MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
TARAS SHEVCHENKO NATIONAL UNIVERSITY OF KYIV

Qualification scientific work on manuscript rights

CHUNMEI JI

UDC 004.58+378

PHD THESIS

MODELS AND METHODS FOR SUPPORTING DECISION-MAKING IN THE ACTIVITIES OF THE AGRICULTURAL SECTOR UNDER ENVIRONMENTAL UNCERTAINTY

122 Computer science
12 Information Technology

Applying for the Doctor of Philosophy degree

The PhD Thesis contains the results of own research. The use of ideas, results and texts of other authors are linked to the corresponding source

______________ Chunmei Ji

Supervisor – **Oleksandr Kuchanskyi**, Doctor of Technical Science, Professor

KYIV – 2023

SUMMARY

Chunmei Ji. Models and methods for supporting decision-making in the activities of the agricultural sector under environmental uncertainty. – *Qualifying scientific work as a manuscript.*

Thesis for the Doctor of Philosophy Degree in Specialty 122 «Computer science». – Taras Shevchenko National University of Kyiv, Kyiv, 2023.

Abstract. The dissertation is dedicated to developing models and methods necessary for the functioning of an agrarian enterprise's decision support information system, considering the conditions of environmental uncertainty.

In the modern world, the agricultural sector faces numerous challenges that require effective decision-making. Scientific research in the support field is focused on developing models and tools that facilitate the adaptation of agricultural enterprises to changing conditions and optimize their operations. Contemporary research emphasizes information technologies for analyzing large volumes of data on weather conditions, soil state, and other environmental factors. These technologies allow for predicting changes in the environment and adapting to them quickly, which is critically important for ensuring the stability and efficiency of agricultural activities. Modern decision support systems in the agricultural sector integrate forecasting, planning, resource management, and risk management. They use advanced analytical models to assess the impact of climate change, economic situations, and market trends on agricultural production. Such systems help farmers and agricultural companies determine the optimal timelines for sowing and harvesting, choose the most suitable agricultural crops and treatment options, and predict and minimize risks associated with environmental changes.

This work addresses the important task of developing mathematical models and methods for forming strategies of activity and supporting the making of optimal decisions by an agrarian enterprise, considering the incompleteness and fuzziness of data caused by the uncertainty of environmental conditions (scientific component), as

well as the development of a decision support information system in the agricultural sector, especially in conditions of environmental uncertainty, which allows for the automation of decision-making and the prediction and minimization of risks associated with environmental changes (practical component).

The research object is the decision-making process in the agricultural field under environmental uncertainty.

The research subject is models and methods of decision support considering factors of environmental uncertainty.

Research methods. The conducted research is based on decision-making methods, risk management, fuzzy set theory, optimization theory, artificial intelligence methods, object-oriented programming.

The goal of the research is to increase the efficiency of an agricultural enterprise's operations through the adoption of scientifically based decisions, taking into account factors of environmental uncertainty.

Scientific novelty of the obtained results:

- *For the first time*, a decision-making model for an agricultural enterprise has been developed as a managed multi-stage process, taking into account fuzzy input parameters. This will enhance the efficiency of the agricultural enterprise's operations, considering factors of environmental uncertainty.
- The model of an agricultural enterprise's activities *has been improved* in terms of increasing the yield of agricultural crops under conditions of environmental uncertainty. The proposed model, unlike existing ones, is a combined model, which allows for the consideration of more factors of environmental uncertainty and provides a broader coverage of the connections between these factors.
- The fuzzy hierarchical model for minimizing risks in the activities of an agricultural enterprise *has been improved*. Unlike other models, this one proposes solutions for a unified assessment of individual types of risks and the integral risk in the activities of an agricultural enterprise. This allows for a more accurate

assessment of the risks of each process in the activities of the agricultural enterprise and a more effective response to them.

The first chapter of the dissertation contains an analysis of existing theoretical and practical research on modern decision-making models in managing agrarian enterprises. Through the prism of international experience, the necessity of implementing information technologies in the management process of agrarian enterprises is shown. The approach to considering the system of agrarian production – external environment is proposed. The main factors of mutual influence are identified. As a result of the analysis, it was established that risk management in the agricultural sphere should be considered as an integral part of managing the activities of an agricultural enterprise. The review of known multicriteria decision-making methods shows their potential application for the task of managing an agrarian enterprise.

In the second chapter, the task of decision-making is formalized as a multicriteria conditional optimization problem. According to this model, the structure of the decision support information system is proposed. A conceptual model of developing a decision support information system in conditions of environmental uncertainty has been developed, which includes four components: goal setting, principles, functional components, and diagnostic component. A mathematical model has been developed that takes into account the uncertainty in decision-making caused by environmental and economic factors. Two mathematical models of the decision-making task in conditions of uncertainty based on multicriteria optimization and risk minimization are proposed. Approaches for assessing the efficiency of economic decisions are described.

In the third chapter, decision-making in the agricultural field is considered as a optimization problem for a controlled multi-stage project managment. A model of decision-making of an agrarian enterprise based on multicriteria conditional optimization has been developed. An analysis was carried out, and 20 factors necessary for decision-making were identified. To consider the conditions of environmental uncertainty, 7 parameters of the decision-making model of an agrarian enterprise based on multicriteria conditional optimization are proposed to be considered as fuzzy input parameters. The use of fuzzy variables with a bell-shaped membership function is justified for determining these parameters. The use of statistical parameters of historically collected data for determining the parameters of membership functions for fuzzy variables is proposed. The fuzzy hierarchical model of risk minimization in the activity of an agrarian enterprise has been improved. This model proposes methods for a unified assessment of individual types of risks within each process and the integral risk of the entire enterprise activity. It is proposed to describe risk factors as fuzzy variables. The use of linguistic variables is proposed for describing risk factors for which there is insufficient historical data, or there are expert assessments. A method of their fuzzification is proposed, based on representing them as fuzzy numbers with a trapezoidal membership function. 4 groups of risks are identified, allowing the model to take into account more factors. The Mamdani procedure for obtaining fuzzy logical output and defuzzification of the integral risk assessment is considered. I

In the fourth chapter, the implementation of a decision support information system in the agricultural sector under conditions of environmental uncertainty is presented. The requirements for the technical and software needed to implement the decision support information system are considered, and the algorithms for implementing a fuzzy hierarchical model for minimizing risks in the activities of an agricultural enterprise and a decision-making model for an agricultural enterprise based on multi-criteria conditional optimization are described.

Practical significance of the obtained results. The main scientific positions of the dissertation have been brought to the level of methodological generalizations and applied tools, allowing for the support of decision-making in the activities of enterprises in the agricultural sphere. The decision support information system of an agrarian enterprise in conditions of environmental uncertainty was validated using simulation modeling methods. For validation, data on weather conditions in China from the China Meteorological Data Service Centre were used, as well as data on the yield of wheat, rice, and corn in the Yancheng region, which belongs to the middle-

lower plain of the Yangtze. To model the impact on yield, an economic-climatic model based on the Cobb-Douglas production function was used. The consideration of 3 classes of scenarios showed that they can worsen the results of the activity of an agrarian enterprise from 4.31% to 18.57%. The use of the decision support information system allows mitigating the negative impact of scenarios to 0.98%. The analysis of the results shows the validity of the fuzzy model of decision-making of an agrarian enterprise in conditions of environmental uncertainty.

The main provisions and results of the research have been implemented and applied in the activities of Yancheng Polytechnic College

Keywords: agricultural sector, environmental uncertainty, project management, project planning, decision-making, risk management, hierarchical model, fuzzy logic, optimization, linear optimization.

LIST OF PUBLICATIONS OF THE APPLICANT BY PHD THESIS TOPIC

Articles in professional publications of Ukraine (included in the list of the Ministry of Education and Science of Ukraine)

1. **Ji, C.,** & Andrashko, Y. V. (2019). Conceptual model of information system for supporting decision making in the agrarian sphere. Scientific Bulletin of Uzhhorod University. Series of Mathematics and Informatics, 2(35), 156–161. https://doi.org/10.24144/2616-7700.2019.2(35).156-161 [category «B»]
2. **Ji, C.** (2019). Management of the activity of agrarian enterprises for accounting risk management and multicriteria decision making, 38, 151–155, https://doi.org/10.6084/m9.figshare.9788633 . [category «B»]
3. **Ji, C.** (2019). Decision making in agricultural sector in view of the environment. Management of development of complex systems, 37, 160–163, https://doi.org/10.6084/m9.figshare.9783224 . [category «B»]

4. **Ji, C.** (2022). Risk management for the functionality component of an agricultural enterprise's decision-making support information system. Management of Development of Complex Systems, (52), 35–38. https://doi.org/10.32347/2412-9933.2022.52.35-38 [category «B»]

Articles in professional publications of Ukraine (not included in the list of the Ministry of Education and Science of Ukraine)

5. **Ji, C.** (2020). formation of requirements for the information system of environmental monitoring. Science Journal Innovation Technologies Transfer, 4, 31-34. https://doi.org/10.36381/iamsti.4.2020.31-34.

Approbation works:

6. **Ji, C.** (November 20-21, 2018). Decision making in the activities of agrarian enterprises. V *International Scientific and Practical Conference "Information Technologies and Interactions" (IT&I-2018),* Kyiv, Ukraine, 56

7. **Ji, C.** (2019). View on the problem of decision-making in the agaricultural sector as a risk management task. *I International Scientific and Practical Conference (IMTCK2019)*, Chernivtsi, Ukraine, 7.

8. **Ji, C.** (December 20, 2019). Development of the information system for supporting decision making in the agrarian sphere. *VI International Scientific and Practical Conference "Information Technologies and Interactions" (IT&I-2019)*, Kyiv, Ukraine, 95-96.

9. **Цзі, Ч.** (March 25-26 2020). Формування вимог до інформаційної системи підтримки прийняття рішень в умовах екологічної невизначеності. *Seventh international scientific practical conference «Management of the development of technologies»*, Kyiv, Ukraine, 135-136.

10. **Ji, C.** (2021). The impact of environmental factors on the decision making in agriculture. Information Technology and Implementation (IT&I-2021), 16-17.

11. **Ji, C.,** Andrashko, Y., Biloshchytska, S. & Tsiutsiura, S. (2021). Conceptual Research Model of Developing the Decision Support System for Agriculture Under Uncertainty, *2021 IEEE International Conference on Smart Information Systems and Technologies (SIST)*, Nur-Sultan, Kazakhstan, 1-5, doi: 10.1109/SIST50301.2021.9465888**.** [abstracts **Scopus, Web of Science**]

АНОТАЦІЯ

Чуньмей Цзі. Моделі та методи підтримки прийняття рішень у аграрному секторі в умовах екологічної невизначеності. – *Кваліфікаційна наукова праця на правах рукопису.*

Дисертація на здобуття наукового ступеня доктора філософії за спеціальністю 122 «Комп’ютерні науки». – Київський національний університет імені Тараса Шевченка, Київ, 2023.

Зміст анотації. Дисертація присвячена побудові моделей і методів для забезпечення підтримки прийняття рішень у діяльності аграрного підприємства в умовах екологічної невизначеності.

У сучасному світі аграрний сектор зіштовхується з численними викликами, що вимагає ефективного прийняття рішень. Наукові дослідження у сфері підтримки прийняття рішень спрямовані на розробку моделей та інструментів, які сприяють адаптації аграрних підприємств до змінних умов та дозволяють оптимізувати їхню діяльність. Сучасні дослідження акцентують увагу на використанні інформаційних технологій для аналізу великих обсягів даних про погодні умови, стан ґрунту та інші екологічні фактори. Ці технології дозволяють передбачати зміни у навколишньому середовищі та швидко адаптуватися до них, що є критично важливим для забезпечення стабільності та ефективності аграрної діяльності. Сучасні системи підтримки прийняття рішень у аграрному секторі інтегрують прогнозування, планування, управління ресурсами та ризиками. Вони використовують передові аналітичні моделі для оцінювання впливу змін

клімату, економічної ситуації та ринкових тенденцій на аграрне виробництво. Такі системи допомагають фермерам і аграрним компаніям визначати оптимальні часові рамки для посіву та збору врожаю, вибирати найбільш підходящі сільськогосподарські культури та варіанти їх обробки, а також прогнозувати і мінімізувати ризики, пов'язані з екологічними змінами.

В даній роботі вирішується важливе завдання, а саме: розроблення математичних моделей та методів для формування стратегій діяльності та підтримки прийняття оптимальних рішень аграрним підприємством з урахуванням неповноти та нечіткості даних, яка спричинена невизначеністю екологічних умов (наукова складова), а також розроблення інформаційної системи підтримки прийняття рішень в аграрному секторі, особливо в умовах екологічної невизначеності, що дозволяє автоматизувати прийняття рішень, а також прогнозувати і мінімізувати ризики, пов'язані з екологічними змінами (практична складова). Все це важливо для управління програмами та змінами в діяльності аграрного підприємства.

Об’єктом дослідження є процес прийняття рішень в аграрній сфері в умовах екологічної невизначеності.

Предметом дослідження є моделі і методи підтримки прийняття рішень з урахуванням факторів екологічної невизначеності.

Методи дослідження. Проведені дослідження базуються на методах прийняття рішень, управління ризиками, теорії нечітких множин, теорії оптимізації, методах штучного інтелекту, об'єктно-орієнтованого програмування.

Метою дослідження є розробка моделей і методів підтримки прийняття рішень для підвищення ефективності функціонування аграрного підприємства з урахуванням факторів екологічної невизначеності.

Наукова новизна отриманих результатів :

- *Вперше* розроблено модель прийняття рішень аграрного підприємства як керованого багатоетапного процесу з врахуванням нечітких вхідних параметрів, що дозволить підвищити ефективності функціонування аграрного підприємства з урахуванням факторів екологічної невизначеності.

- *Удосконалено* модель діяльності аграрного підприємства в частині підвищення урожайності сільськогосподарських культур в умовах екологічної невизначеності. Запропонована модель, на відміну від існуючих, є комбінованою, що дає змогу врахувати більше факторів екологічної невизначеності та забезпечує більш широке охоплення зв'язків між цими факторами.

- *Удосконалено* нечітку ієрархічну модель мінімізації ризиків в діяльності аграрного підприємства. Дана модель, на відміну від інших, пропонує рішення для уніфікованої оцінки окремих видів ризиків та інтегрального ризику в діяльності аграрного підприємства. Це дає змогу точніше оцінювати ризики кожного процесу в діяльності аграрного підприємства та більш ефективно реагувати на них.

