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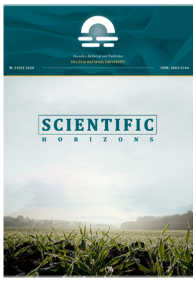

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Methodological foundations of information support for decision-making in the field of food, environmental, and socio-economic components of national security

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Abstract. The negative impact of strategic threats to the development of the state in the context of the development of its national security, in particular food, environmental, and socio-economic components, has intensified in the context of Ukraine's geopolitical challenges. This issue has become particularly acute as a result of open military aggression, which makes it necessary to develop and implement a system of information support for decision-making in the field of national security of Ukraine. Therefore, the purpose of the study is to substantiate methodological foundations of information support of decision-making in the field of national security of Ukraine and their implementation within the framework of the created system, which provides for the collection of information, in particular, using space and geographic information systems, and the use of mathematical modelling and situational analysis methods for data processing. In the course of the research, methods of econometric modelling, structural and functional modelling, and spatial analysis were used. A methodological framework has been developed for decision-making support to address the problems of food, environmental, and socio-economic components of national security. A functional model and algorithm of the decision-making

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process in the field of national security are constructed and, based on the results obtained, a decision-making system in the field of food, environmental, and socio-economic security is developed. In addition, the study formalises the conceptual provisions of the decision-making support process in the field of national security; a procedure for modelling the country's food security indicators is proposed. Based on the proposed methodological approach, it was determined how much the area of crops decreased due to the temporary occupation and military operations, and the post-war state of fields (minelaying, destruction of crops, equipment, etc.), which allowed forming input data for further projecting of indicators of the development of the agricultural sector and food security in Ukraine, the EU, and the world. The proposed methodological provisions, algorithms, models, and the developed system can be used by state authorities to make managerial decisions on the development of policy in the areas of ensuring food, environmental, and socio-economic security of the country

Keywords: information support; functional modelling; econometric model; information system; management solution; remote sensing of the Earth

INTRODUCTION

Modern threats to the sustainable development of Ukraine, which negatively affect the level of national security, are associated, in particular, with the deformation of the structure of the economy both in terms of optimal criteria for self-sufficiency and foreign economic specialisation, as well as with scientific and technological, social, and environmental positions; with the fact that the proposed world-class scientific results do not find application in the economy due to the low susceptibility of the business sector to innovation; low technical and technological level of production; the development of environmentally hazardous industries; the growth of negative impact on the environmental situation and public health of processes related to waste management; the outflow of qualified personnel; ageing and deterioration of the state public health, etc. The negative impact of these threats has intensified in the context of modern challenges to the national security of Ukraine as a result of the open aggression of the russian federation.

Most of the research papers that deal with decision-making processes in the field of ensuring national security are devoted to the organisational features of this process and the development of national security policies both in general and in individual countries (Bearne, 2005; Freilich, 2006). A separate issue in the context of studying the decision-making process is its information support, since the development of an effective solution is based on timely access to accurate adequate input information. According to the practical experience of some developed countries, specially created and authorised institutions, whose activities are clearly declared, are responsible for information support of the decision-making process in the field of national security (Routray, 2013; Heazle, 2010). According to S. Freilich (2006), one of the problems of the decision-making process in the field of national security in Israel was the need for decision-making actors to rely on their own experience, intuition, and recommendations of other, often interested, individuals. At the same time, since the 2000s, Israel has been actively developing the field of military and political planning (Freilich, 2006), which contributes to improving the effectiveness of policy-making.

But to substantiate specific actions and policies in the agricultural sector, scenario projections are built that take into account potential changes in factors through the adoption and implementation of relevant political decisions. It is this methodological approach that has proven its effectiveness in the process of developing the agricultural policy of EU countries and identifying threats in the medium term. In particular, R. Jongeneel and A.R. Gonzalez-Martinez (2022) investigated the impact of the abolition of the EU milk quota system on the development of the dairy industry. The studies by M. Haß (2022) and Mathenge *et al*. (2022) examine whether coupled support for sugar beet in the European Union would lead to market distortions. An important role in decision-making in the field of ensuring food security in the country is played by the development of scenario projections, considering potential threats to the development of the agricultural sector. In particular, R. Jongeneel *et al*. (2020) created a projection for the development of pig breeding in the EU, considering the potential impacts of the spread of African swine fever. Projections developed by O. Nykolyuk *et al*. (2021) and Gorbilin (2021) demonstrate potential changes in key indicators of the agricultural sector of Ukraine due to the consequences of the introduction of quarantine measures after the start of the COVID-19 pandemic.

Among the alternative types of data that are actively used in decision-making in the field of food, socio-economic, and environmental safety, there is spatial data that is accumulated and processed based on geographic information systems (GIS). According to the study by M. Mathenge *et al*. (2022), GIS-based data analysis methods can be used to make policy decisions in the area of sustainable agricultural development. The researchers note the lack of spatial data necessary for the development and implementation of agricultural policy. L. Beni *et al*. (2011) offer an information product that provides for the integration of ArcGis and Arena systems, for the purpose of modelling and monitoring the spread of contamination in a food distribution network and information support for operational decision-making in the field of food quality control as one of the key elements of food security. Similar are the conclusions of E. Vandecandelaere *et al.* (2018), which prove the absolute importance of GIS for ensuring the development of sustainable food systems, considering the territorial characteristics of countries and their individual regions.

As for the field of ecology, K.T. Nemec and C. Raudsepp-Hearne (2012) suggest using GIS to evaluate the effectiveness of ecosystem services, which should be considered in the management decision-making process in ecology, and also provide a comparative analysis of existing software products. Lant *et al.* (2012) use GIS to model the effectiveness of policies that affect agricultural watersheds (Lant, 2005). The use of GIS in the process of land use regulation in the context of combating problems of environmental safety of land (in particular, soil degradation and erosion, land pollution) is reflected by (Xie, 2022). Integrated GIS and remote sensing work successfully for mapping nature reserve sites, especially fire area and scale analysis, fire research (Skydan, 2021; Fedoniuk, 2022), tracking the spread from multiple plant and animal individuals to species, ecosystems, landscapes, and identifying factors that contribute to local and global biodiversity changes, the spread of invasive species, etc. (Fedoniuk, 2022; Orlov, 2021).

The purpose of this study is to substantiate methodological aspects of information support for decision-making in the field of national security, which will involve the use of data from a wide range of information sources and the use of formalised methods and models.

MATERIALS AND METHODS

The experiment on information support for decision-making in the field of food security was conducted on the example of accumulating data on the acreage of agricultural crops, taking into account the impact of military operations on the territory of Ukraine. After the full-scale invasion of the russian federation, Ukraine was faced with the task of assessing the potential negative effects on food security at the regional, European, and global levels. The key problem was that a significant part of the country's agricultural land was under temporary occupation as of the beginning of the sowing campaign in 2022 and it was impossible to grow crops on the corresponding areas. As of March-April 2022, it was impossible to estimate potential crop losses in such areas using conventional methods and based on statistical data. In addition, a number of grain storage facilities are located in the temporarily occupied territories, where reserves should be defined as losses of the country's strategic food reserves.

