirror those of this investigation.

N. Nilsson (1998), in a study of the development prospects and practical applications of artificial intelligence systems, concluded that the further spread of artificial intelligence information systems in various areas of daily life opens great opportunities to solve a range of tasks that were previously unattainable. The author emphasises that the application of information management systems for agricultural enterprises enables effective control over all areas of agricultural activity, including animal husbandry, the planting of crops or the cultivation of fruit and berries. According to the scientist, this can be achieved through the use of large amounts of data containing information about all aspects of the activities of agricultural enterprises at all its stages. The conclusions drawn do not clearly contradict the findings of this study, aligning with them in substantial terms. Zh. Abuova *et al.* (2023) studied the possibilities of creating a favourable environment for outsourcing relationships in the agro-industrial complex of Kazakhstan. Scientists noted that there are critical problems facing agricultural organisations in Kazakhstan due to inadequate market infrastructure and lack of support systems. In this regard, they believe that the use of outsourcing can help solve these difficulties. The use of outsourcing is often also associated with the implementation of information and management systems, since it requires more active and efficient management of processes in such enterprises (Potryvaieva & Palieiev, 2023). In this regard, this work generally supports the idea of this study that increased implementation of management systems is an important component of agricultural development in Kazakhstan.

R. Dulambayeva *et al.* (2023) in turn analysed the relationship between innovation and the development of the agro-industrial complex in Kazakhstan. They noted that there is a significant positive impact from the introduction of new technologies on the agricultural sector. They considered agricultural credit one of the most effective methods for creating more active innovative development. In addition, they noted the role of stimulating agricultural enterprises to develop in this direction. They emphasised government support for such enterprises as one of the proposed ways to achieve this. This study also suggested that this could be a qualitative method for both increasing the efficiency of companies in Kazakhstan and ensuring a higher overall level of digital technology adoption in the country.

CONCLUSIONS

The challenges of managing enterprises in the agrarian sector can be successfully solved through the introduction of information intelligent systems into their management practices. Systems of this kind ensure the efficiency of management of all processes occurring throughout the activities of enterprises of the agrarian sector, through the practical application of management decision-making models for all common scenarios occurring in the activities of a single agrarian enterprise. The integration of such systems has significantly improved the efficiency of management practices in the agricultural sector of Kazakhstan, particularly by automating decision-making processes, optimising resource utilisation, and enhancing productivity. For example, between 2000 and 2024, the average yield of all crops increased by 153%, which highlights the positive impact of management automation.

Decision-making models in the management systems of enterprises of the agro-industrial complex of the Republic of Kazakhstan are created using the capabilities of the available mathematical apparatus. At the same time, it is necessary to consider such factors as business options within a particular management model, the acceptable variants of events and decisions, and the amount of the input data, which determine the nature of the optimal options to resolve the situation in the management of the agricultural enterprise, along with the utility function, the relationship between decisions and the results, uncertainty of the external environment parameters. Consideration of the above factors in their systemic variation allows the creation of effective decision-making models in control systems. The study assessed certain indicators that may indirectly indicate an increase in the efficiency of governance in the agricultural sector. Additionally, the data indicated that the overall trends in the dynamics of management

efficiency remain positive, with a noticeable increase in agricultural production and improved labour productivity, driven in part by the implementation of automated management systems.

The tasks solved by implementing these models into the information management systems of agricultural enterprises are performed sequentially, as the data processing speed increases. The efficiency of an agricultural enterprise and the timeliness of practical solutions to problems arising in the process of its economic activity depend on the quality of its solution. Furthermore, automated decision-making systems have minimised the impact of human error, leading to more accurate and faster management decisions, which directly improves operational efficiency. The study demonstrated that the use of automated information management systems can enhance the operational efficiency of agricultural enterprises in the country. Notwithstanding the favourable trends, Kazakhstan's agricultural investment has varied, exhibiting a significant reduction in 2023 and 2024. The overall expenditures for information and communication technology in Kazakhstan have increased by nearly 3.5 times, signifying a favourable trend towards digital transformation. In 2022, Kazakhstan's innovation expenditure constituted under 0.1% of GDP, a figure that is comparatively low against global standards and underscores the inadequate momentum of innovation within the agricultural sector.

The state can facilitate this process by formulating its own policy in this domain. This approach can foster more favourable conditions for the integration of intelligent information systems in agriculture, enhance investment appeal by promoting innovation, and establish targeted initiatives to improve digital literacy among agricultural enterprises. The state might also support digital transformation expenditures for small and medium-sized firms and enhance infrastructure, particularly in regional areas. These initiatives should considerably expedite the implementation of information systems in agricultural operations.

Further examination of enhancement chances for decision-making models in management information systems has significant prospects for the advancement of enterprise management systems within Kazakhstan's agricultural sector. The practical efficacy of these technologies will manifest as heightened agricultural output, augmented worker safety, and bolstered economic stability within the agriculture sector. These developments will enhance the profitability of these firms and contribute to the general prosperity of Kazakhstan's agro-industrial complex.

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CONFLICT OF INTEREST

None.

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Моделі прийняття рішень в інформаційних системах управління агропромисловими підприємствами

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Анотація. Актуальність заявленої теми визначається широким поширенням інформаційно-інтелектуальних систем (ІІС) у різних сферах сучасної науки, техніки та промисловості, а також необхідністю розробки та впровадження ефективних алгоритмів прийняття рішень на основі технологій ІІС в аграрному секторі економіки Республіки Казахстан. Основною метою дослідження було запропонувати модель прийняття управлінських рішень в аграрному секторі Казахстану. Методологічний підхід ґрунтувався на поєднанні методів комплексного дослідження основних принципів прийняття рішень в інформаційних управлінських системах та аналітичного дослідження перспектив практичного застосування технологій штучного інтелекту в процесах управління підприємствами агропромислового комплексу. Також використовувалися методи аналітичного порівняння та синтезу даних, зібраних під час дослідження. Отримані результати визначали основні завдання методів прийняття рішень в інформаційних мережах управління підприємствами аграрного сектору Республіки Казахстан з урахуванням сучасних проблем цієї сфери та практичних варіантів їх вирішення. У дослідженні було виявлено, що в період з 2000 по 2024 рік середній урожай усіх культур зріс на 153%, при цьому спостерігалися значні поліпшення у вирощуванні олійних культур, соняшнику та картоплі. Також було зафіксовано значне збільшення використання інформаційно-комунікаційних технологій у Казахстані, з майже 3,5-кратним зростанням витрат на ці технології. Крім того, дослідження підкреслило потенціал для автоматизації аграрного сектору, зокрема для покращення використання ресурсів та підвищення продуктивності. Практична значущість результатів полягає у їх впровадженні в діяльність підприємств аграрного сектору для створення ефективних управлінських систем з використанням технологій штучного інтелекту. Ці розробки сприятимуть подальшій модернізації сектора, підвищенню його економічної сталості та узгодженості з глобальними тенденціями цифрової трансформації

Ключові слова: штучний інтелект; інформаційні інтелектуальні системи; аграрний сектор; сільське господарство; управлінські рішення; інноваційні технології