Перший розділ дисертації містить аналіз існуючих теоретичних та практичних досліджень моделей прийняття рішень при управлінні аграрними підприємствами. Крізь призму міжнародного досвіду показано необхідність впровадження інформаційних технологій в процес управління аграрними підприємствами.

Запропоновано підхід до розгляду системи «аграрне виробництво – зовнішнє середовище», виділено основні фактори взаємного впливу.

В результаті аналізу встановлено, що менеджмент ризиків в аграрній сфері необхідно розглядати як невід'ємну складову частину управління діяльністю сільськогосподарського підприємства. Огляд відомих багатокритеріальних методів прийняття рішень показано можливість їх застосування для задачі управління аграрним підприємством.

В другому розділі здійснено формалізацію задачі прийняття рішень як багатокритеріальної задачі умовної оптимізації. Відповідно до цієї моделі запропоновано структуру інформаційної системи підтримки прийняття рішень.

Побудовано концептуальну модель інформаційної системи прийняття рішень в умовах екологічної невизначеності, яка включає компоненти: цілепокладання принципів, функціональний компоненти та компонент діагностики.

Розроблено математичну модель, що враховує невизначеність при прийнятті рішень, спричинену екологічними та економічними факторами. Запропоновано дві математичні моделі опису задачі прийняття рішень в умовах невизначеності на основі багатокритеріальної оптимізації та мінімізації ризиків. Описано підходи щодо оцінювання ефективності господарських рішень.

В третьому розділі розглянуто прийняття рішень в аграрній сфері як задачу оптимізації керованого багатоетапного процесу управління проєктами. Розроблено модель прийняття рішень аграрного підприємства на основі багатокритеріальної умовної оптимізації. Проведено аналіз та визначено двадцять факторів необхідних для прийняття рішень. Для врахуванням умов екологічної невизначеності запропоновано сім параметрів моделі прийняття рішень аграрного підприємства на основі багатокритеріальної умовної оптимізації з нечіткими вхідними параметрами.

Обґрунтовано використання для визначення цих параметрів нечітких змінних із дзвіноподібною функцією належності. Запропоновано використовувати статистичні параметри історично зібраних даних для визначення параметрів функцій належності для нечітких змінних.

Удосконалена нечітка ієрархічна модель мінімізації ризиків в діяльності аграрного підприємства. Дана модель, пропонує методи для уніфікованої оцінки окремих видів ризику в рамках кожного процесу та інтегрального ризику всієї діяльності підприємства. Пропонуються фактори ризику описувати як нечіткі змінні. Запропоновано використання лінгвістичних змінних для опису факторів ризику, для яких відомо недостатньо історичних даних, або є експертні оцінки. Запропоновано метод їх фазифікації, на основі представлення їх нечіткими числами із трапецевмдною функцією належності. Визначено чотири групи ризиків, що дозволяє моделі врахувати більше факторів.

Розглянуто процедуру Мамдані для отримання нечіткого логічного виводу та дефазифікації інтегральної оцінки ризику.

В четвертому розділі наведено реалізацію інформаційної системи підтримки прийняття рішень у аграрному секторі в умовах екологічної невизначеності. Розглянуто вимоги до технічного та програмного забезпечення, яке необхідно для реалізації інформаційної системи підтримки прийняття рішень та описано алгоритми реалізації нечіткої ієрархічної моделі мінімізації ризиків в діяльності аграрного підприємства та модель прийняття рішень аграрного підприємства на основі багатокритеріальної умовної оптимізації.

Практичне значення одержаних результатів. Основні наукові положення дисертації доведені до рівня методичних узагальнень і прикладного інструментарію, що дає змогу здійснювати підтримку прийняття рішень діяльності підприємств в аграрній сфері, а також управління проєктами та програмами в діяльності аграрних підприємств.

Інформаційну систему підтримки прийняття рішень аграрного підприємства в умовах екологічної невизначеності валідовано методами імітаційного моделювання. Для валідації використано дані погодних умов в КНР із сервісу China Meteorological Data Service Centre, також використано дані про урожайність пшениці, рису та кукурудзи в регіоні Янченг, який належить до регіону середньо-нижньої рівнини Янцзи. Для моделювання впливу на урожайність застосовано економіко-кліматичну модель на основі функції виробництва Кобба-Дугласа. Розгляд 3 класів сценаріїв показав, що вони можуть погіршити результати діяльності аграрного підприємства від 4,31% до 18,57%. Застосування інформаційної системи для підтримки прийняття рішень дає змогу нівелювати негативний вплив сценаріїв до 0,98%. Аналіз результатів показує валідність нечіткої моделі прийняття рішень аграрного підприємства в умовах екологічної невизначеності.

Основні положення та результати дослідження впроваджено та застосовано в діяльності Yancheng Polytechnic College.

Ключові слова: аграрне підприємство, екологічна невизначеність, управління проєктами, планування проєктів прийняття рішень, управління ризиками, ієрахічна модель, нечітка логіка, теорія оптимізації, лінійна оптимізація.

CONTENT

INTRODUCTION

In the modern world, the agricultural sector faces numerous challenges that require effective decision-making. Scientific research in the field of support is aimed at developing models and tools that facilitate the adaptation of agrarian enterprises to changing conditions and optimize their activities. Contemporary studies emphasize the use of information technologies for analyzing large volumes of data about weather conditions, soil state, and other environmental factors. These technologies enable predictions of changes in the environment and rapid adaptation to them, which is critically important for ensuring the stability and efficiency of agricultural activities. Modern decision support systems in the agricultural sector integrate forecasting, planning, resource management, and risk management. They utilize advanced analytical models to evaluate the impact of climate changes, economic situations, and market trends on agricultural production. These systems assist farmers and agricultural companies in determining optimal timelines for planting and harvesting, selecting the most suitable agricultural crops and treatment options, and predicting and minimizing risks associated with environmental changes.

The dissertation work was carried out in accordance with the research plan of Taras Shevchenko National University of Kyiv within the framework of the topic: 'Information technologies for analysis and forecasting of processes invariant to the subject area', No. 0123U101621, scientific supervisor Paliy S.V. The applicant conducted data collection and processing.

The development of decision support systems (DSS) in the agricultural sector is a key element of effective management in the context of increasing complexity and unpredictability of agricultural production. Modern technologies, such as artificial intelligence, machine learning, and big data, play a significant role in enhancing DSS, allowing agrarians to optimize processes, minimize costs, and increase yields.

However, the scientific community and practitioners face a number of unresolved issues in this field. The issue of environmental uncertainty, especially in the context of global climate changes, is particularly acute. This includes challenges in predicting weather conditions, adapting to extreme climatic events, like droughts and floods, and managing resources in a changing climate.

Considering environmental uncertainties in the agricultural sector requires the development of more flexible and adaptive DSS, capable of quickly responding to changing conditions and ensuring accurate decision-making based on current data. This means integrating big data from various sources, including satellite data, field sensors, and weather stations, to create a comprehensive real-time situation picture.

A key unresolved issue is creating effective mechanisms for processing and analyzing fuzzy data related to environmental parameters. Such data often contain significant uncertainty, complicating accurate forecasting and analytics. Developing machine learning algorithms and artificial intelligence capable of efficiently working with fuzzy data is an urgent need in this field.

There is also a need to enhance the resilience of agricultural systems to climate changes by integrating models of environmental sustainability into DSS. This includes considering long-term environmental trends and impacts, as well as developing strategies capable of adapting to changing conditions.

In summary, the development of DSS in the agricultural sector is an important direction that requires further research and innovation for effective resolution of problems related to environmental uncertainty and climate changes.

This work addresses the important task of developing mathematical models and methods for forming strategies of activities and supporting the making of optimal decisions by an agrarian enterprise, considering the incompleteness and fuzziness of data caused by the uncertainty of environmental conditions (scientific component), as well as the development of a decision support information system in the agricultural sector, especially in conditions of environmental uncertainty, which allows for automating decision-making and predicting and minimizing risks associated with environmental changes (practical component).

The research object is the decision-making process in the agricultural field under environmental uncertainty.

The research subject is models and methods of decision support considering factors of environmental uncertainty.

The goal of the research is to increase the efficiency of an agricultural enterprise's operations through the adoption of scientifically based decisions, taking into account factors of environmental uncertainty.

To achieve the goal, the following tasks must be solved:

1. Analyze the general theoretical foundations of decision-making in the agricultural sphere and factors influencing the choice of DSS in the context of environmental factors.
2. Build a conceptual model of research for developing a decision support information system in conditions of environmental uncertainty.
3. Develop models for decision-making by an agrarian enterprise using conditional multicriteria optimization.
4. Develop models for risk minimization in the activity of an agrarian enterprise.
5. Improve models for evaluating the efficiency of economic decisions.
6. Implement a decision support information system for an agrarian enterprise, considering factors of environmental uncertainty.
7. Validate the developed models and methods using the information system through simulation modeling.

The scientific novelty of the obtained results includes:

- For the first time, a decision-making model for an agricultural enterprise has been developed as a managed multi-stage process, taking into account fuzzy input parameters. This will enhance the efficiency of the agricultural enterprise's operations, considering factors of environmental uncertainty.
- The model of an agricultural enterprise's activities has been improved in terms of increasing the yield of agricultural crops under conditions of environmental uncertainty. The proposed model, unlike existing ones, is a combined model, which

allows for the consideration of more factors of environmental uncertainty and provides a broader coverage of the connections between these factors.

The research methods are based on decision-making methods, risk management, fuzzy set theory, optimization theory, artificial intelligence methods, and object-oriented programming.

The first chapter of the dissertation contains an analysis of existing theoretical and practical research on modern decision-making models in managing agrarian enterprises. Through the prism of international experience, the necessity of implementing information technologies in the management process of agrarian enterprises is shown.

The approach to considering the system of agrarian production – external environment is proposed. The main factors of mutual influence are identified.

As a result of the analysis, it was established that risk management in the agricultural sphere should be considered as an integral part of managing the activities of an agricultural enterprise.

The review of known multicriteria decision-making methods shows their potential application for the task of managing an agrarian enterprise.

The chapter provide a comprehensive foundation for understanding the role and importance of modern decision-making models in the management of agrarian enterprises. The chapter sets the stage for a detailed and nuanced exploration of decision-making in the context of agrarian enterprise management. By laying out the theoretical framework and practical considerations, you are well-positioned to delve deeper into specific models, technologies, and strategies that can enhance the efficiency and sustainability of agricultural operations. This chapter effectively underscores the importance of advanced decision-making tools and risk management in the ever-evolving agricultural sector.

In the second chapter, the task of decision-making is formalized as a multicriteria conditional optimization problem. According to this model, the structure of the decision support information system is proposed.

A conceptual model of developing a decision support information system in conditions of environmental uncertainty has been developed, which includes four components: goal setting, principles, functional components, and diagnostic component.

A mathematical model has been developed that takes into account the uncertainty in decision-making caused by environmental and economic factors. Two mathematical models of the decision-making task in conditions of uncertainty based on multicriteria optimization and risk minimization are proposed. Approaches for assessing the efficiency of economic decisions are described.

The chapter delves into the more technical aspects of decision-making in agricultural management, focusing on formalizing the process and developing a structured approach to managing environmental and economic uncertainties. This chapter establish a robust theoretical and mathematical foundation for the decision support system, ensuring it is well-equipped to handle the complexities and uncertainties inherent in agricultural management. The combination of multicriteria optimization, risk minimization, and efficiency assessment within your proposed models and system structure is particularly impressive, likely offering a comprehensive and effective tool for agricultural decision-making.

In the third chapter, decision-making in the agricultural field is considered as a task of optimizing a controlled multi-stage process. A model of decision-making of an agrarian enterprise based on multicriteria conditional optimization has been developed. An analysis was carried out, and 14 factors necessary for decision-making were identified. To consider the conditions of environmental uncertainty, 7 parameters of the decision-making model of an agrarian enterprise based on multicriteria conditional optimization are proposed to be considered as fuzzy input parameters.

The use of fuzzy variables with a bell-shaped membership function is justified for determining these parameters.

The use of statistical parameters of historically collected data for determining the parameters of membership functions for fuzzy variables is proposed.

The fuzzy hierarchical model of risk minimization in the activity of an agrarian enterprise has been improved. This model proposes methods for a unified assessment of individual types of risks within each process and the integral risk of the entire enterprise activity. It is proposed to describe risk factors as fuzzy variables. The use of linguistic variables is proposed for describing risk factors for which there is insufficient historical data, or there are expert assessments. A method of their fuzzification is proposed, based on representing them as fuzzy numbers with a trapezoidal membership function. 4 groups of risks are identified, allowing the model to take into account more factors. The Mamdani procedure for obtaining fuzzy logical output and defuzzification of the integral risk assessment is considered.

The chapter advances the discussion into a more nuanced and detailed exploration of decision-making in agriculture, focusing on optimizing a controlled multi-stage process. The chapter presents a comprehensive and technically advanced approach to decision-making in agriculture. By combining multicriteria optimization, fuzzy logic, and risk management, valuable insights and tools for managing the complexities and uncertainties inherent in agrarian enterprises are offered. This approach is particularly relevant given the increasing environmental and economic challenges faced by the agricultural sector.

In the fourth chapter, the implementation of the decision support information system in the agricultural sector in conditions of environmental uncertainty is presented.

Practical significance of the obtained results. The main scientific positions of the dissertation have been brought to the level of methodological generalizations and applied tools, allowing for the support of decision-making in the activities of enterprises in the agricultural sphere.

The decision support information system of an agrarian enterprise in conditions of environmental uncertainty was validated using simulation modeling methods. For validation, data on weather conditions in China from the China Meteorological Data Service Centre were used, as well as data on the yield of wheat, rice, and corn in the

Yancheng region, which belongs to the middle-lower plain of the Yangtze. To model the impact on yield, an economic-climatic model based on the Cobb-Douglas production function was used. The consideration of 3 classes of scenarios showed that they can worsen the results of the activity of an agrarian enterprise from 4.31% to 18.57%. The use of the decision support information system allows mitigating the negative impact of scenarios to 0.98%. The analysis of the results shows the validity of the fuzzy model of decision-making of an agrarian enterprise in conditions of environmental uncertainty.

The main provisions and results of the research have been implemented and applied in the activities of Yancheng Polytechnic College.