Considering the above, the task was set to project the potential volume of gross harvest and export of strategic export-oriented agricultural crops in war conditions. Such crops primarily include wheat, corn, and oilseeds. The main task that was carried out in the course of the study since the beginning of the war was to develop a methodology for estimating the area of agricultural land in the temporarily occupied territories, in order to further projecting the potential volume of gross harvest and export of strategic export-oriented agricultural crops the production and export of agricultural crops, sunflower and other types of oils based on the AGMEMOD model (Salamon *et al.*, 2019). According to the developed methodology, it is determined how much the area of crops has decreased due to temporary occupation, military operations, and the post-war state of fields (minelaying, destruction of crops, equipment, etc.).

According to the proposed methodology for generating input data for further projecting indicators of the development of the agricultural sector and food security in Ukraine, the EU, and the world, satellite survey data processing is provided, which included the following stages:

1. Determination of the range of temporarily occupied territories, which was carried out based on information from the Centre for Environmental Initiatives "Ecoaction" (Almost, 2022).

2. Calculation of the area of agricultural land based on geodata obtained in 2019 using the TERRA and AQUA spacecraft using the Moderate Resolution Imaging Spectroradiometer (MODIS). Geoinformation is presented in the form of 17 classified types of land cover in Ukraine.

3. Selection from a classified image of an area located within the temporarily occupied territory of Ukraine.

4. Calculation of the geodetic area of plots whose class corresponds to agricultural land (Table 1). As a result of this operation in ArcGIS PRO, it was determined that the area of agricultural land within the temporarily occupied territories as of March 22, 2022, amounted to 33% of the area before the start of hostilities, or 12.8 million hectares.

5. To clarify the available food volumes of crop production stocks (primarily wheat, corn, and sunflower seeds), the task was set to determine possible grain losses due to temporary occupation and military operations in the territories where grain storage facilities are located.

***Table 1**. Share of temporarily occupied territories of Ukraine (as of March 2022)*

Surface classes in Ukraine	Area. thous. ha	Temporarily occupied territories	%
Evergreen coniferous forests	716	256	36
Deciduous coniferous forests	2	0	23
Deciduous broad-leaved forests	2.684	448	17

Table 1, Continued

Surface classes in Ukraine	Area. thous. ha	Temporarily occupied territories	%
Mixed forests	2.668	727	27
Closed shrubs	0.04	0.02	60
Woody shrubs	2.395	814	34
Open woodlands	3.882	1.534	40
Pastures	4.730	2.793	59
Permanent wetlands	255	84	33
Agricultural land (cultivated)	39.056	12.749	33
Urban and built-up land	1.093	420	38
Seed plots / Natural plant mosaics	1.435	351	24
Barren lands	17	14	81
Water bodies	1.168	486	42
Total	60.101	20.677	34

Source: *authors' own research*

Geospatial data obtained according to the algorithm described above (Skydan, 2022) is used to calculate such areas:

1. Defining a range of temporarily occupied territories (Almost, 2022).
2. Collecting data on the location, characteristics, and occupancy rate of grain storage facilities.
3. Conducting a geolocation procedure for the data obtained above, to determine the geographical coordinates of grain storage facilities.
4. Identifying grain storage facilities located in the temporarily occupied territories and calculating the amount of stocks stored in them.

RESULTS

Use of GIS in assessing food security indicators. Food security, as an element of a country's national security, is based on the ability to meet domestic demand for food through current production and existing stocks. Consequently, the accumulation of data on the available volume of agricultural and processed products is of primary importance for an adequate assessment of food security. Based on the results of geospatial analysis conducted in accordance with the above methodology, the locations of grain storage facilities located in the temporarily occupied territories as of March 2022 were determined and the reserves stored in them were calculated (Table 2). Considering the riskiness of approaching the front line, a buffer zone of 50 km was built, where 17.5% of grain reserves or 3.86 million tonnes are concentrated (Fig. 1).

The information obtained is used as input data entered into the database and used for modelling food security.

Table 2*. Share of product stocks in grain storage facilities of Ukraine located in the temporarily occupied territories*

Indicator	thousand tonnes	%
Temporarily occupied territory	5.140	23.29
50 km buffer zone	3.859	17.49
Balance in Ukraine	13.068	59.22
Total	22.068	100.00

Source: *authors' own research*

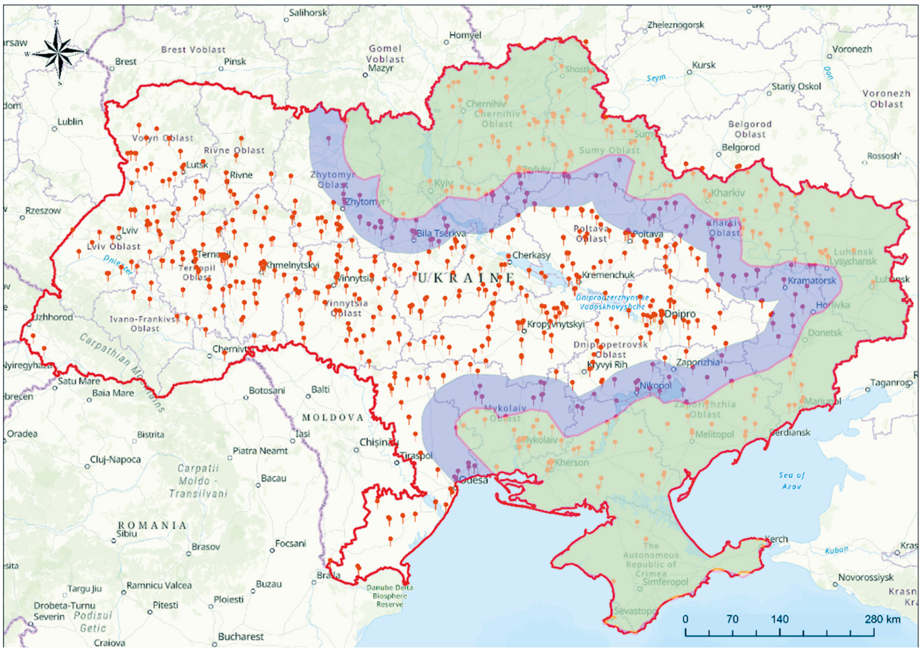

Figure 1*. Grain storage facilities of Ukraine located in the temporarily occupied territories;*
** grey – temporarily occupied territories, blue – 50 km buffer zone (as of March 22, 2022)*
Source: *authors' own research*

Functional modelling of the process of information support for decision-making in the field of food, environmental, and socio-economic security. The definition of methodological aspects of the decision-making support system (DMSS) in the process of developing national security should be based on the logic of business processes that are components of management activities. These business processes include the formation of data sets, the creation of products and/or the substantiation of a set of alternative solutions to problems in this area, and the collection and processing of data based on algorithms and techniques developed for specific types of requests within the framework of national security issues. In general, these business processes are a providing component of the decision-making process in the relevant area, which is responsible for the generation of input information necessary for the decision-makers (Fig. 2).