Personal Contribution of the Applicant. The applicant personally contributed to the main provisions and results of the dissertation work. In the work [1], a conceptual model of an information system for supporting decision-making in the agrarian sphere is presented. The applicant's personal contribution lies in the analysis of methods of decision support in the agricultural field. In the solo work [2], the management of the activity of agrarian enterprises for accounting risk management and multicriteria decision-making is considered. In the solo work [3], a mathematical model of the interaction of an agrarian enterprise and the environment was developed. In the solo work [4], the development of the functionality component of an agricultural enterprise’s decision-making support information system is proposed, through the development of a hierarchical fuzzy model. In the solo work [5], the applicant proposed requirements for the information system of environmental monitoring.

Materials from international conferences were also published, in which the provisions of the dissertation work are revealed in more detail [6-11].

Approbation of the Dissertation Results. The main results of the work were reported, discussed, and received a positive evaluation at the IEEE conference "Smart Information Systems and Technologies" (SIST-2021), Astana, Republic of Kazakhstan, as well as at international conferences "Information technologies and interactions", Kyiv (2018, 2019, 2021), "Project Management in the Development of

Society", Kyiv (2019), "Information Modeling Technologies, Systems and Complexes", Chernivtsi (2019), "Technology Development Management", Kyiv (2020).

Publications. Based on the dissertation materials, 11 scientific works have been published, including 4 scientific articles in specialized publications of Ukraine, 1 article in a publication that is not included in the list of the Ministry of Education and Culture, and 6 materials of international conferences. The main results of the work were obtained by the author personally. Of the scientific works published in co-authorship, the dissertation research describes those provisions resulting from the author's personal work.

Structure and Volume of the Work. The dissertation consists of an introduction, four chapters, conclusions for each chapter, main conclusions, a list of used literature, and appendices. The total volume of the dissertation is 144 pages, of which the main part comprises 125 pages, including 28 figures, 4 tables, a bibliography with 102 entries, and 2 appendices.

CHAPTER 1. THEORETICAL BASIS OF DECISION-MAKING OF AGRICULTURAL ENTERPRISES UNDER ENVIRONMENTAL UNCERTAINTY

1.1. Management of agricultural enterprises

The problem of reliable food and agricultural raw material supply to the country remains unresolved. The sustainable development of agricultural production is crucial for the functioning of other sectors that process and utilize its products. Ensuring food security, economic, and social stability is a nationally important issue for every country.

Another important factor is the need to provide food for the world's constantly growing population. According to [12], 820 million people lack sufficient food. The further growth of the planet's population will only increase the burden on agriculture. It is recommended that by 2050, food production should be increased by 70%.

It is also worth noting the significant volume of investments directed towards the informatization of agriculture by both state and private structures. Projects such as the EU-PLF project, Anemon (Switzerland), eCow (UK), Connected Cow (Medria Technologies and Deutsche Telekom), Sensorfish (EU), among others [13], should be considered. Therefore, the relevance of developing information technologies to support decision-making in agriculture is indisputable.

In the agricultural sphere, the main characteristics to consider in planning include dependence on natural conditions, the length of the production cycle, and seasonality. Numerous studies explore ways to develop the agricultural sector and its various aspects. One approach involves strengthening the coordinating role of the state and improving efficiency [14, 15]. Another approach advocates for a resource-saving development path [16]. Diversification of rural economy and creating modern infrastructure in rural areas is a third approach [17, 18]. Common to all approaches is the need for high and sustainable agricultural growth rates, which is impossible without improving management methods.

Contemporary research shows that the impact of agriculture on the environment cannot be ignored [19]. Therefore, in making decisions in agriculture, it is necessary to consider the alignment of the economic interests of agriculture with the environmental requirements for environmental conservation. The most pressing issue is increasing the efficiency of agricultural production through its ecologization. The first step is planning the rational use of natural resources.

The significant international experience in managing the agricultural sector should also be considered.

The current state of natural resources necessitates their value assessment, which will determine the amount of payment for their use and expenses for restoration. For example, to ensure the restoration of natural resources and environmental protection, the US Government applies two levers of influence on agricultural producers: partial reimbursement of expenses (up to 75%) associated with ecologizing production activities and stimulating payments to farmers. In Germany, a subsidy approach is used, aimed at supporting the population living in rural areas. Approximately 55% of the income of agricultural enterprises is related to state support [Letter]. In China, production on order is being developed. Additionally, peasants are encouraged to directly enter the urban market [16].

In the EU countries, environmental directions are implemented, including: withdrawal of eroded lands from circulation and compensation to farmers for partial income loss due to their withdrawal from exploitation. Non-food crops are grown on the conserved lands (rapeseed for biodiesel production, biomass for energy purposes). The second direction involves paying farmers subsidies for reducing the use of fertilizers and pesticides, thus promoting extensive agriculture and creating conditions for using the natural fertility of soils. The third direction is targeted support for special agroenvironmental measures, which is an instrument for ensuring rural development.

In Europe and the USA, there is a demand for environmentally friendly agricultural products, for the production of which extensive technologies can be used. 1% of the arable land in the world is used for organic farming. Leaders in its application are Sweden and Switzerland up to 7% [20].

Decision-making is a creative voluntary action of a management subject, aimed at resolving a specific situation or problem. Decision-making is the central link in any activity. By scale, all decision-making processes can be divided into 3 levels: strategic, administrative, and operational decisions. Strategic decisions are associated with external problems, administrative with creating the maximum production potential based on rational resource use, and operational with maximizing the profitability of current operations.

Management is a set of techniques and methods for targeted influence on an object to achieve a certain result. The main functions of management include: preparation and making management decisions, organizing and stimulating their execution, analysis, and correction of the execution process.

Effective management involves anticipating possible deviations in the functioning processes of the managed object and taking measures to eliminate them [22].

There are different approaches to decision-making that can be divided by national characteristics [23]. The American school of managerial decision-making involves the following technology, which contains 5 stages [24]:

Diagnosing the problem is establishing the causes of difficulties or the presence of opportunities, which helps define the problem in general terms.

1. Forming constraints and criteria for decision-making.
2. Identifying alternatives.
3. Evaluating alternatives.
4. Choosing alternatives.

The German school of managerial decision-making views the decision-making process as part of planning and control processes and includes the following stages:

1. Problem formulation.
2. Information search.
3. Evaluation.
4. Making a decision.

The Japanese school of managerial decision-making involves responsibility for decision-making not by an individual but by a group. It is assumed that no one person has the right to make decisions personally. It consists of three stages:

1. Problem formulation.
2. Development of alternative decisions.
3. Selection and implementation of the best decision.

Contemporary management methods increasingly focus on increasing the efficiency of regional management. The potential of economic policy based on methods and tools of parity efficiency and uniform development is being exhausted [25]. One method to address this issue is to choose points of prospective economic growth. It requires the formation of a development indicator system for monitoring and evaluating the progress of the sector's development.

1.2. Monitoring of agricultural enterprise activities

From the perspective of development prospects for agricultural enterprises, there arises a need to identify patterns of their development, to discern trends, and to determine their parameters. To formulate a strategy for the development of agriculture in a region or for individual enterprises, a dynamic model characterizing the temporal progression of the process is necessary. Economic monitoring tools are most convenient for achieving these goals. Monitoring is a specific type of management activity performed by the managing subsystem by making management decisions based on reliable, timely, sufficiently complete, and relevant information about all changes occurring in the managed subsystems [26].

Evaluation is a quantitative characterization of the state of a particular indicator or an integral characteristic of an object. The main questions to be answered for effective management are "Will the indicators be achieved within the set timeframe?" and "What factors influence the indicators?".

A broader concept than analysis and evaluation is diagnostics, which involves qualitative identification of the state and prediction of the behavior of an object. Therefore, the sequence of actions should be considered: analysis - evaluation - diagnostics. Such an approach allows for a comprehensive set of studies to determine the goals of functioning, ways of achieving them, identifying problems, and options for their resolution. Diagnostics is based on analysis and evaluation. Its result is a static model.

Monitoring is one of the essential elements of control over the implementation of various development programs of the managed object, relying on key indicators and allowing for long-term development correction. Monitoring includes continuous observation of the object's indicators to study its development relative to the initial state and expected result. Based on monitoring, objective information about the results of implementing management decisions is formed, ensuring coordination and control over the organization of work, and using the results for further planning of the development of the managed object.

Agricultural monitoring includes numerous indicators, such as investment volume, resources of households and farms, machinery renewal, mineral fertilizer application, etc. Forming a set of such indicators is also an extremely important task.

The informational component of the monitoring system is statistical indicators characterizing economic processes. In this context, the application of statistical methods of analysis and forecasting, particularly multidimensional statistical methods, is justified in conducting economic monitoring. Statistical methods provide depth to the analysis of phenomena and processes, more accurately identify objective trends and regularities, and ensure the making of well-founded management decisions.

Diagnosis of the agricultural sector includes forecasting its parameters. There are two types of forecasting: trend and factor forecasting. Factor forecasting is based on studying and quantitatively measuring the interrelationship between factors. Trend extrapolation forms the basis of time series forecasting methods [27], based on trend regression models. The construction of forecasts of the state and development indicators of agricultural production based on time series trends is conditioned by the fact that agriculture has a great inertia of development, which cannot be changed over a short period. Another significant argument for using the trend is its formation under the influence of all real natural and economic factors [28]. Thus, trend models take into account the influence of all factors without complete and reliable information about them.

Variant forecasting (forecasting by determinants) is one of the effective tools of strategic planning. A determinant is a factor that is the cause of a certain phenomenon. The productivity of agricultural production depends on many determinants. Determinants can be divided into two groups: natural and economic.

The gross harvest of agricultural crops depends on first-order determinants – the size of the sown area and yield. At the same time, each of these determinants depends on second-order determinants – crop failure due to adverse conditions, soil fertility, material and technical conditions, weather, etc. Yield is determined by the level of agrotechnics, quality of work by specialists, seed material, etc. Livestock production depends on two first-order determinants - livestock headcount and its productivity. But each of these determinants depends on others – diet, living conditions, level of veterinary service, etc.

The main managed determinants affecting agricultural production can be identified by the correlational-regression method.

Thus, economic monitoring is a universal management tool for the development of agriculture. Monitoring as a set of methods and processes that transform input data allows for the fullest use of available information resources to enhance the effectiveness of regulatory influences aimed at the development of the agrarian economy.

Agriculture significantly affects the environment, while environmental factors are the basis of agriculture. Their interdependence necessitates the consideration of the system of agricultural production – the environment.

Figure 1.1. the system of agricultural production – the environment.

For the analysis of the impact of environmental factors on the efficiency of agricultural production, it is necessary to determine the relationship between environmental and economic indicators using various calculated and statistical data.

In statistical research, two main tasks need to be solved. The first is to establish the fact of the presence or absence of a statistical dependency between variables. The second requires forecasting average results based on the given values of factor variables.

The significance of the relationship is assessed using the Student's t-test. The significance of the regression equation is checked using the Fisher's F-test. Correlation indicators serve as assessments of statistical regularity, and the strength of the connection between indicators is calculated using the Spearman correlation coefficient.

The list of characteristics of the agrarian sector is described by a large set of indicators. Environmental factors influencing the economic indicators of agricultural production include: environmental stability of the territory; anthropogenic load on the territory; land erosion, application of organic fertilizers, application of mineral fertilizers, use of pesticides, humus content, etc. These indicators reflect the overall environmental state of crop farming. The resulting indicator, characterizing the efficiency of agricultural production, is the volume of gross agricultural production per unit area of agricultural land.

Each branch of agriculture is characterized by its impact on the environment, for example, farming is characterized by the application of mineral fertilizers, use of pest control methods, and landscape changes as a result of plowing for sowing. The application of mineral fertilizers changes the composition of the soils. It is also a cause of water pollution. This leads to eutrophication of water bodies, increased development of phytoplankton, water blooming, etc., causing a lack of oxygen in the water and fish death. Accumulation of ammonia and hydrogen sulfide makes water unusable. The use of pesticides threatens not only changes in flora and fauna but also the possibility of their accumulation followed by poisoning of animals and humans.

The creation of large livestock complexes is accompanied by environmental pollution with excrements. There is a problem of utilizing waste from agricultural production, slaughterhouses, meat processing, and dairy enterprises.

The main environmental problems in agriculture are [29]:

- Plowing agricultural lands, disrupting the landscape and natural ecosystems;
- Increasing planting areas by deforestation and draining swamps;
- Unjustified use of plant protection products, fertilizers;
- Deterioration of soil fertility and its natural structure due to water and wind erosion;
- Irrational use of freshwater for irrigation and other agricultural needs;

- Groundwater pollution, deterioration of drinking water quality (increased content of nitrates, phosphorus, organic compounds, bacteriological contamination).

It is evident that further growth of these problems can lead to a catastrophe. It is necessary to replace traditional production, aimed at maximizing yield with minimal labor, with alternative (organic) agriculture. According to the International Federation of Organic Agriculture Movements (IFOAM), organic agricultural production is an agricultural system that promotes environmental conservation. Organic farming does not use chemically synthesized fertilizers, pesticides, or other chemical preparations. Its main goal is to produce environmentally friendly products, preserve soil fertility, use renewable resources in agriculture, and reduce environmental pollution levels. The annual growth of environmentally friendly products in the world market reaches 25%, and in the EU countries – 15%. The highest demand for such products is observed in Germany, Italy, and France [32]. The idea of organic production lies in the complete abandonment of the use of antibiotics, agrochemicals, and mineral fertilizers. This leads to an increase in natural biological activity in the soils, restoration of the balance of nutrients, enhancement of regenerative properties, normalization of the functioning of living organisms, an increase in humus, and increased yield of agricultural crops.

Natural resources are components of the agricultural ecosystem. To keep land and water resources as a constant source of wealth for people and means of agro-industrial production, a concept of achieving an optimal balance between economic growth, normalization of the qualitative state of natural resources, and meeting the needs of the population is needed.

Competitive agricultural products can be realized only by enterprises that produce products that meet international standards of the ISO 9000 series and other requirements [33]. Product certification allows not only raw materials but also finished products to be marketed. This is possible in the case of the implementation of an environmental management system into the overall enterprise management system.

1.3. Modern approaches to project management in the agrarian sector

Effective management is only possible when maintaining a balance of functions, powers, and responsibilities. Each subject of managerial activity must be responsible for the possible consequences of risky decisions to the extent of their participation in their development and their real ability to influence the degree of risk in the implementation process. Opportunities for regulating the risk of agricultural production can only be determined through the analysis of adaptive technologies and the assessment of the likelihood of expected weather, economic, and other operating conditions.

To improve the situation in agriculture, there is a need to apply new management methods based on systemic analysis. Let's consider the main approaches to managing the activities of agrarian enterprises: the approach based on risk management and multi-criteria management methods.

Among the researchers of risk theory, it is important to highlight J. Keynes, A. Marshall, O. Morgenstern, F. Knight, J. Neumann. In the works [33, 34] of these authors, the categorical content of risk is defined, theoretical approaches to the classification of risks are revealed, methodological approaches to risk assessment and its impact on economic entities are substantiated. These results can be applied to management in the agrarian sector.

Risk is the probabilistic assessment of the uncertainty and unpredictability of activity results. The increased level of uncertainty in the activities of agrarian enterprises requires special management decisions for risk analysis and developing measures to reduce them.

Agriculture, like any other economic sector, has its specific features that determine the particular nature of risks. In their works [36], these types of risks are highlighted: economic, organizational, technological, and social. The work [37] presents a classification of risks by origin, including:

Risks not related to human volition on the environment (frost, freezing, ice, hail, lightning strike, earthquake, avalanche, landslide, mudflow; fire; storm, hurricane, snowstorm; heavy rain, flood, flooding; drought; epiphytotic development of plant diseases, epiphytotic reproduction of harmful plants, secondary plant diseases).

Risks related to human volition on the environment, including agrotechnical, agrochemical, production, environmental, marketing, radiation, institutional, social, managerial, and image risks.

Financial-economic risks, including price, credit, investment, and liquidity risks.

Therefore, risk in the agrarian environment is interpreted as the probability of certain positive or negative changes in the process of production, processing, and sale of agricultural products. The occurrence of risk is associated with certain material and/or natural costs. Agrarians constantly encounter situations that generate some uncertainty, which can be interpreted as various forms and types of risks.

Risk management in the agrarian sector should be considered as a multi-stage process aimed at reducing or compensating for damage to economic entities in the event of an adverse event. It should be noted that the risk management system does not eliminate these risks but allows for a high degree of probability to predict and minimize possible losses in case of adverse events. This is related to the fact that the potential of the risk assessment system allows identifying all sources of risk, establishing their nature, conducting quantitative and qualitative assessments, managing risks on a single methodological basis, and making management decisions at different levels.

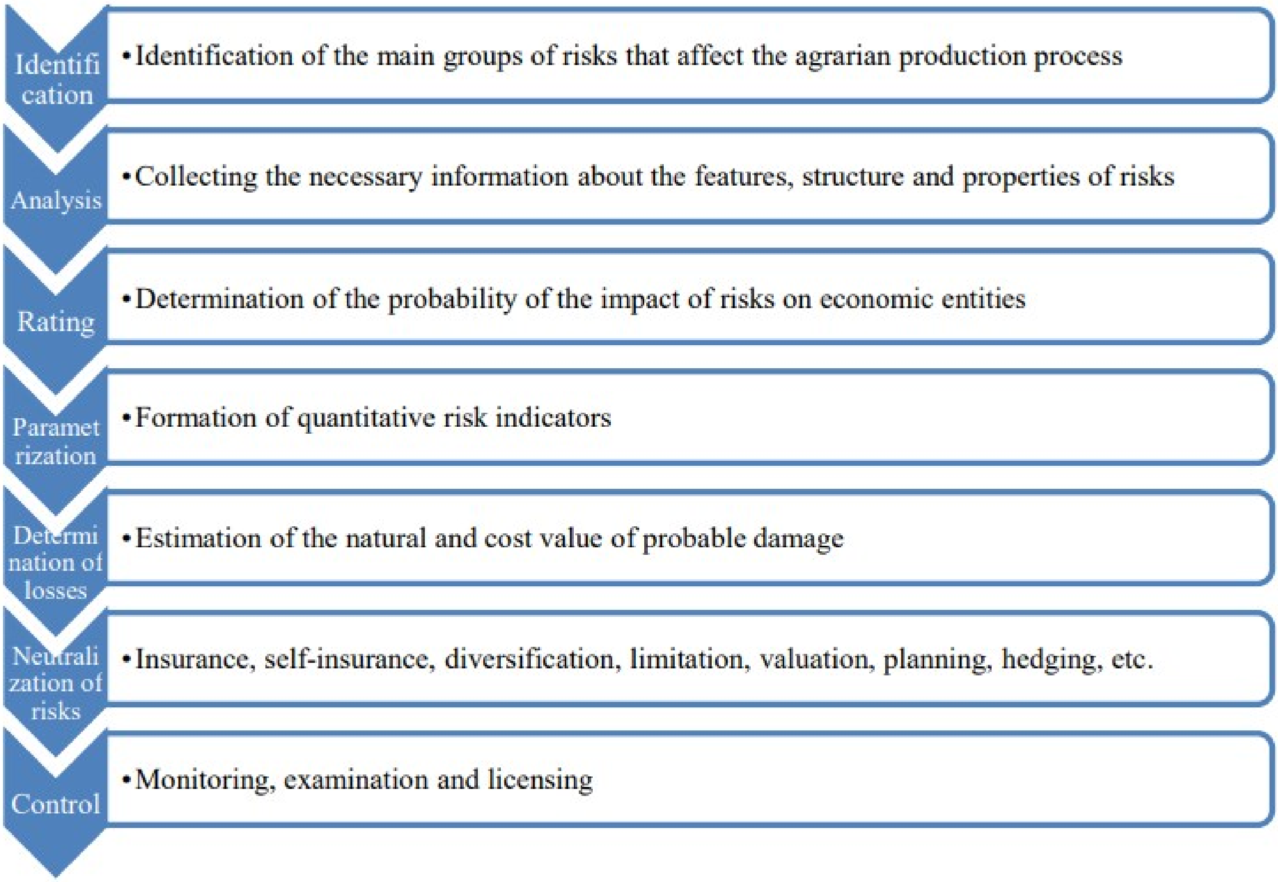


Figure 1.2. Risk management scheme

Risk management should be considered as an integral part of the overall management system for implementing strategic, tactical, and operational goals (tasks) of the development of an agricultural enterprise. At the same time, management efficiency should be determined by the optimal ratio between the profitability from conducting agricultural activities and the level of risks threatening the normal functioning of the economic entity. The process of risk management in the agrarian sector consists of these seven stages.

The goal of risk identification is to detect and compile a comprehensive list of risks that can impact the activities of an agrarian enterprise. This list should be as complete as possible, as unidentified risks pose a significant danger in achieving set goals, losing control over management processes and coordination of the enterprise's activities, as well as failing to utilize existing development opportunities. A necessary condition for conducting a thorough and comprehensive risk identification is the quality of information, which is determined by parameters such as reliability, objectivity, timeliness, relevance, and completeness of coverage.

The main sources of information used in risk identification include:

1. Forecasts of changes in meteorological and hydrometeorological phenomena and processes affecting the state of agricultural production.
2. The level of provision with financial-economic, technological, and labor resources.
3. The level of technology application used by agrarians.
4. Assessment of the condition and trend changes in the domestic and external markets of agricultural products.
5. Changes in institutional conditions regarding the implementation of agrarian policy.
6. The level of management and organizational decisions regarding production, processing, and marketing of agricultural products.

Risk analysis is conducted to obtain necessary information about the characteristics, structure, and properties of risks that could potentially threaten the socio-economic and environmental interests of an agrarian enterprise. The analysis involves identifying risks, studying their causes, and forecasting scenarios of adverse situations. It consists of constructing a probability distribution function, occurrence of losses depending on its size. The analysis helps to identify and group risks by the level of potential danger and assess the possible consequences of their occurrence. Risks are divided into three groups based on the probability of occurrence:

1. Probable events.
2. Acceptable risks.
3. Emergencies.

The purpose of risk assessment is to increase the level of socio-economic and environmental safety of the economic entity's production and business activities. Risks need to be evaluated based on two main parameters: quantitative and qualitative. Common methods of quantitative analysis of widespread risks include: statistical estimation methods, cost-effectiveness analysis, expert estimation method, the method of analogies, a group of analytical methods [38]. The main results of qualitative risk analysis include the identification of specific risks and their sources, analysis and cost equivalent of hypothetical consequences of existing risks realization, suggestions for damage minimization measures, and finally, cost evaluation. Additional results include determining the possible change values of all variables under risk assessment.

Parameterization of risk involves defining the characteristics of risk as a random variable. Determining the expected value and variance of each type of risk helps to define the range of possible fluctuations in expected profit from business activities under uncertainty and conflict.

In managing risks in the agrarian sector, it is important to adhere to the concept of acceptable risk, i.e., risk that would not threaten the process of production, processing, and marketing of agricultural products. The concept of acceptable risk involves defining and substantiating levels of acceptable risks at all stages of the agricultural product life cycle (from selection of planting material to product marketing).

To assess the relationship between risk and the efficiency of business activities, the coefficient of variation is used.

The strategy for managing agrarian risks can be based on choosing the level of risk within the values of risks from minimal to acceptable, determined for a specific type of business activity. Comparing the current value of risk with the acceptable one, determining measures to reduce risk, influencing the parameters of hazard sources, assessing the effectiveness of the measures taken - these are necessary components of risk management. In case of risk reduction, it is mandatory to consider the cost of measures aimed at reducing the likelihood of emergencies and mitigating their impact. The application of the risk indicator allows comparing the effect of dangerous factors of different nature and type, determining with the contribution of each separate factor an integral degree of danger of any type of agricultural activity. In its nature, risk management in the agrarian sector is systematic and aimed at reducing the integral risk caused by the combined effect of dangerous natural, technogenic, and anthropogenic factors.

Risk management in the agrarian sector should be considered an integral part of the overall strategy for managing the activities of an agricultural enterprise. A necessary condition for such management is to find an optimal ratio between the level of agrarian income and the total level of risks that threaten effective agricultural activity. Only under the condition of finding such a consensus are the necessary conditions for the effective development of agrarian production ensured.

Risk management in the agrarian sector is a complex and essential process, encompassing various steps and considerations to ensure the safety and efficiency of agricultural enterprises.

In summary, effective risk management in the agrarian sector involves a detailed and systematic approach, encompassing risk identification, analysis, assessment, and management. This process is crucial to maintaining a balance between profitability and safety, ensuring sustainable and efficient agricultural operations.

1.4 Multicriteria decision-making methods based on linear and nonlinear optimization problems

For managing agricultural enterprises, multicriteria decision-making methods can be used. These methods are intensively developed, modified, and improved. Let's consider the main methods of multicriteria choice from a set of alternatives and their application possibilities in the agricultural sphere.

The theory of fuzzy sets and fuzzy analysis is an effective tool for making multicriteria decisions [39]. This theory is based on the concept of a fuzzy set and a membership function. Incompleteness and imprecision of data are characteristic features of many practical tasks. Therefore, the application of fuzzy logic allows for effectively solving applied management tasks, including in the agricultural sector. The advantage of this approach is the conciseness of the task description with a set of fuzzy rules. However, the disadvantage is the need for simulation modeling before the methods can be used to choose optimal decisions.

The traditional approach for solving complex decision-making tasks is the Analytic Hierarchy Process (AHP) [40, 41]. This approach is based on pairwise comparisons of alternatives. Its advantage is scalability and ease of implementation. The main drawback is the need for expert assessments.

For assessing risks and the degree of uncertainty, as well as for making multicriteria decisions, the Multi-Attribute Utility Theory (MAUT) is used [43]. In many studies, MAUT is used in natural resource management, for example, in work [44], it is considered for determining the risks of land resource use. In work [45], a combination of spatial analysis methods and multicriteria decision-making methods based on MAUT was used to assess soil pollution risks in Europe. Work [46] describes a MAUT-based model using institutional, cultural, technical, and other criteria to promote stability and development in specific regions. The SANEX decision support system, successfully implemented in Indonesia, was created based on this model. MAUT's use for multicriteria assessment of climate change trends is discussed in work [42].

In India, the Data Envelopment Analysis (DEA) method was successfully used for agricultural tasks [47]. The authors were able to identify weaknesses in the agriculture of a particular region by ranking farms. DEA is based on measuring the relative efficiency of alternatives by solving a linear programming problem. Alternatives are rated on a scale from 0 to 1, which can be considered as weight coefficients of respective alternatives. This method is often combined with the simple additive weighting (SAW) method [48], frequently used in business and finance for quick calculations in determining a rational alternative.

Analysis of known methods of multicriteria decision-making and multicriteria analysis suggests that their isolated use can complicate the interpretation of results. It should be considered that choosing the wrong strategy for the functioning of an agricultural enterprise can lead not only to significant financial losses but also to irreversible impacts on the environmental state. There are also difficulties in making adjustments and changes during the strategy implementation. Therefore, it is proposed to use several methods focused on decision-making in conditions of uncertainty for the selection of alternatives. Appropriate methods should take into account the fuzziness of data, i.e., work with fuzzy quantities. Also, for the interpretation of results, it is necessary to develop scales of quantitative or qualitative assessments without the constant involvement of experts or the decision-maker.

Special attention should be paid to the MAUT theory, used for assessing risks and the degree of uncertainty, as well as for making multicriteria decisions. This technology combines the advantages of risk management and multicriteria decision-making and has positive examples of implementation in the agricultural sector.

1.5. Formalization of decision-making problem of agricultural enterprises under environmental uncertainty

The decision-making task in the activities of agricultural enterprises under conditions of environmental uncertainty can be outlined as follows:

Let's consider the activity of a particular agricultural company. Suppose there is some information about the company's history, the state of the regional environment, and the economic market. This information might be incomplete and inaccurate, so we will assume that the company's activity takes place under conditions of uncertainty and risk.

Assume that a set of alternatives has been formed, describing the company's future functioning $s_1, s_2, \dots s_n$, where n is the number of alternatives. Also, a set of criteria $c_1, c_2, \dots c_m$ has been formed, based on which the alternatives can be evaluated, where m is the number of criteria for evaluating alternatives. The decision-making task involves choosing a certain alternative $s_j^* \in \{s_1, s_2, \dots s_n\}$ for the company's future functioning, which is the best in a certain sense. This choice should consider existing resource, financial, and legislative constraints.

Let $x_1, x_2, \dots x_k$ be the factors influencing the functioning of the agricultural company, where k is the number of factors. It should be noted that firstly, the considered factors are dynamic variables, meaning their values change over time. Secondly, the factors may contain uncertainty, so fuzzy quantities can be used to describe them. Thirdly, among the factors, there might be factors that depend on the alternatives of the company's functioning in previous periods. Considering the significant dependence of agricultural enterprises' activities on weather conditions, it is natural to use time periods corresponding to seasonality.