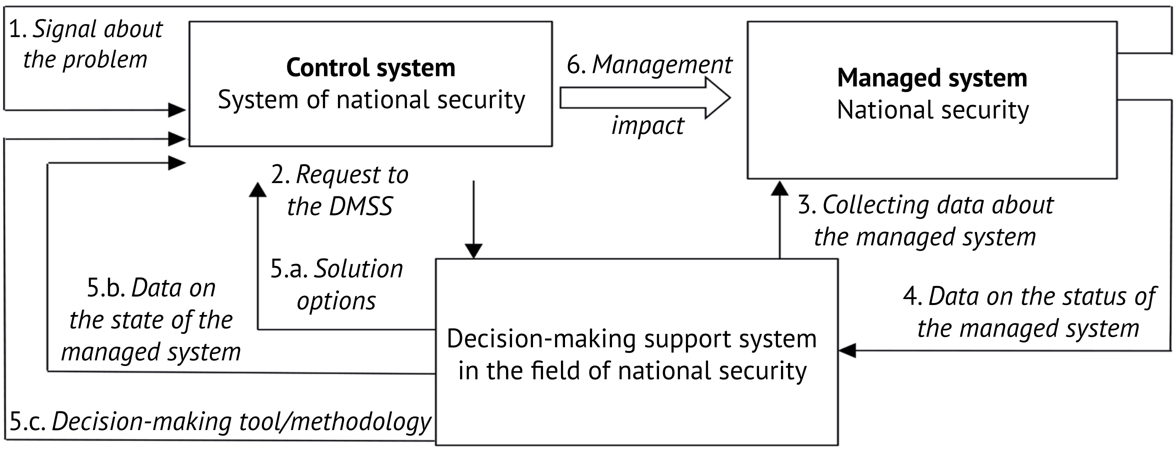

Figure 2*. National security decision-making scheme*
Source: *authors' own research*

The main functions that are performed within the framework of information support for decision-making in the field of national security include information collection (including substantiation of optimal sources, frequency of data collection, time interval, qualitative characteristics of data, etc.), processing the received data, creating a finished product or substantiating solutions to the problem (if necessary), transmitting a response to a request (Fig. 3).

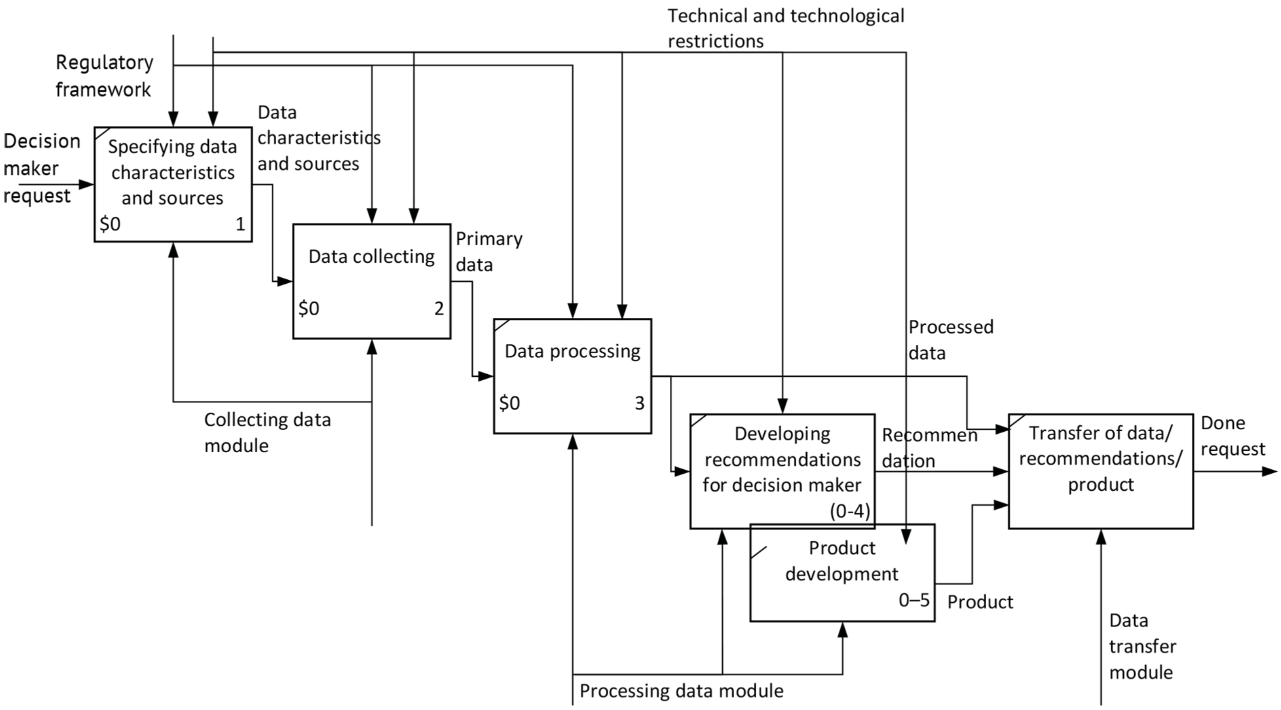

Figure 3. *Functional model of the national security decision-making support system*
Source: *authors' own research*

Requests for information required for decision-making involve the collection and processing of data necessary for solving a number of tasks within the framework of the establishment of food, socio-economic, and environmental safety (Fig. 4).

Considering the hierarchy of the system of state regulation and the development of national security, decision-making is based on the collection and processing of data within objects of various levels, in particular, the state, regional, and community levels. In addition, Ukraine is an actor of global space and, accordingly, an element of global security. That is why decision-making in the field of national security involves processing requests not only at the state (national, regional, community level), but also at the continental level (for example, at the European and global levels).

Methodological basis for information support of the process decision-making in the field of food, environmental and socio-economic components of national security. The national security decision-making support process is based on the following conceptual provisions:

1) at each point in time, there are two states of the object of management (i.e., the national security of the country at different levels of the hierarchy), namely: current/projected at a specific point in time $C(t)$ and target C^p states. Quantitatively, the state of the object takes the form of values of indicators of the country's security. Purposeful management influence on the control object becomes necessary if its current/predicted and target states do not coincide:

$$C(t) \neq C^p. \quad (1)$$

Usually, the situation (1) in the context of national security management of a country is caused by a radical change in external and/or internal conditions, accompanied by the emergence of additional threats to the country's security;

2) determination of the target state of the control object is based on a set of indicators of w_i national security $W(w_1, w_2, w_3, \dots, w_n, \dots, w_N)$ within the framework of food, socio-economic, and environmental security. The decision-making process involves finding a solution that would ensure the transition of the control object from the current state to the target (optimal) one by optimising factors $X(x_1, x_2, x_3, \dots, x_m, \dots, x_M)$ affecting the level of national security:

$$W(w_1, w_2, w_3, \dots, w_n, \dots, w_N, x_1, x_2, x_3, \dots, x_m, \dots, x_M) \underset{x}{\rightarrow} \max; \quad (2)$$

3) there are many limitations that should be considered in the process of substantiating optimal solutions. One of the main types of restrictions is resource restrictions:

$$R(r_1, r_2, r_3, \dots, r_l, \dots, r_L, x_1, x_2, x_3, \dots, x_m, \dots, x_M). \quad (3)$$

Hence, at a specific point in time t in the event of a mismatch of the current/predicted state $C(t)$ target C^p, the object of national security management should be transferred to the state of C_k^p ($C_k^p \in C^p$), which is optimal for a given time point t, subject to current restrictions R_k:

$$<C(t), C^p, C_k^p, R_k>; \quad (4)$$

4) within the framework of the decision-making support process in the field of national security, there are four basic stages of solving the decision-making problem.