Thus, the decision-making task can be formally presented as a multi-criteria conditional optimization problem.

$$\begin{gathered} c_1(s_1(x_1, x_2, \dots x_k), s_2(x_1, x_2, \dots x_k), \dots s_n(x_1, x_2, \dots x_k)) \underset{S}{\rightarrow} max; \\ \dots \\ c_m(s_1(x_1, x_2, \dots x_k), s_2(x_1, x_2, \dots x_k), \dots s_n(x_1, x_2, \dots x_k)) \underset{S}{\rightarrow} max; \\ G(x_1, x_2, \dots x_k) = 0. \end{gathered} \qquad (1.1)$$

where G is a functional constraint that defines the feasibility of implementing a corresponding alternative for the company's operation.

It is understood that to find a solution to this problem, it is necessary to apply multi-criteria decision-making methods, which are used in conditions of uncertainty.

In the process of decision-making in this case, the following stages can be identified:

- Forming a set of alternatives and criteria for their evaluation.
- Determining or estimating the values of factors for the specific period of time for which the choice of alternatives needs to be made.
- Filtering out inadmissible alternatives.
- Evaluating alternatives. Numerical calculation of criteria for each alternative with a fixed value of factors (found in step 2).

- Constructing a certain convolution of criteria to determine the optimal solution.

For this, the weighting of criteria is most often used. Each criterion is assigned a weight$w_1, w_2, \dots w_m$which determines its importance in the evaluation of alternatives, $\sum_{i=1}^{m} w_i = 1$.

Thus, to solve the problem of multi-criteria decision-making in the functioning of an agrarian enterprise, it is necessary to develop such a method or methods that would satisfy the conditions:

- Functioning in conditions of uncertainty, i.e., the methods should work with fuzzy quantities.
- The criteria for evaluation and alternatives should adequately reflect the activity of the agrarian enterprise and its interaction with the environment.
- Functional constraints should take into account all existing limitations on resources, funds, and natural possibilities.
- Decomposition of the method into stages, with the possibility of combining and modifying methods that implement each stage.
- Simplicity and clarity in the interpretation of the evaluation results of alternatives, i.e., creating appropriate scales and descriptions of the evaluation results, which would facilitate the work of the decision-maker.
- The possibility for the decision-maker to choose other alternatives if the proposed ones are not satisfactory. This requirement can be met by presenting the solution of the problem not as one optimal alternative, but as a ranked set of permissible alternatives.

The formulated scientific hypothesis determined the author's vision for the organization of effective activity of an agrarian enterprise based on multi-criteria decision analysis methods in conditions of uncertainty.

According to the formulated task, it is necessary to develop a decision support information system that should solve the following main tasks:

1. Ensure the collection and storage of factors, including data on the soils of the region, weather forecast, information about seed material, price situation, and demand for products, etc.
2. Ensure the functioning of models for choosing the optimal alternative of operation, taking into account the formation of a set of alternatives, a set of criteria, relevant multi-criteria decision-making methods.
3. Ensure the functioning of the decision support system as a whole, including forecasting the values of relevant factors for the required period, providing expert evaluation, etc.
4. Interaction with the user. The system should present information in a convenient form. In particular, it should show the criteria values for the optimal alternative of enterprise operation and justify its selection with a report on the expected results of the agrarian enterprise's operation. Data requests from the user should be made in a dialogue mode.

The proposed decision support system, grounded in multi-criteria optimization and fuzzy logic, is a thoughtful response to the challenges faced by modern agricultural enterprises. This system is designed not only to aid in decision-making but also to enhance the overall efficiency and adaptability of agricultural operations.

According to these tasks, it is proposed to develop a DSS consisting of four subsystems (Fig 1.3):

- User interface
- Data storage subsystem
- Model management subsystem
- Subsystem for ensuring operation and computation.

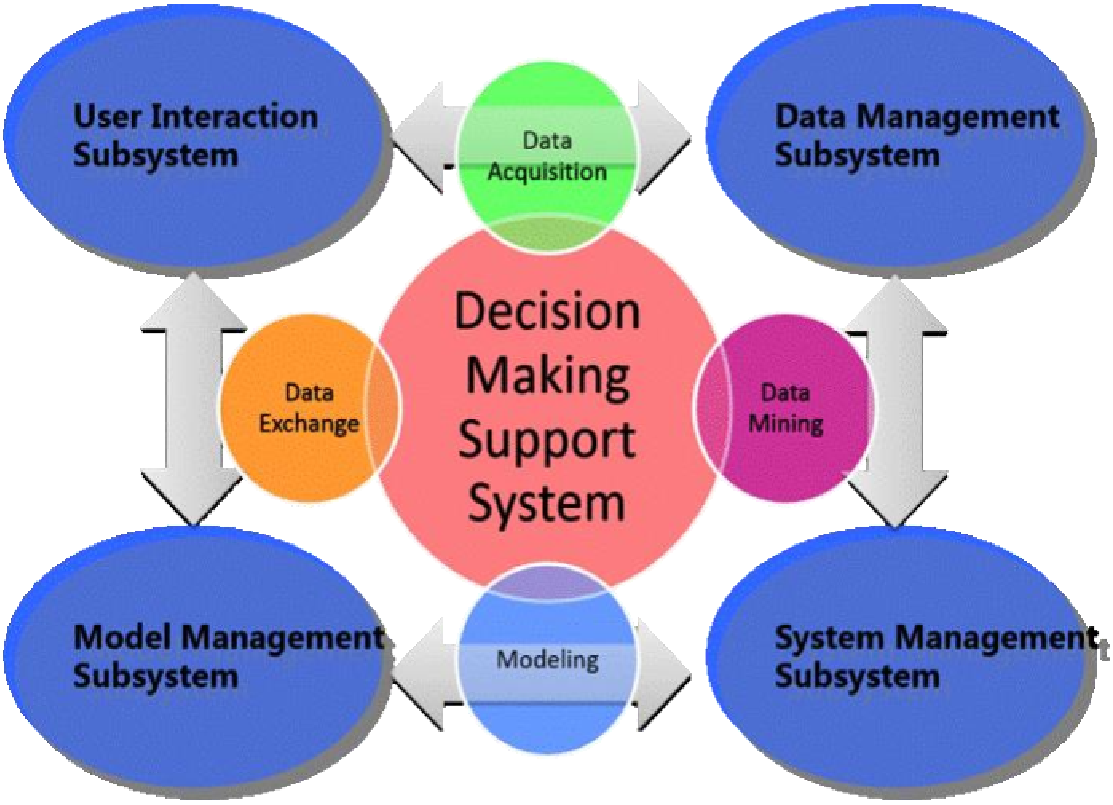


Figure 1.3. Decision support system conceptual scheme

Each subsystem can be considered as a separate module. The modular structure of the system allows for the expansion and modification of the capabilities of each module independently of the others. Also, the modular structure enhances the system's stability and flexibility. Considering the modern approach to software development, the modular approach allows for the implementation of a microservices approach, where the system consists of a set of independent microservices.

Conclusions to Chapter 1

1. The main concepts and features of decision-making by agrarian firms in conditions of uncertainty are considered. The need to improve the efficiency of the operation of agrarian enterprises and the main approaches to their solution through improvement are justified. Various approaches to improving the management of agrarian enterprises are considered, including strengthening the coordinating role of the state, transitioning the industry to a resource-saving path of development, and

diversification. Through the prism of international experience, the necessity of implementing information technologies in the management process of agrarian enterprises is shown.

2. It is shown that agriculture significantly affects the environment. At the same time, environmental factors are the basis of agriculture. An approach to considering the system of agrarian production – the external environment is proposed. The main factors of mutual influence are highlighted.

3. The risk management approach to managing agrarian enterprises is considered. Risk management in the agrarian sphere should be viewed as an integral part of the overall strategy for managing the activity of an agricultural enterprise. A necessary condition for such management is finding an optimal balance between the income level of the agrarian and the total level of risks threatening effective agricultural activity. Only under the condition of finding such a consensus are the necessary conditions for the effective development of agrarian production ensured.

4. A review of known multi-criteria decision-making methods shows their applicability for the task of managing an agrarian enterprise. Since choosing the wrong strategy for the functioning of an agrarian enterprise can lead not only to significant financial losses but also to irreversible impacts on the environmental state. Considering the difficulties that arise when it is necessary to make adjustments and changes during the implementation of the strategy, it is advisable to use several methods for selecting alternatives, which are focused on making decisions in conditions of uncertainty. Requirements to be followed in the development of the corresponding methods are formed. It is also shown that to interpret the results, it is necessary to develop scales of quantitative or qualitative assessments without the constant involvement of experts or the decision-maker.

5. Special attention should be paid to the theory of MAUT, which is used for assessing risks and the degree of uncertainty, as well as for making multi-criteria decisions. This technology combines the advantages of risk management and multi-

criteria decision-making and has positive examples of implementation in the agrarian sphere.

6. The task of decision-making as a multi-criteria conditional optimization problem is formalized.

7. A scientific hypothesis is formulated that defines the author's vision for the organization of effective activity of an agrarian enterprise based on multi-criteria methods of decision analysis in conditions of uncertainty.

8. According to this hypothesis, the structure of a decision support information system is proposed. Four main subsystems and a set of tasks that they should solve are highlighted.

CHAPTER 2. CONCEPTUAL MODEL OF RESEARCH FOR THE DEVELOPMENT OF THE DECISION SUPORT SYSTEM IN UNDER ENVIRONMENTAL UNCERTAINTY

2.1. Agricultural Enterprise Management Concept

With climate change, agricultural enterprises face new challenges such as extreme weather conditions and crop instability. Effective management helps adapt to these changes and minimize their impact. Increasing competition and the need to optimize costs require agrarian enterprises to implement innovative technologies and management approaches. Considering environmental aspects and sustainable resource use becomes increasingly important for ensuring the long-term viability of agrarian enterprises. Management of an agrarian enterprise must comply with numerous regulatory requirements, product quality, and safety standards. The openness of global markets and international trade requires agrarian enterprises to be flexible and competitive. As a consequence, markets for agrarian products are highly volatile. Effective management allows quick adaptation to changes in demand, prices, and market conditions. Digitalization and the use of modern IT solutions in the agrarian sector open new opportunities for data collection, analysis, and process optimization.

Dividing the management of an agrarian enterprise into strategic, tactical, and operational levels is important for several reasons: The distribution of responsibility and roles helps the enterprise more effectively allocate and use its resources while ensuring actions align with long-term goals. Management division ensures quick response to both local changes in operating conditions, such as weather changes, and to market conditions and changes in the external environment. Different management levels allow the enterprise's leadership to more effectively control the entire production process. A clear division into levels helps improve internal communication and cooperation between different departments and employees of the enterprise.

The ability to quickly adapt to changes in the agrarian sector is critically important. Different levels of management allow the enterprise to effectively respond to new challenges and opportunities. This three-level approach allows agrarian enterprises to be more resilient and competitive while adapting to the rapidly changing conditions of modern agribusiness. Each management level is responsible for its area of work, ensuring more effective and targeted task execution. The strategic level focuses on the general direction and goals of the enterprise, the tactical level is responsible for developing and implementing specific plans and strategies, and the operational level deals with daily operations.

Strategic planning helps the enterprise determine its market position and develop a stable foundation for future growth, while tactical planning ensures the implementation of these strategies.

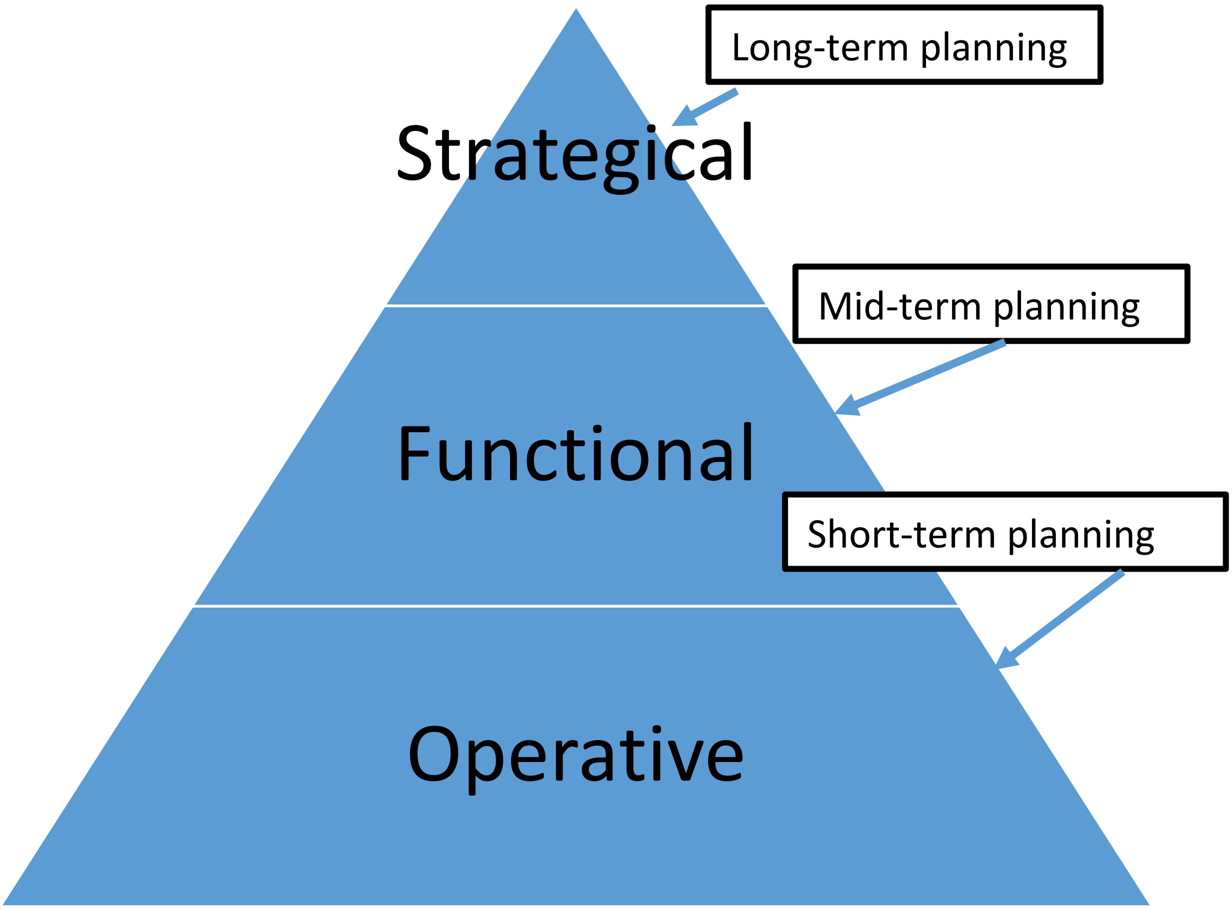


Figure 2.1. Management levels

Each level has its own characteristics and tasks:

1. The strategic management level is responsible for long-term planning, defining the main goals and development directions of the enterprise for a period of 3 years and more. At the strategic level, the main markets, cultures, technologies are selected, and business strategies are formed. Also, there is a distribution of main resources, including finances, land, equipment. Establishing and maintaining long-term relationships with partners, investors, suppliers is also important. At the strategic level, the assessment and management of strategic risks, such as climate changes, fluctuations, are carried out.
2. The tactical management level is responsible for medium-term planning for a year or season, which corresponds to strategic goals. The main tasks of tactical management include setting budgets, monitoring expenses and income, and improving methods of agriculture, logistics, and sales.
3. The operational management level is responsible for short-term planning and building daily and weekly work schedules. At the operational level, control over fieldwork, equipment and materials management, quality checks of work, the condition of cultures, equipment is conducted. Collection and analysis of data on work efficiency are necessary for reporting to higher management. The operational management level allows for quick adaptation to changes in weather conditions, technical problems, etc.

Each management level of an agrarian enterprise requires the application of specific management models and methods. At the strategic level, models are used that help in analyzing the external environment, such as SWOT analysis, PEST analysis, defining long-term goals, and developing strategies. Methods are aimed at developing business plans, strategic planning, risk analysis, change management.

At the tactical level, models are used for medium-term planning, process and resource optimization, such as supply chain models, logistical models. Methods are aimed at management by objectives, budgeting, project management, quality management.

At the operational level, models are used for daily process management, such as optimization models for work shifts, inventory management. Methods are aimed at daily planning and resource allocation, task execution control, monitoring, and analysis of production data.

The variety of these methods and management models at different levels allows an agrarian enterprise to effectively respond to various challenges and manage resources according to its strategic, tactical, and operational needs.

Project management provides agrarian enterprises with a number of significant advantages that help optimize their activities and increase efficiency: Project management helps clearly define project goals, providing all project participants with a common understanding of its expected outcomes.

Setting specific, measurable, achievable, realistic, and time-bound (SMART) goals contributes to more effective planning and management. Effective resource planning, including labor, equipment, and finances, is key to the successful completion of agrarian projects. Planning allows for anticipating potential problems and developing strategies to overcome them in advance.

Project management allows for systematic identification, assessment, and minimization of risks associated with agrarian projects. Conducting risk management increases the chances of project success and helps avoid unforeseen expenses.

Project management enables more efficient use of resources, reducing costs and increasing profitability. This includes optimizing logistics, inventories, as well as managing work time and production capacities.

Project management provides clear communication channels among all stakeholders, including project teams, management, investors, and clients. Regular project status updates and reporting help avoid misunderstandings and ensure transparency in decision-making.

Project management allows agrarian enterprises to be more flexible and adaptive to changes in market conditions, technological innovations, and other external factors.

The use of adaptive methodologies, such as Agile, can help quickly respond to changes and make adjustments to the project plan.

Clear procedures and standards within project management help ensure high-quality project execution. Systematic monitoring and quality control throughout the project implementation process allow for timely detection and correction of errors.

The application of project management in an agrarian enterprise not only increases its efficiency and productivity but also helps ensure stability and resilience in a rapidly changing market environment.

The process in enterprise project management is a structured set of actions or stages aimed at achieving specific project goals. In the context of project management, the process represents a sequence of steps or actions that need to be taken for planning, developing, implementing, and completing a project. Each process typically includes defined inputs, tools, and techniques for processing these inputs, and outputs.

Processes play a key role in enterprise project management, providing structure, efficiency, and consistency in project implementation. Here are a few aspects that highlight their importance:

Processes help organize projects, from their initiation to completion. Clearly defined processes provide guidance for each stage of the project, allowing project managers to effectively plan, execute, control, and complete projects.

Effective processes help manage resources, including time, human resources, and material resources. This allows for the optimization of resource use, reducing costs and increasing productivity.

Processes establish quality standards for various aspects of the project. They ensure that all project elements meet pre-defined quality criteria and requirements.

Clearly defined processes facilitate effective communication within the project team and with stakeholders. They help establish accountability and provide regular project status updates.

Processes help identify, assess, and manage risks associated with the project

They provide a systematic approach to minimizing potential problems and delays.

Processes in project management support continuous improvement, allowing teams to analyze and learn from completed projects for improving future initiatives.

In project management, there are different process groups, such as initiation, planning, execution, monitoring and control, and project completion, each including its specific processes.

The discussion of the different levels of management and the integration of project management within each level offers a nuanced understanding of how agrarian enterprises can effectively respond to various challenges and manage resources. This approach underscores the importance of tailored strategies and processes at each management level to optimize operations and ensure long-term success in the agricultural sector.

In summary, each management level in an agrarian enterprise plays a vital role in its overall success, employing tailored methods and models. Project management, with its structured processes and focus on efficiency, communication, and quality, significantly enhances the enterprise's productivity and adaptability in a dynamic market environment.

2.2. The conceptual research model of developing the decision support system for agriculture enterprise under environmental uncertainty

We will consider the model of an information system for decision support in the agrarian sector under environmental uncertainty as a certain image of the system being developed, which reflects the features and key characteristics of the system and ensures the achievement of the goals of development and use of the information system.

In developing the model of the information system for decision support in the agrarian sector in conditions of environmental uncertainty, the principles of openness of science and data openness should be taken into account. These principles are becoming the dominant principles of today [57].

Let's break down the construction of the model of the information system for decision support in the agrarian sector in conditions of environmental uncertainty into four components:

1. The component of goal setting. This component defines the main objects and subjects of the environment and the requirements for the properties of the final product and the result of implementing the model.

2. The component of principles. This component defines scientific approaches and principles that correspond to the openness of science and FAIR (Findability, Accessibility, Interoperability, and Reusability), considering the peculiarities of decision support, environmental uncertainty, and the agrarian sector.

3. The component of functionality. This component includes the corresponding mathematical models and methods, software, hardware.

4. The component of diagnostics. This component includes criteria and indicators for evaluating the system's performance.

The model for a decision support information system in the agrarian sector under environmental uncertainty is well-structured and covers all essential aspects from goal setting and principles to functionality and diagnostics. This comprehensive approach not only aligns with modern scientific and data management principles but also ensures that the system is robust, adaptable, and capable of meeting the complex demands of agricultural decision-making under uncertain environmental conditions. By integrating these components thoughtfully, the system is positioned to effectively support agricultural enterprises in making informed, strategic decisions.

By incorporating these principles, the decision support system for the agrarian sector under environmental uncertainty can not only address the immediate and complex challenges of agricultural management but also contribute to a more open, collaborative, and sustainable approach to agriculture. This model can set a benchmark for future developments in agricultural decision support systems.

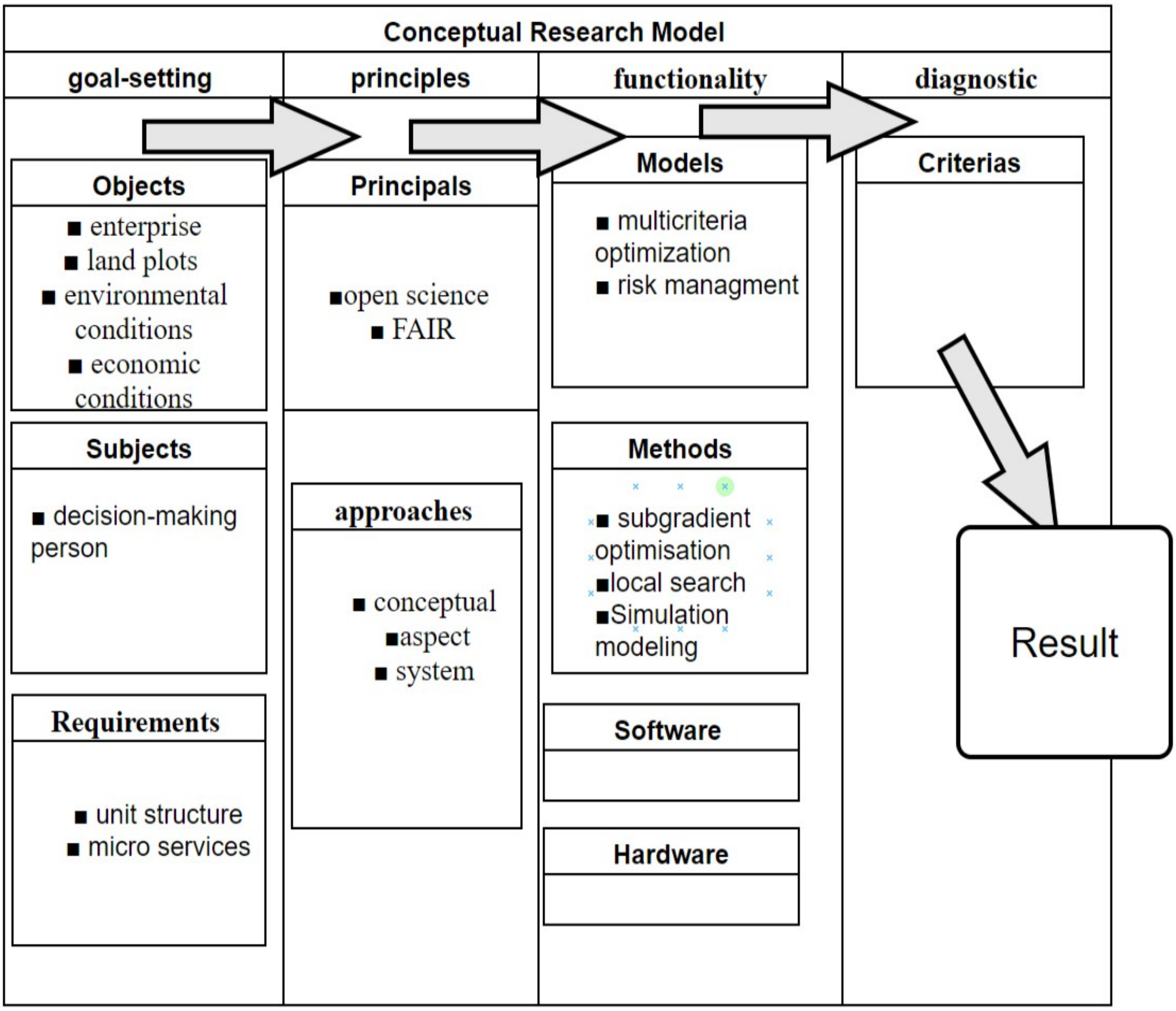


Figure. 2.2. The conceptual research model of developing the decision support system for agriculture enterprise.

The considered components form a cohesive structure for the development of the information system model for decision support in the agrarian sector under conditions of environmental uncertainty. Let's take a closer look at each component of the information system.

The goal-setting component is developed in accordance with international and national requirements for information systems. It also takes into account the specifics of the subject area of research: the agrarian sector that operates under conditions of environmental uncertainty. This component declares the goal, which implies the development of an information system. The use of this system as a tool to simplify the decision-making process in the agrarian sector. The information system should help achieve better results in the enterprise's operation.

In the development of the goal-setting component, the following main environmental objects were identified in which the information system will operate:

1. An enterprise engaged in certain activities in the agrarian sector. This could be an enterprise growing certain agricultural crops such as wheat, rice, cabbage, potatoes, etc., or an enterprise engaged in breeding certain types of animals, birds like cows, pigs, chickens, etc., or the enterprise may combine these activities. We will generalize the concept of "agrarian enterprise" and further consider it as an object that uses land plots, funds, and other types of resources to generate another type of resource. The agrarian enterprise is the main operating unit and the object over which management is exercised using the corresponding information system.

2. Land plots are considered the main resource of the agrarian enterprise's activity. This object has certain characteristics that affect the result of the enterprise's operation. These characteristics are not homogeneous and stable. They depend on the geographical location of the plot and the influence of other objects, particularly the history of the agrarian enterprise's operation. For example, if sunflowers are grown on one field for several years in a row without using the appropriate fertilizers, the soil's yield can significantly decrease. The characteristics of the land plot are usually known and can be considered as clear input parameters of the information system for decision support in the agrarian sector under conditions of environmental uncertainty. Desired characteristics of the land plot can also be used as a component in formulating the objective of the agrarian enterprise's operation.

3. Environmental circumstances are also an important object. Environmental circumstances include meteorological indicators such as precipitation, temperature, air humidity, intensity of solar radiation, etc., and environmental factors like air, water, and soil pollution with harmful substances. Also, biological factors such as pests, bacteriological and viral diseases can be considered environmental circumstances. All

these factors are characterized by chaotic processes, making long-term forecasting impossible [58]. However, short-term forecasting of these values is possible, especially using methods based on fuzzy logic in the agrarian sector [59]. Therefore, we will consider environmental circumstances as a certain object of the external environment described by fuzzy quantities. The values describing environmental circumstances change very quickly and should be considered as fuzzy input parameters of the information system for decision support in the agrarian sector under conditions of environmental uncertainty.

For obtaining environmental circumstance indicators, a formalized approach to environmental monitoring can be used [60]. According to this approach, information systems not only provide data about the current state of indicators but also have methods for predicting their state in future periods [61].

4. Economic circumstances should also not be overlooked as an important object. Economic circumstances, first and foremost, include the prices of the products produced by the agrarian enterprise. Prices are determined by methods independent of the agrarian enterprise. These can be market methods such as trading on the commodity exchange or administrative methods involving price regulation by authorities.

5. The main subject is the decision-maker – the director of the agrarian firm, or a collective body, like a supervisory board. They decide on the objective of the agrarian enterprise's operation and make the final decision regarding the choice of the operating strategy. They have motives for seeking a solution to the management of the agrarian enterprise, including financial incentives. The decision-maker also determines which means are permissible to achieve this goal. The decision-maker is the main user of the information system for decision support in the agrarian sector under conditions of environmental uncertainty.

Requirements for the properties of the final product and the result of implementing the information system for decision support in the agrarian sector under conditions of environmental uncertainty are described in works [62].