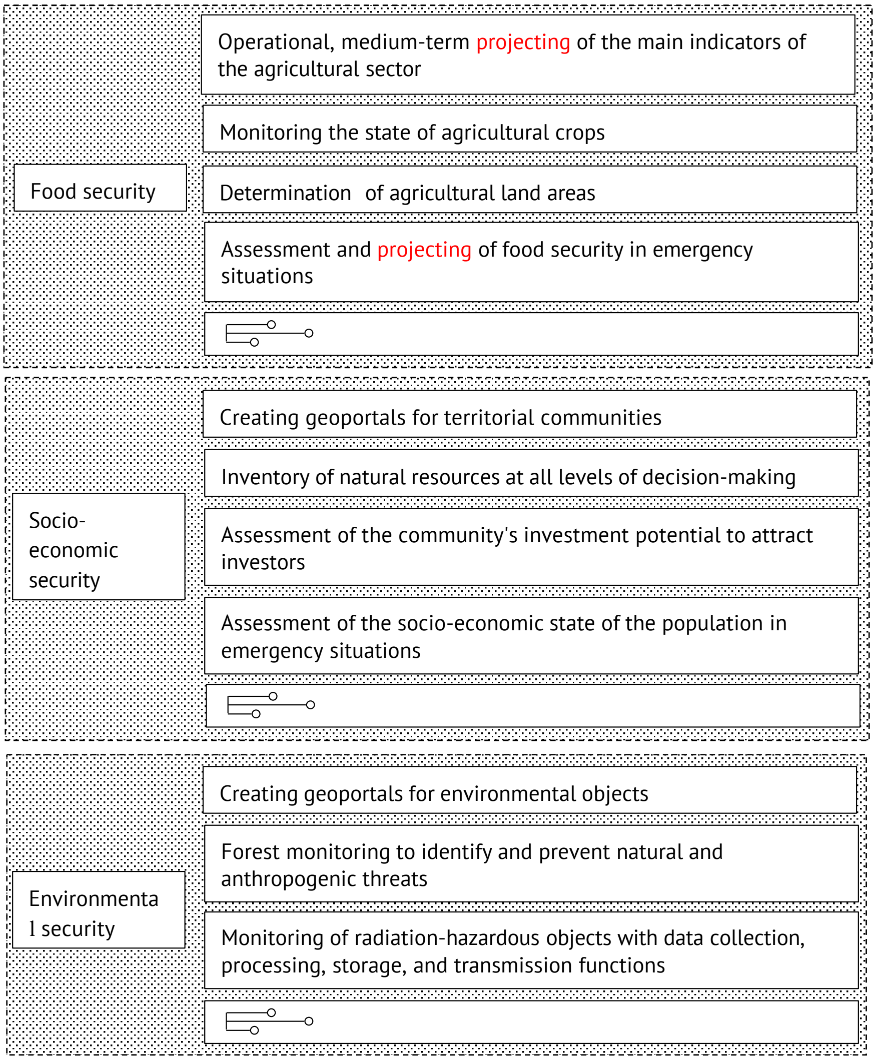

***Figure 4**. Functional model of the national security decision-making support system*
***Source:** authors' own research*

The first step is to identify the discrepancy between the current/predicted and target states of the control object. In other words, at this stage, it is necessary to compare the current/projected values of indicators of national security $W(w_1, w^2, w_3, \ldots, w_n, \ldots, w_N)$ with target users. In this case, the hypothesis $C(t) \subseteq C^p$ is tested.

The second stage involves determining the target state of the system C_k^p at a particular point in time t:

$$W_1(C_k^p) = \max W_1(C_i^p : \forall C_i^p \in C^p). \quad (5)$$

In a formalised form, the target state is displayed as an objective function (or a system of objective functions).

At the third stage, restrictions are defined $R_k \in R$, taking into account which measures will be taken to transfer the system from state $C(t)$ to state C_k^p:

$$W_2(R_k) = \max W_2(R_i : \forall R_i \in R). \quad (6)$$

At this stage, the system of restrictions is formalised.

The fourth stage involves determining the mechanisms for achieving the target state $M_k \in M$, the implementation of which would ensure the transition of the system from the current unsatisfactory state $C(t)$ to the target state C^p in the situation $<C(t), C^p, C_k^p, R_k>$:

$$W_3(M_k) = \max(M_i : \forall M_i \in M). \quad (7)$$

At the fifth stage, the subjects of decision-making substantiate and specify the methods, tools, and measures that need to be implemented to get out of the state of increased danger. In a formalised form, they take the form of values of unknown variables under previously defined objective functions and constraints.

Within the framework of information support for decision-making in the field of national security, first of all, tasks are solved within the first three stages. As for the fourth stage, it directly involves the decision-maker at the appropriate level of management.

The basis of the first stage of support for decision-making in the field of national security is the collection of data for detection of discrepancies between the current/predicted and target states of the control object. To ensure that the input data is as complete and relevant as possible, it should be collected from a wide range of sources to ensure maximum accuracy of the output results and efficiency of decision-making. In the field of analytical data processing and decision-making at all levels of the hierarchy of food, socio-economic, and environmental spheres, it is advisable to use the following data:

– *statistical information*. The advantage of using statistical data is a stable frequency of collection, a significant number of indicators, and data collection both at the state and regional levels, which allows generating large amounts of panel data;

– *geospatial* data which are characterised by maximum accuracy and objectivity. It is advisable to use such data in support of agricultural policy decisions in two ways. Firstly, to clarify data obtained from other sources. It concerns assessments of the level of food and socio-economic security (for example, arable land, agricultural land, plantings in the context of agricultural crops, forest stands, and other geographical features). Secondly, the accumulation of geospatial data is indispensable when it comes to collecting data that cannot be accumulated from other sources. This is especially important during military operations, when it is impossible to collect information within the temporarily occupied territories and/or territories where active military operations are taking place (Gorbulin, 2021).

After the termination of the preparation of statistical reports at the level of districts of administrative regions of Ukraine, it became almost impossible to form an array of operational data on the area of crops/plantings, which are an integral part of assessing and projecting the level of food security. An alternative source of collecting such data is the processing of satellite images and the creation of algorithms for classifying territories by culture;

– *sociometric survey data*. The practice of carrying out economic activities in the context of the COVID-19 pandemic and martial law has shown the existence of a high level of risk that business entities may be outside the physical access zone. Since the source of some statistical information can only be the results of sociometric surveys, it is extremely important to find and use software that is maximally adapted to the conditions of remote surveys. In addition, when choosing software, it is necessary to consider the simplicity of its application and the ability to identify spatial reference to the received data, which would allow indicating the location of the survey subject or any other object;

– *data from global, international, and domestic organisations and institutions*.

The algorithm of information support for decision-making in the field of national security of the country is shown in Figure 5.

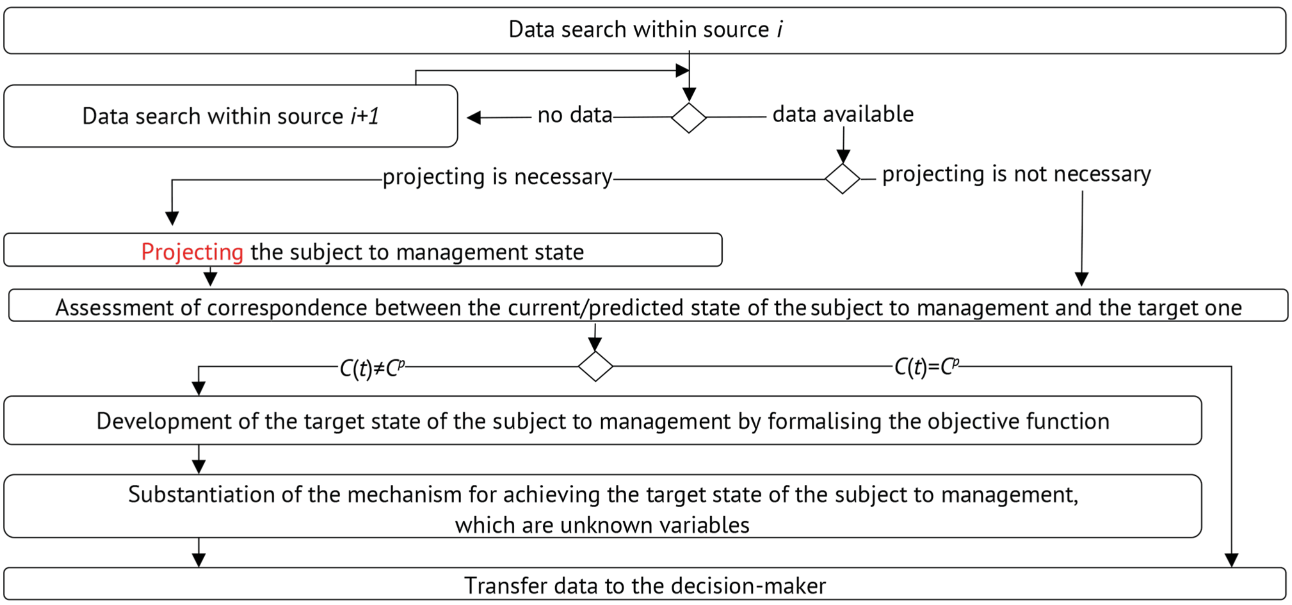

Figure 5. *Algorithm of information support for decision-making in the field of ensuring national security*
Source: *authors' own research*

Within the framework of the study of information support for decision-making in the field of national security of the country, the key role is played by the development and implementation of unified projecting methods, the use of which would allow identifying threats of crisis situations in advance and developing mechanisms for their prevention in advance. The relevant issues are investigated within the framework of the choice of methodological approaches to projecting indicators – indicators of the level of food security, for which the method of econometric modelling is used.

A system of information support for decision-making in the field of food, environmental, and socio-economic components of national security. The proposed methodological foundations of information decision-making support are implemented as part of the development of an information decision-making support system in the field of national security. The main principles of building and operating this system are as follows:

1) *openness*. The architecture and software part of the system are open, meaning that users can change them in accordance with external conditions. The implementation of this principle becomes more relevant in the face of new challenges, algorithms for responding to which were not previously developed. In 2020-2022, this principle of operation of the system ensured its prompt adaptation to meet requests for information support for decision-making in the context of a pandemic and war;

2) *flexibility*. The structure, functionality, methods, and tools of the system are adapted to the needs of decision-making entities in the field of national security and defence, restrictions, and environmental factors;

3) *efficiency*. The ability to meet requests for information for making operational decisions in the shortest possible time;

4) *cost-effectiveness*. The cost of creating, administering, and using the system cannot exceed the overall effects of using it. The effect should be understood as any positive effect from the application of the system (economic, environmental, social) in value terms. The effect can also be presented in the form of losses that were avoided as a result of the decision;

5) *purposefulness*. The purpose of the system is to form an information base for making adequate decisions in the field of national security. Any goal of the system should be based on a clearly formulated and quantifiable goal that will meet the request of decision-makers.

The decision-making support system in the field of national security consists of three modules, namely, modules for collecting, processing, and transmitting information that is necessary to substantiate decisions in the areas of food, socio-economic, and environmental security (Fig. 6). The function of the data collection module is to create queries on obtaining information, accumulating and storing data that is responsible for a previously defined and restricted request of the decision-making subject.

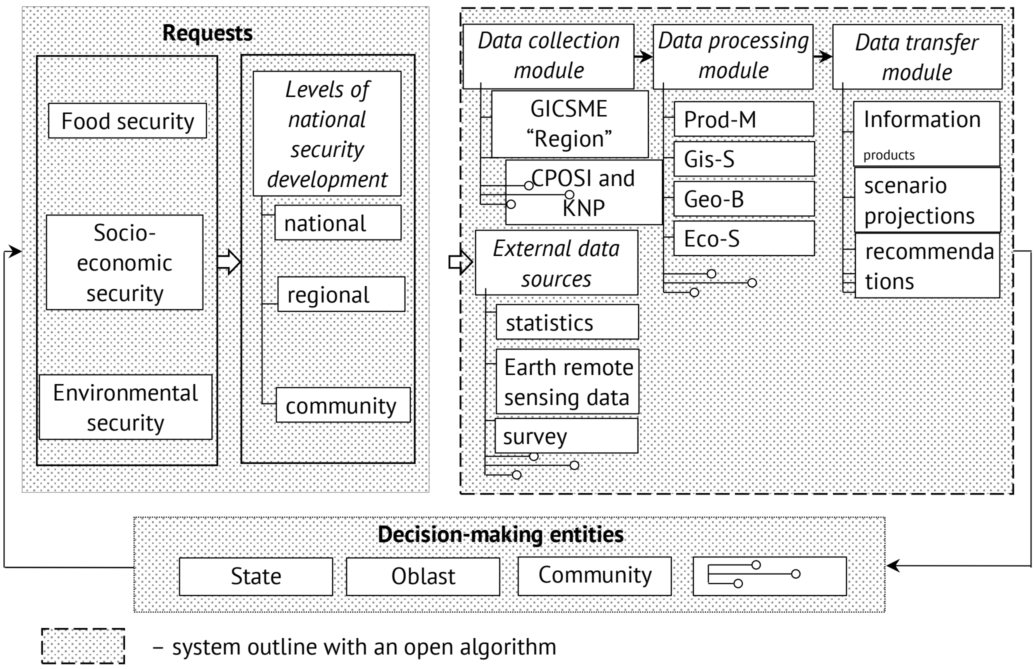

Figure 6. *Scheme of the decision-making support system in the field of national security formation*
Source: *authors' own research*

The main data sources from which the module accumulates information are the region subsystem (Ground Information Complex for Space Monitoring of the Earth, created by Polissya National University); Centre for receiving and processing special information and monitoring the navigation field, which is a branch of the National Centre for Vontrol and Testing of Space Assets of the State Space Agency of Ukraine (CPOSI and KNP); statistical data of Ukraine and international organisations; results of sociometric surveys collected with the involvement of automated information collection system Survey 123. At the same time, the list of sources is open. Figure 6 shows the functional model of the data collection module.