Special attention should be paid to the requirements for the modularity of the system. The advantage of using a modular system structure lies in the possibility to expand and change each of the modules independently of others. Such a structure significantly enhances the stability and flexibility of the system. Also, the modern approach to software development should be considered, such as the use of microservices. Each module should be implemented as an independent microservice.

The principles component includes such principles that should be followed in the process of development and operation of the information system for decision support in the agrarian sector under conditions of environmental uncertainty:

1. The principle of openness in science involves using the most modern results of scientific research in the design, development, and implementation of the information system.

2. The FAIR principle involves using such input data and formulating the results of the system's work so that they are easily discoverable, accessible, compatible with other information systems, and can be reused multiple times.

Following the FAIR principles in data management means that

- Data should be easy to find for both humans and computers. Metadata and data should be well-described so they can be discovered and accessed.
- Data should be retrievable by their identifier using a standardized communications protocol.
- Data should be compatible with applications or workflows for analysis, storage, and processing.
- Data should be well-described so they can be replicated and combined in different settings.

In the development of the information system, it is important to adhere to the sequence of scientific approaches. First, using a conceptual approach, develop the main provisions that define the general direction, sequence, and architecture of the decision support system development. Then, relying on the aspectual approach, identify the most significant components. And finally, define the nature of the links between aspects and their properties using a systems approach.

The functionality component primarily includes mathematical models and methods that ensure the functioning of the information system for decision support in the agrarian sector under conditions of environmental uncertainty.

As shown in work [63], two main approaches can be considered for determining the optimal decision.

The first approach involves formulating the decision-making task as a multi-criteria optimization problem:

$$c_i(s(x)) \rightarrow max, i = \overline{1, m}, \qquad (2.1)$$

$$G_j(x) = 0,\ j = \overline{1, r}. \qquad (2.2)$$

where x is a fuzzy vector value that represents the factors of the environmental conditions and economic conditions, $s(x)$ is some strategy of the agricultural enterprise functionality, c_i are criteria based on which the strategy can be evaluated, m is the number of criteria for evaluating the strategy of the agricultural enterprise functionality, G_j are functional restrictions that determine the feasibility of implementing a suitable strategy of the agricultural enterprise in terms of available resources and r is the number of restrict.

To solve such a multi-criteria optimization problem, appropriate methods should be used. The traditional approach involves the application of one of the local search methods. Such a method allows for finding local optimal solutions to the optimization problem [65]. Also, the use of subgradient methods are traditional [66]. A more modern approach to solving optimization problems is simulation modeling [67].

The second approach to decision-making involves minimizing risks. Initially, risk identification occurs, which involves compiling a complete list of risks that can positively or negatively impact the operation of an agrarian enterprise. For the considered model, all fuzzy input parameters, namely environmental and economic circumstances, are risk factors. Next, the analysis of risk distribution functions takes place. The loss or profit functions are evaluated in case a particular risky situation occurs.

Let f is the function for assessing losses or profits at a certain fixed value of a risk factor x. Then the overall expected effect of the operation of an agrarian enterprise can be calculated as the mathematical expectation:

$$M(x) = \int_0^1 f(x)\mu(x)dx \tag{2.3}$$

and the risk of operation is determined through the standard deviation:

$$\sigma(x) = \sqrt{\int_0^1 (f(x) - M)^2 \mu(x)dx}. \tag{2.4}$$

Since there are many risk factors, integration should be carried out for each risk factor.

To find the optimal decision in terms of risk management, the solution to such a problem is to minimize the coefficient of variation

$$\frac{\sigma(x)}{M(x)} \rightarrow min \tag{2.5}$$

Figure 2.3. Decision making scheme

Finally, let's consider the diagnostic component. This component includes criteria and indicators of the operation of an agrarian enterprise. It allows for the quantitative assessment of the results of operations for a certain season. This is a diagnostic tool that allows assessing the decisions made by the decision support system and improving the efficiency of the operation of the agrarian enterprise in subsequent seasons ions.

The content of the main principles of modeling the mechanism of management decision-making as a whole corresponds to the following principles:

1. System representation. This principle requires considering phenomena in terms of the systemic structure and relationships between subsystems.

2. Model homomorphism. The model must reproduce all the essential properties of the system. It simplifies the representation of the system's structure and the nature of the interrelationships of its elements.

3. "Occam's Razor". It is impractical to model all aspects and levels of the system. It should be done selectively, taking into account the correspondence between the research results and its goals and objectives. This principle radically reduces the labor intensity of applying the methodology, making its practical and flexible use possible.

4. Necessary diversity. Research on the system will not be effective if the model has insufficient own complexity of behavior.

5. The presence of feedback channels. If feedback does not provide information about the degree of adequacy of the model, then the effectiveness of modeling and the entire management process is greatly reduced.

6. Permanent forecasting. In the management system, forecasting should be constant over time. When considering the external environment, it is necessary to anticipate several alternative variants of its change.

7. Multivariance. For each situation in the management system, several action options justified by calculations according to the model can be foreseen.

8. Modular structure. The principle indicates the need to separate modules in the system and the model, considering them as a set of modules.

9. Development, improvement. It involves taking into account the variability of the system, its ability to develop, replace parts, and accumulate information.

From this hypothesis of "simplicity of the primary cause of a complex situation," three important practical implications arise:

1. When analyzing complex and unique situations, it is necessary to focus on identifying a small number of simple causes.
2. Understanding the logic of an event allows for predicting its development.
3. Situations can be managed.

Developing a modeling concept requires a comprehensive analysis of management processes to identify their goals and tasks, as well as tools and methods for decision support.

The conceptual model of the management decision-making process represents a formalized description of the main management processes - situation review, decision support analysis, decision-making, predictive analysis - and the connections between them (Fig. 2.3). It defines the structure of the process, causal relationships inherent in it, and essential for achieving the goals of modeling.

Each separate process, associated with solving specific tasks, can be formalized at the mathematical level and requires the involvement of corresponding mathematical models and methods.

The development of an information system for decision support in the agrarian sector under conditions of environmental uncertainty involves several key components, each addressing different aspects of the system.

The information system for decision support in the agrarian sector is designed to be comprehensive, modular, and adaptable to changing environmental and economic conditions. It incorporates advanced scientific principles and methodologies to enhance decision-making processes, aiming for improved efficiency and effectiveness in agrarian enterprise management.

2.3 Agrarian enterprise decision effectiveness assessing

An important aspect of assessing the effectiveness of a management system is defining basic criteria for comparison or a normative level of effectiveness. One methodological approach involves comparison with indicators reflecting the effectiveness of the organizational structure of a benchmark management system, which is formed based on all available methods and tools for designing management systems. Characteristics of such a variant become expressions of normative indicators. It is also appropriate to compare with the indicators of effectiveness and characteristics of the management system chosen as a benchmark, which defines an acceptable or sufficient level of effectiveness.

The main criterion of effectiveness is the ability to achieve the final goals of the management system with minimal operating expenses. The indicators used to evaluate the effectiveness of the management apparatus and its organizational structure can be divided into three interrelated groups:

- Indicators reflecting the efficiency of the management system through the final results of the organization's activities and management costs.
- Indicators covering the content and organization of the management process, including direct results and expenses on managerial labor.
- Indicators reflecting the rationality of the organizational structure and its technical-organizational level.

To assess the effectiveness of management, it is important to determine how much the management system and its organizational structure correspond to the management object, considering the balance of functions, goals, personnel numbers, volume and complexity of work, information provision, as well as technological means.

The correspondence of the organization's structure to its tasks, goals, and factors influencing its successful operation is analyzed. It is important to study the existing structure, identify its weaknesses and strengths, and understand how informal elements compensate for deficiencies in the formal structure.

The effectiveness of the organizational structure cannot be assessed by a single indicator. It is necessary to consider both the ability of the structure to achieve the goals set for the organization and the adequacy of its internal construction and functioning. The key criterion of effectiveness is the complete and stable achievement of goals, but its practical implementation into specific indicators is often complex. Therefore, it is appropriate to apply a complex of normative characteristics of the management apparatus: efficiency in processing information, timeliness of decisions, reliability, adaptability, and flexibility.

Economic efficiency assessment often relies on criteria such as profit growth, production and sales volume, reduction of management apparatus maintenance costs, and similar indicators. However, such evaluation methods have limitations, as they do not always reflect the specifics of management and its impact on production.

Overall, assessing the effectiveness of a management system requires a comprehensive approach that includes analyzing various aspects and interconnections within the management process.

Possible criteria for evaluating business decisions are presented in Table 2.1.

A set of properties of a phenomenon and corresponding numerical values form a measurement scale, which is fundamental for scientific analysis. The development of such a scale involves creating a comprehensive list of potential variants and selecting criteria for evaluation, which includes various scales (accurate, approximate, relative assessments, scores, verbal assessments, as well as the application of the concept of fuzzy sets).

There are three main approaches to justifying and selecting decisions:

The mathematical approach to decision-making (normative approach), which is based on the rational choice of the best alternatives according to defined criteria and conditions for decision-making. Normative models focus on an optimal approach to decision-making, assuming that decision-makers aim to maximize benefits, but in practice, they often choose a solution that is "satisfactory" or "appealing."

Table 2.1. Criteria for evaluating business decisions

Criteria Group	Indicators
Technological	Repairability, reliability, durability, quality, waste-free production, possibility of automation, etc.
Technical-Economic	Power, productivity, time expenses, payback period, investments, energy intensity, operational costs, effectiveness of advertising, etc.
Ergonomic	Safety, convenience in operation, impact on the worker's well-being, etc.
Sociological	Standard of living, opportunity for professional development, state assistance, social work conditions, etc.
Psychological	Leadership skills, personal characteristics, behavior in a team, etc.
Legal	Legislative and legal norms
Environmental	Environmental protection norms, environmental standards, environmental monitoring and consequences, etc.

There are three main approaches to justifying and selecting decisions:

The mathematical approach to decision-making (normative approach), which is based on the rational choice of the best alternatives according to defined criteria and conditions for decision-making. Normative models focus on an optimal approach to decision-making, assuming that decision-makers aim to maximize benefits, but in practice, they often choose a solution that is "satisfactory" or "appealing."

The qualitative-subjective approach (descriptive approach) focuses on the behavioral aspects of decision-making, including psychological models that consider the actual behavior of decision-makers, not just the theoretical aspects of this process.

The comprehensive approach to decision-making combines elements of both of the above approaches, including both formal and informal methods. This approach involves using a set of techniques for justifying decisions, including structuring the task, characterizing its elements, and optimizing decisions.

The decision-making process requires deep knowledge of the subject and the ability to think analytically, and mathematical modeling and modern information technologies contribute to a scientifically substantiated approach. However, it is important to consider that real decision-making often combines informal aspects, such as intuition and emotional factors. Management decisions are thus the result of a complex interaction of formal and informal processes, requiring a deep understanding of both theoretical and practical aspects of management.

Comprehensive approach to assessing the effectiveness of a management system, especially in the context of decision-making in the agrarian sector under environmental uncertainty, integrates various methodologies and criteria. This approach is vital for a nuanced understanding and evaluation of management effectiveness.

Evaluating the effectiveness of a management system acknowledges the complexity of management processes, especially in dynamic environments like the agrarian sector. This approach is comprehensive, integrating quantitative and qualitative measures and considering both theoretical models and practical behavior of decision-makers. By doing so, it offers a robust structure for understanding and improving management effectiveness in various contexts.

Conclusions to chapter 2

1. A conceptual model for researching the development of an information system for decision-making in conditions of environmental uncertainty has been constructed, which includes four components. The Goal-setting component defines the basic objects and subjects of the environment in which the information system operates. It also contains requirements for the properties of the final product and expected outcomes from the implementation of the decision support system. The principles component determines the principles that should be used in the development of the Decision Support System, with a particular emphasis on following the principles of open science and data. The functionality component defines mathematical models for multi-criteria optimization and risk minimization models. The Diagnostic component establishes criteria for evaluating the effectiveness of the decisions made. These components form a coherent system that supports the process in the development of the decision support system. The model takes into account the uncertainty in decision-making caused by environmental and economic factors and proposes two mathematical models for describing decision-making tasks in uncertain conditions.

The information system for decision support in the agrarian sector is designed to be comprehensive, modular, and adaptable to changing environmental and economic conditions. It incorporates advanced scientific principles and methodologies to enhance decision-making processes, aiming for improved efficiency and effectiveness in agrarian enterprise management.

2. Approaches for evaluating the effectiveness of economic decisions are described. Managerial decisions are the result of the interaction of formal and informal processes, requiring a deep understanding of both theoretical and practical aspects of management. It has been established that the assessment of the effectiveness of a management system depends on the determination of basic criteria for comparison or establishing a normative level of efficiency. The ability of the system to achieve its final goals with minimal operational costs is a key criterion of its effectiveness.

Indicators of the efficiency of the management apparatus and its structure can be divided into three groups that reflect different aspects of efficiency, including final results, the management process, and the rationality of the organizational structure. There are various approaches to decision-making, including mathematical (normative), qualitative-subjective (descriptive), and integrated approaches, each with its own features and importance in the context of managerial decisions. Mathematical modeling and information technologies contribute to a scientifically grounded approach to decision-making, although it is also important to consider informal aspects, such as intuition and emotions.

CHAPTER 3. MATHEMATICAL MODEL OF DECISION MAKING UNDER ENVIRONMENTAL UNCERTAINTY

3.1. Environmental uncertainty modeling

Mathematical models of environmental uncertainty are used to account for uncertainties in various aspects of environmental systems. Such models allow quantitatively assessing the impact of various factors, changes, and decisions on the ecosystem and the environment, taking into account a large number of uncertainties that may arise due to randomness, data incompleteness, or uncertainty in model parameters.

Some types of mathematical models used to account for environmental uncertainty:

- Stochastic models - these models use random variables to model uncertainty in parameters or influences on the ecosystem. They can help determine the distributions of possible outcomes and the probabilities of different scenarios.

- Input data uncertainty models: These models allow for the consideration of uncertainty in the data used to build the model. This can be a lack of precise data or variation of parameters within a range of values.

- Parameter uncertainty models: They allow modeling situations where the exact values of model parameters are unknown and are determined with a certain distribution. This allows for the consideration of variability in parameter estimates.

- Models with fuzzy quantities: These models allow for the consideration of fuzzy or blurred information. They can be useful when precise values are unknown or when environmental concepts are difficult to define unambiguously.

- Uncertainty in systemic connections models: They help account for uncertainty in the connections between different components of the ecosystem and their interactions.