Subsystem GICSME "Region" and "CPOSI and KNP".

Analysis and modelling of the current security situation requires regular receipt and analysis of objective data on various components of the environment. Space-based remote sensing systems (remote sensing systems) are a source of up-to-date and reliable information that does not depend on possible distortions. The use of remote sensing data provides the following advantages: relevance of incoming information; high reliability of the information received; absence of restrictions related to state borders; high frequency of receiving information; coverage of large territories; obtaining information in a single standardised form; the ability to accumulate information and use it for projections and risk assessment.

Modern remote sensing systems have technical properties that allow solving a whole range of tasks – from mapping to analysing changes that have occurred in the study area. Using multi-time images allows tracking the dynamics of changes on the Earth's surface, identifying areas affected by human activity, predicting the consequences of emergencies, and many other tasks.

Obtaining remote sensing data in the system under consideration is provided by a complex consisting of a system of radio engineering, electronic computing, and software tools for receiving and processing data from remote sensing spacecraft in the L- and X- frequency bands. The use of the complex for its intended purpose is organised by preparing and conducting communication sessions with KA stations for receiving information. The information registered during the communication session is transmitted to the software and hardware complex of the remote sensing data archiving, display, and preprocessing system. For further use of remote sensing data, thematic data processing is carried out in accordance with the content of the problem being solved.

The main element of the region complex is the SNPI-8.2 ground information reception station, created by Polissya National University, which is the first Ukrainian university data reception station in the X-frequency range.

The data processing module operates on the basis of the subsystems "Prod-M", "Gis-S", "Geo-B", "Eco-S". Depending on requests for solution support, the system can be extended to other subsystems (Fig. 7). Similarly, the list of sources of data (now the main ones are satellite images, survey data, statistics) and ready-made results of the system's operation, which are transmitted to the subject of decision-making in the field of national security, remains open.

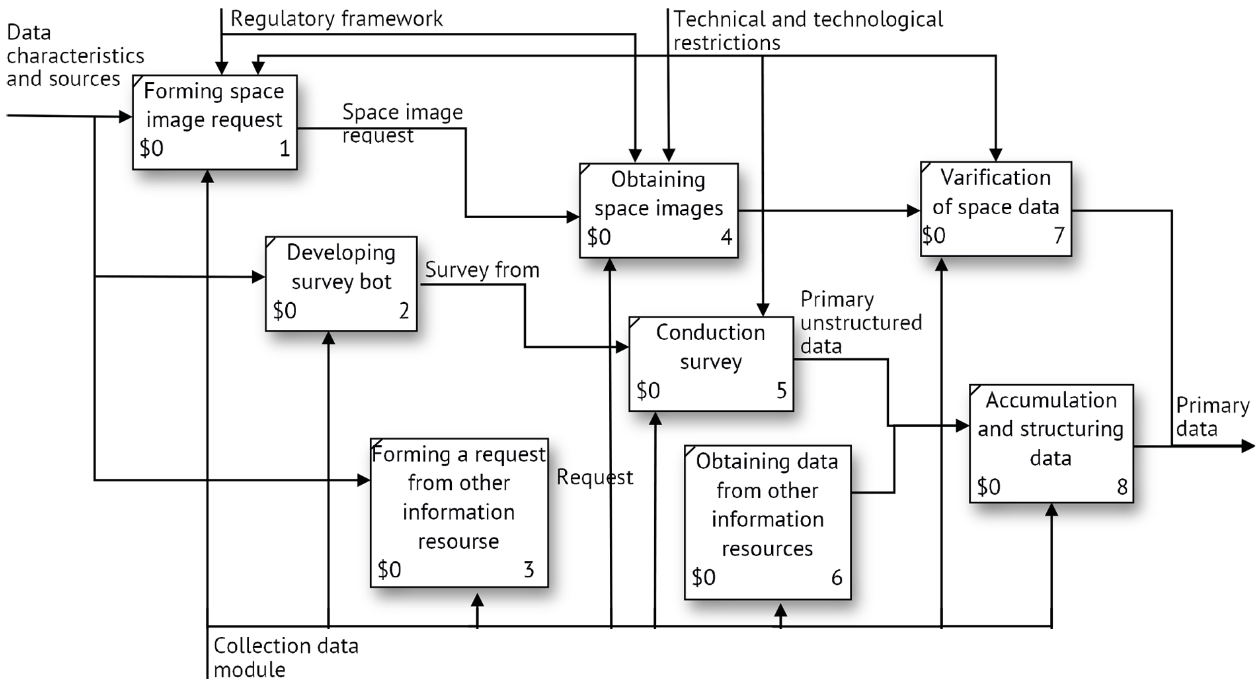

***Figure 7**. Functional model of the data obtaining module*

***Source:** authors' own research*

As of mid-2022, the subsystems of the data processing module are focused on providing users with satellite images, creating scenario projections, developing information systems based on geospatial data, and substantiating possible solutions (Fig. 8).

The "GIS-S" subsystem. The subsystem is designed to collect, transmit, process, analyse, and display spatial data in real time. It consists of hardware and software tools for geospatial support, in particular, geocoding of information (Survey 123, Insights, QuickCapture) –

accumulation of information on the server (ArcGIS Online) – processing, visualisation and transmission of information in a specialised software environment (ArcGIS Pro, ArcGIS Online).

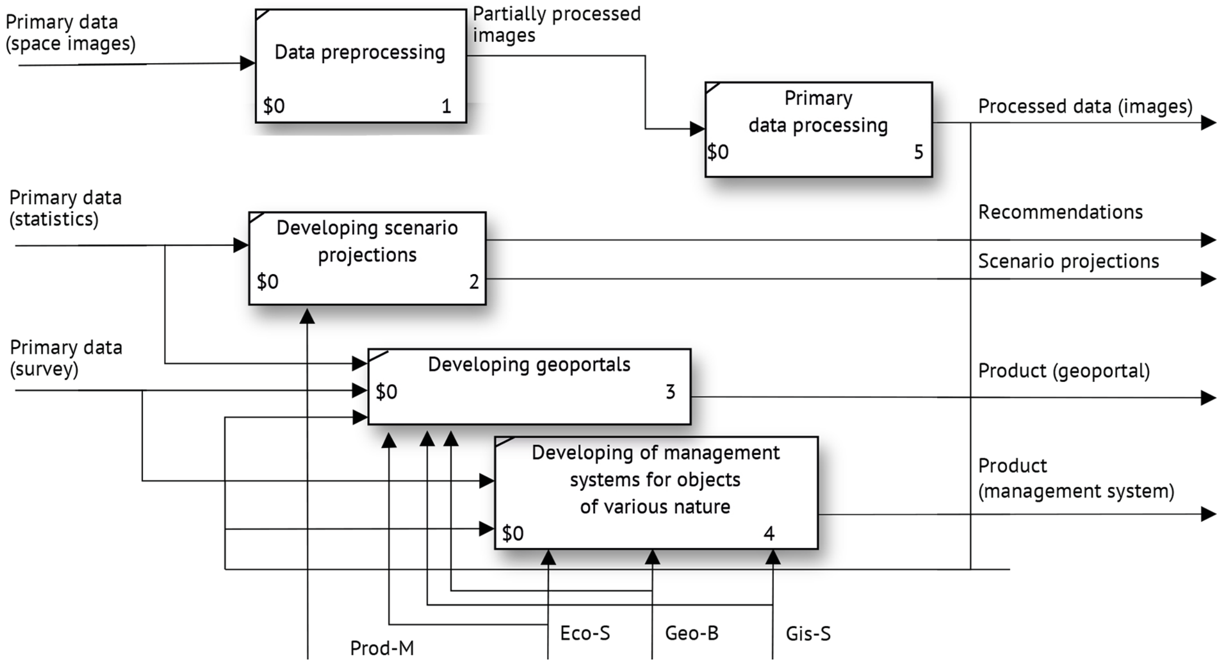

***Figure 8**. Functional model of the data processing module*

***Source:** authors' own research*

The "GEO-B" subsystem. The subsystem provides real time display of geospatial data about communities (in particular, the boundaries of communities and settlements, soil types, topographic basis, land structure, water bodies, roads, railways, power grids, gasification system, solid waste landfills, legal entities, individuals, population, medicine, gyms, and investment facilities). The main element of the subsystem is a geoportal, which is implemented using the ArcGIS Pro – Hub software environment application. Sources of filling in geospatial data databases at the level of the United territorial community can be: public cadastral map of Ukraine, Gosgeokadastr, OpenStreetMap, Natural Earth, UNEP Geodata, Global Administrative Areas, DIVA-GIS, Global Map, SEDAC, GeoNetwork, USGS Land Cover Institute.

The "ECO-S" subsystem. The subsystem is designed to collect, process, store and analyse information about the state of the natural environment, predict its changes and develop scientifically based recommendations for making effective management decisions at various levels. The software package of the subsystem provides the collection of in-kind data using the Survey 123 mobile application and satellite data, their accumulation on the ArcGIS Online server, processing, visualisation in the specialised ArcGIS Pro software environment and further transmission of information for making managerial decisions in environmental protection activities. The main types of information that circulate in the subsystem are remote sensing data, as well as data from field observations on the state of the main components of ecosystems and their changes under the influence of natural, biotic, and anthropogenic factors.

The "Prod-M" subsystem. The subsystem is designed to form an information base for supporting agricultural policy decision-making at the European, state, regional, and business entity levels. The initial parameters of the subsystem are short- and medium-term projections for the development of the agro-industrial sector of the country's economy. Software tools that provide input data processing by the "Prod-M" subsystem include information systems AGMEMOD and GAMS, R software environment, MS Excel.

Modelling of food security indicators of the country using the "Prod-M" module. One of the current problems of information support for making agricultural policy decisions in Ukraine is the lack of a unified methodology for scenario projecting of the development of the agricultural sector of the economy. Most of the relevant decisions are made based on the experience and intuition of officials. The key problem of this is that the agro-industrial sector of Ukraine is a complex open system, the components of which closely interact with each other and changes in one of them can lead to changes in all the others.

Therefore, when planning certain reforms in a particular sector of agriculture, it is necessary to be aware that they can lead to significant consequences in other sectors (including negative ones). This means that even if the changes affect only one sector, projections should be developed for all sectors. These needs are met by the AGMEMOD information system (platform) (Salamon *et al.*, 2019), which is currently widely used to generate medium-term projections for EU member states and their key partners, as well as to support agri-policy decision-making in the EU and EU-members. Every year, AGMEMOD databases and mathematical models are updated in accordance with socio-economic and market changes at the country level and for the EU as a whole.

The procedure for modelling the country's food security indicators includes three stages:

1) development of a system of econometric models of the dependence of each result indicator of food security on each factor. For the individual outcome indicator *y*, hypotheses are first developed based on the provisions of microeconomic theory, interviews and discussions with experts on a number of factors that may affect food security. After that, simple regression models (which show the dependence of the outcome variable *y* on each factor *x*) are developed. The requirement for the list of factor attributes is the availability of data on their values in the database of the *Prod-M* subsystem:

$$y=f(x)\forall x\in S, \quad (8)$$

where *S* – set of numeric values of the indicator in the database of *Prod-M* subsystem.

Since the AGMEMOD model is linear, if a nonlinear relationship is detected between the food security indicator and its factor, the linearisation procedure is an additional stage of modelling. The time for each individual change is checked for an autocorrelation effect. Each individual regression model is checked for statistical significance using a criterion *p-value* (*p*), and to fulfil the condition of the logical nature of the relationship between variables in accordance with the laws of microeconomics:

$$\text{if } p\leqslant 0.1 \text{ and } a_x>0 \ (\text{for } x\in\{K_{y_i}\}) \text{ or } a_x<0 \ (\text{for } x\in\{L_{y_i}\}), y_i\in Y \\ \text{else } f''(x)\in\{F^1\}-\text{TRUE}, \quad (9)$$

where a_x – regression coefficient (*slope*), which corresponds to the variable *x*; $f''(x)$ – one-factor econometric model; $\{F^1\}$ – set of one-factor econometric models of effective indicators of food security *y*; $\{K_{y_i}\}$ – set of factor features that, according to the laws of microeconomics, must be directly related to i-th effective feature *y*; $\{L_{y_i}\}$ – set of factor features that, according to the laws of microeconomics, should be inversely related to *i*-th effective feature y; *Y* – multiple effective indicators of food security;

2) development of preliminary econometric models of each individual performance indicator. If, as a result of preliminary econometric analysis, several factors that affect the result indicators are identified, then a multiple regression model is developed. Multiple regression models, like the previous stage, must meet the condition of statistical significance ($p\leqslant 0.1$) and the logic of the nature of the relationship between variables:

$$\text{if } p\leqslant 0.1 \text{ and } a_{x_j}>0 \ (\text{for } x_j\in\{K_{y_i}\}) \text{ or } a_{x_j}<0 \ (\text{for } x_j\in\{L_{y_i}\}), y_i\in Y \\ \text{else } f'(x)\in\{F'\}-\text{TRUE}, \quad (10)$$

where a_{x_j} – regression coefficient (slope) for j-th factor *x*; $f'(x)$ – preliminary econometric model that will be used to develop scenario projections; $\{F'\}$ – set of previous econometric models of resulting indicators *y* which will be used to develop scenario projections;

3) analysis and adjustment of multi-factor multiple models of indicators of food security. First of all, intercept of the model is adjusted (a_0). To do this, the forecast projected values of each individual indicator are determined based on the equations developed at the previous stage. If the actual value of the intercept in the current year significantly deviates from the value in the first year of forecasting, the coefficient a_0 is readjusted:

$$\text{if } |y(t\text{-}1)\text{-}y(t)|\geqslant \Delta\_\text{max} \\ \text{else } a_0=y(t\text{-}1)\pm\Delta \text{ and } f(x)\in\{F\}-\text{TRUE}, \quad (11)$$

where a_0 – intercept; *t* – first year of projecting; *f*(*x*) – adjusted econometric model that will be used to develop scenario projections {*F*} – set of adjusted econometric models of variable *y* which will be used to develop scenario projections; Δ – scientifically based/expert-determined possible increase/decrease in the result variable in the first year of projecting compared to its actual value in the last year of the time entered in the AGMEMOD database; Δ_{max} – the maximum deviation of the result variable in the first year of projecting compared to its actual value in the last year of the time series entered in the AGMEMOD database.

In general, tasks that are solved within the framework of the subsystem of information support for making agricultural policy decisions *"Prod-M"*, include:

1) development of medium-term projections of the main indicators of the agro-industrial sector of the Ukrainian economy under current conditions. To solve this problem, projections of balance sheets and prices of agro-industrial products for the next 10-30 years are developed at intervals of 1-2 years, reflecting the expected trends in their changes. As part of this task, the subsystem *"Prod-M"* identifies unfavourable trends, and the developed projections serve as an indicator of negative shifts and signal the need to form a new package of agricultural policy solutions;

2) projecting the consequences of each individual political decision. Results of the subsystem *"Prod-M"* within the framework of this task, have the form of projections for each type of agro-industrial products. If the goals of the relevant agricultural policy measure/reform are achieved, the subsystem determines the solution to be potentially effective;

3) operational short-term forecasting in conditions of turbulence and large-scale socio-economic and political shifts. Examples of situations where there was a need for the subsystem to perform *"Prod-M"* as part of

this task, there is a COVID-19 pandemic and the invasion of the russian federation on the territory of Ukraine. Both events have global implications not only for the country but also for the global economy and food security.

A distinctive feature of this study is that methodological approaches to information support are partially covered in research papers, for example, in (Liao, 2004; Lant, 2005; Xie, 2022) integrated into the unified national security decision-making support system with an open algorithm. The uniqueness of this study lies in the emphasis on procedures for collecting operational data in accordance with time-limited requests from decision-makers. It is proved that the timeliness and efficiency of incoming information for managing the country's food security requires the use of GIS. In particular, in contrast to the practice of using only official statistics (Haß, 2022; Jongeneel, 2022), in the process of creating unique scenarios for the development of the agricultural sector of the economy based on the AGMEMOD model (Salamon *et al.*, 2019) it is proposed to collect and process geospatial data (in particular, to determine the volume of crop stocks in grain storage facilities in Ukraine during the war). In the course of this study, it was found that the use of panel data, which was also successfully used in research, is quite reasonable for projecting the agricultural sector of Ukraine (Jongeneel, 2022; Corn, 2021).

Efficiency of information support of the decision-making process in the field of environmental safety is achieved by accessing the data of the software and hardware complex within the “Region” subsystem. In particular, the efficiency of obtaining and processing space survey data using the region subsystem allows quickly (45 min.) identifying the sources and location of forest fires, which is faster than in similar Chinese ones (Liiew, 2019) (100 min.) and open American (3 hours.) (Çolak & Sunar, 2020) systems.

Consequently, it was found that the efficiency of decision-making in the field of ensuring food, socio-economic, and environmental safety is based on the ability to provide timely decision-making entities with the necessary information.

CONCLUSIONS

The study has established that in this context, the determining factor is the development of an information support system that would minimise the time of transmitting a request for data and their accumulation and processing, and ensure maximum compliance of the transmitted data with the request. Along with statistical data, GIS plays a special role in providing information in a short time, which is actively used for rapid accumulation and thorough processing of geospatial data.

In addition, it is extremely important to formalise the decision-making process in the event of an urgent need to solve problems related to threats to national security. This would allow adhering to a clear algorithm of actions in case of an immediate response to danger. Considering the above, decision-making in the field of ensuring food, socio-economic, and environmental security should include the following stages: identifying discrepancies between the current/projected and target states of the management object; determining the target state of the system at a given time; formalising restrictions; determining mechanisms for achieving the target state; clarifying methods, tools, and measures that need to be implemented to get out of the state of increased danger.

Time constraints, lack of necessary data, and the need to form scenario projections of key safety indicators are characteristic features of information support in the field of ensuring food, socio-economic, and environmental security of the country. The development and implementation of the information decision-making support system proposed in the study would allow partially automating the processes of collection, processing, and transmission of information, considering these features, and forming and replenishing the information base for making adequate decisions in the field of national security. A separate element of the developed system is the data processing module, which integrates modern methods of modelling and projecting indicators of food, socio-economic, and environmental safety. In the future, it is promising to conduct research on automating data collection and improving their security within the proposed system

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CONFLICT OF INTEREST

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Методичні засади інформаційної підтримки прийняття рішень у сфері продовольчої, екологічної та соціально-економічної складових національної безпеки

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Анотація. Негативний вплив стратегічних загроз розвитку держави в контексті формування її національної безпеки, зокрема продовольчої, екологічної та соціально-економічної складових, активізувався в умовах реалізації геополітичних викликів України. Особливо гостро це питання постало в результаті відкритої військової агресії, що зумовлює необхідність формування та імплементації системи інформаційної підтримки прийняття рішень у сфері національної безпеки України. Відтак, метою роботи є обґрунтування методичних засад інформаційної підтримки прийняття рішень у сфері національної безпеки України та їх реалізація у межах створеної системи, що передбачає збір інформації, зокрема, із використанням космічних та геоінформаційних систем, а також застосуванням методів математичного моделювання і ситуаційного аналізу для обробки даних. У процесі дослідження використано методи економетричного моделювання, структурно-функціонального моделювання та просторового аналізу. Було розроблено методологічні засади щодо підтримки прийняття рішень для вирішення проблем продовольчої, екологічної, соціально-економічної складових національної безпеки. Побудовано функціональну модель та алгоритм процесу прийняття рішень у сфері національної безпеки і, на основі отриманих результатів, розроблено систему прийняття рішень у сфері продовольчої, екологічної та соціально-економічної безпеки. Крім того, у дослідженні формалізовано концептуальні положення процесу підтримки прийняття рішень у сфері національної безпеки; запропоновано процедуру моделювання показників продовольчої безпеки країни. На основі запропоновано методичного підходу визначено, на скільки зменшилась площа посівів у зв'язку із тимчасовою окупацією, військовими діями та післявоєнним станом полів (мінування, знищення посівів, техніки тощо), що дало змогу сформувати вхідні дані для подальшого прогнозування показників розвитку аграрного сектора та продовольчої безпеки України, ЄС та світу. Запропоновані методологічні положення, алгоритми, моделі, а також розроблена система можуть бути використані органами державної влади для прийняття управлінських рішень щодо формування політики у сферах забезпечення продовольчої, екологічної, соціально-економічної безпеки країни

Ключові слова: інформаційне забезпечення; функціональне моделювання; економетрична модель; інформаційна система; управлінське рішення; дистанційне зондування Землі