- Model sensitivity: Used to study the impact of uncertainty in parameters on modeling results, which helps to understand how uncertainty affects conclusions.

These types of models can be combined to build more complex models that consider different aspects of uncertainty. It is important to understand that mathematical models are only approximations of reality, and their results can be limited by the accuracy of input data and the choice of the model.

Stochastic models in ecology are used to model systems where uncertainty plays an important role due to randomness and unpredictability of events. They allow for the consideration of random factors affecting ecosystems and analyze their impact on system behavior and its environmental state. The main idea of stochastic models is that they use random variables to describe uncertainty.

Some key aspects of stochastic models of environmental uncertainty:

1. Randomness in parameters: Stochastic models allow for the consideration of uncertainty in parameter values, such as reproduction rates of organisms, rate of environmental change, etc. These parameters can be modeled as random variables with a certain distribution.

2. Randomness in inputs: In stochastic models, random variables can be used to describe random events, such as natural disasters, climate fluctuations, or other changes in the environment.

3. Event modeling: Stochastic models allow modeling events that have some degree of uncertainty, such as the spread of diseases, migration of species, variations in reproduction, etc.

4. Modeling distributions: Instead of exact values of variables, stochastic models use probabilistic distributions to describe uncertainty. This allows for determining the probability of different outcomes.

5. Risk analysis: Stochastic models allow for analyzing various scenarios and their probabilities in the context of the impact of uncertainty on decision-making.

6. Modeling evolutionary processes: Randomness can reflect uncertainty in processes related to evolution, changes in populations, and interactions in ecosystems.

7. Modeling variability: Accounting for random factors helps describe variations observed in natural systems due to uncertainty and randomness.

Creating stochastic models may involve the use of simulation modeling, differential equations with stochastic additions, Markov random processes, and other approaches. They are a useful tool for studying the behavior of environmental systems in situations where uncertainty plays a significant role.

Models of input data uncertainty under environmental uncertainty are used to assess and manage risks in environmental systems where input data may be incomplete, inaccurate, or change due to natural processes or human activity. These models help better understand the impact of uncertainty on forecast results and make informed decisions even with limited information.

Some types of uncertainty models that can be applied in the context of environmental uncertainty:

- Distribution models: These models use statistical distributions to describe possible values of input data. For example, a normal distribution can be used to model the impact of changes in climatic parameters on the ecosystem.
- Models of linguistic variables: They use fuzzy linguistic variables to express uncertainty. Such models are useful when environmental concepts may be difficult to measure or define unambiguously.
- Bayesian network models: These models allow for considering various sources of information and their uncertainty in decision-making. They are based on probability theory and can consider even complex relationships between variables.
- Models of a priori uncertainty: These models help account for uncertainty in model parameters before data analysis. This allows for more realistic results with insufficient information.
- Stochastic programming models: They are used to optimize decisions under uncertainty. Such models help determine the best course of action considering possible scenarios.

- System dynamics models: These models focus on the dynamics and relationships between different components of the system. They allow exploring how changes in one part of the environmental system can affect other aspects of it.

Bayesian Network Models are a powerful tool for modeling uncertainty and relationships between different variables in conditions of environmental uncertainty. They are based on probability theory and graph theory, allowing for the consideration of various sources of uncertainty and the assessment of the impact of this uncertainty on results.

The main components of Bayesian Networks (BN) include:

1. Nodes (Vertices): Nodes represent variables in the model. For example, a node may represent water pollution, soil contamination, or the amount of precipitation.

2. Edges (Arcs): Edges indicate connections between nodes. They can be directed (when there is a cause-and-effect relationship) or undirected (when the relationship is symmetric). For example, the influence of precipitation on crop yield can be represented by an edge.

3. Probability Tables: Each node can have a probability table assigned to it, indicating the probabilities of different values of that node based on the values of other nodes it is connected to.

In the context of environmental uncertainty, Bayesian Networks allow for:

- Data Uncertainty: If data for certain system parameters are incomplete or inaccurate, BNs can help estimate possible values of these parameters based on other sources of information.

- Relationships: BNs can model complex relationships between different components of an ecosystem. For example, they can help identify how a change in one parameter may affect other aspects of the environmental system.

- Scenario Analysis: You can model various scenarios for the development of an ecosystem with different levels of uncertainty. This can help determine the potential consequences of different decisions.

- Risk and Management Strategies: BNs enable the assessment of risks and the development of management strategies for environmental systems, taking into account uncertainty and possible outcomes.

It's important to note that building and analyzing Bayesian Networks can be a challenging task, especially with a large number of variables and limited data. The quality of the model depends on the quality of the input data and the adequacy of the selected network structure.

In the context of environmental uncertainty, distribution models are used to describe possible values of variables and quantities in environmental systems that may be unpredictable or subject to change due to various factors. Some common types of distribution models used in environmental research include:

1. Normal Distribution: Often used to model continuous variables with a symmetric and bell-shaped distribution.

2. Poisson Distribution: Used for modeling counts of rare events, such as the number of species observed in an environmental survey.

3. Binomial Distribution: Suitable for modeling binary outcomes, such as the presence or absence of a particular species in a habitat.

4. Exponential Distribution: Useful for modeling the time between events, such as the time between arrivals of individuals in a population.

5. Gamma Distribution: Frequently employed for modeling the distribution of waiting times or durations.

6. Log-Normal Distribution: Applied to variables that have a skewed distribution, often encountered in ecology when dealing with biological populations.

These distribution models help ecologists and researchers understand how different parameters may be distributed within an environment and the likelihood of specific events or values occurring. They are valuable tools for studying and making predictions in complex environmental systems.

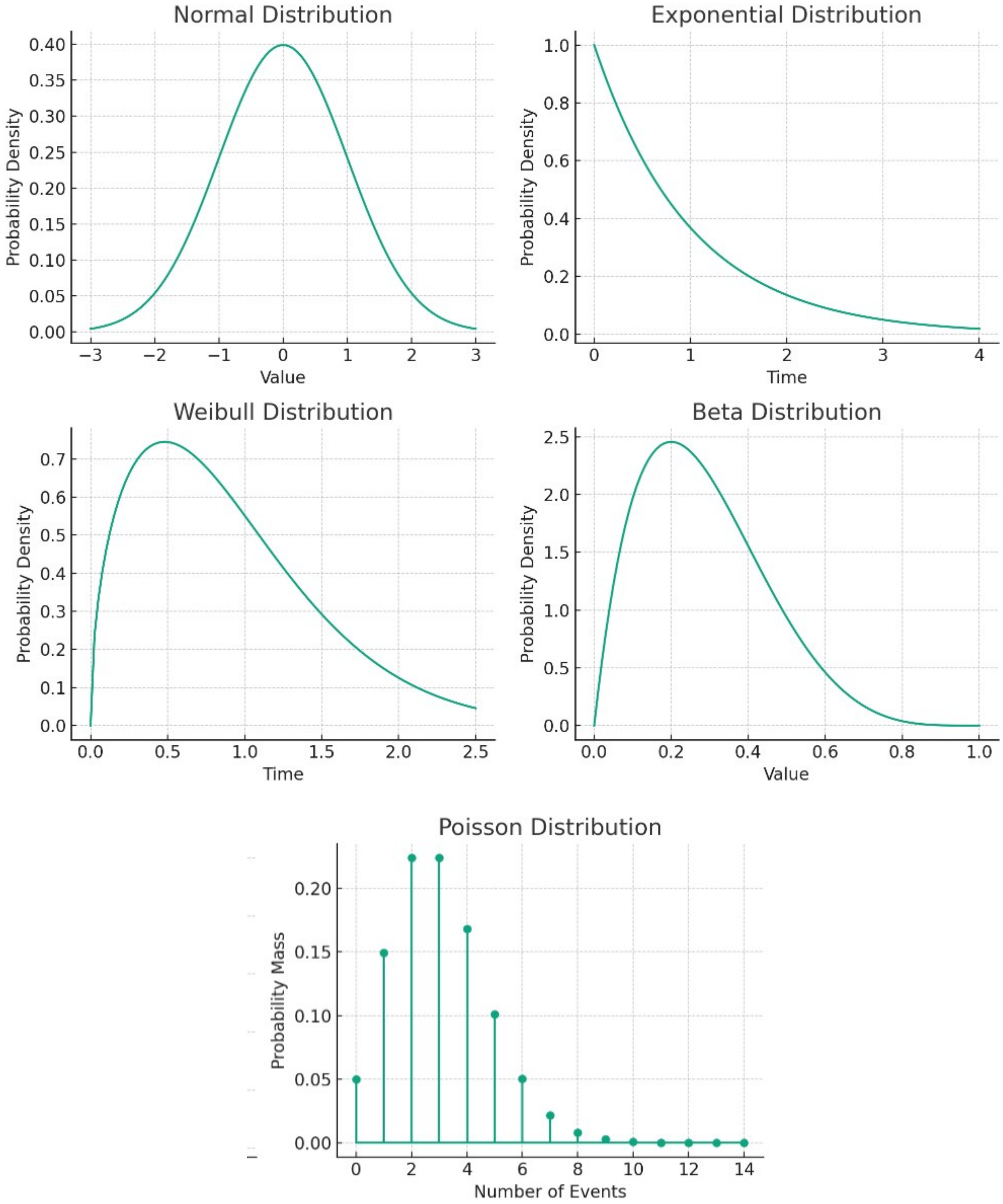


Figure 3.1. Distribution functions.

1. Normal Distribution (Gaussian Distribution): This is one of the most common distributions, often used to describe the values of variables when their random

deviations from the mean are small. In the context of ecology, this distribution can be used, for example, to model the distribution of sizes of animal or plant populations.

2. Exponential Distribution: This distribution is used to model the time between events in a process with the property of memorylessness. In ecology, this can be useful for modeling intervals between events, such as the appearance of new individuals in a population.

3. Poisson Distribution: This distribution is used to model rare events or a random process with the property of discreteness. In environmental studies, this may relate to, for example, the number of appearances of a certain species in a certain place and time.

4. Weibull Distribution: This distribution is applied to model the time until the occurrence of a certain event when the considered quantity has an influence. In ecology, this can be used, for example, to analyze the lifespan of organisms or the time until certain natural phenomena occur.

5. Beta Distribution: This distribution is used to model quantities that are limited from 0 to 1. In ecology, this may relate to, for example, the relative frequencies of certain phenomena.

When choosing an environmental uncertainty model for the decision-making system of an agricultural enterprise, it is important to consider a number of key factors and stages: Define specific goals: What decisions need to be made? For example, planning crops, managing water resources, protecting against pests.

1. Evaluate key tasks: What are the main tasks that the system should solve? For example, forecasting weather conditions, analyzing market trends, assessing soil conditions.

2. Analysis of Internal and External Factors: Consider internal constraints such as available resources, technical capabilities. Take into account environmental conditions, climate changes, market dynamics.

3. The choice of model should be made according to requirements.

Statistical models are advisable to use when there is enough historical data to forecast future conditions.

Fuzzy logic models are best suited for situations with a high degree of uncertainty and for modeling complex environmental systems.

Make sure that the chosen model is compatible with other management systems in the enterprise.

Validation and testing are required before implementation. Test the model on historical data. Assess the accuracy and reliability of the model before its implementation.

Choose an approach that allows you to assess and manage risks.

It is important to involve experts in the fields of ecology, agronomy, and risk management in the development and validation of the model.

Choosing the right model of environmental uncertainty is crucial for successful decision-making in an agricultural enterprise, as it allows effectively responding to changing conditions and optimizing decisions related to production, resources, and risk management.

3.2. Project Management Models of Agricultural Enterprises

Let's consider a decision-making model of a certain agricultural enterprise. Assume that the enterprise is engaged in growing certain crops in open fields. Also, suppose that the enterprise owns a certain limited land resource - Land plot S. For simplicity of modeling, let's introduce certain constraints. Assume that the properties of this plot are homogeneous and the soil properties do not change over time. Also, assume that the enterprise has enough machinery and labor to perform all types of fieldwork:

Soil cultivation: plowing, cultivation, discing, and other technical processes to prepare the soil for sowing.

Sowing and planting: sowing seeds or planting seedlings of various agricultural crops.

- Crop care: weeding, soil loosening, and other agronomic measures.
- Application of fertilizers and plant protection products.
- Fertilizing to increase soil fertility.
- Spraying plants to protect against pests and diseases.
- Harvesting.

Let's assume there is a known set of crops that the agricultural enterprise can grow, n is the number of crops. Denote as $s_1, s_2, ..., s_n$ the areas of the land plot allocated for growing each of the crops. If the yield of these crops for the given soil is known and is $u_1, u_2, ..., u_n$ respectively, then the total harvest of the agricultural enterprise collected over a year can be calculated using the formula:

$$\sum_{i=1}^{n} u_i s_i \tag{3.1}$$

Let's assume the known selling price of each crop is $p_1, p_2, ..., p_n$. Suppose the total costs for technological processes, including the purchase of seed material, soil cultivation, sowing, fertilizing, treatment with weed and pest control agents, harvesting, storage, and transportation are $d_1, d_2, ..., d_n$. Then the total profit of the agricultural enterprise can be calculated using the formula:

$$\sum_{i=1}^{n} (u_i s_i p_i - d_i) \tag{3.2}$$

The decision-making task can be reduced to choosing the sowing area for each of the crops. That is, the model for finding the optimal strategy of the agricultural enterprise can be found as an optimization problem:

$$\sum_{i=1}^{n} (u_i s_i p_i - d_i) \rightarrow max; \tag{3.3}$$

$$\sum_{i=1}^{n} s_i \leq S; \tag{3.4}$$

$$s_i \geq 0, i = \overline{1, n}. \tag{3.5}$$

Task (3.3)-(3.5) describes a simple decision-making model by a firm in the agricultural sphere. This model allows for simple decision-making. However, in constructing a simple decision-making model, too many restrictions and simplifications were made. It poorly describes real processes.

Relaxing some assumptions allows for building a more accurate model. Let's assume the entire cultivation process in the field is described as a sequence of stages $\Omega_1, \Omega_2, \ldots, \Omega_m$ where m is the number of stages of the cultivation process. For example, the cultivation process of crops includes the following stages: soil cultivation, sowing, fertilizing, treatment with weed and pest control agents, harvesting, then m=5. At each stage, there is a finite set of possible execution options: $o_i^1, o_i^2, \ldots, o_i^{k_i}$ where k_i is the number of possible execution options for stage Ω_i. For example, at the sowing stage, possible execution options include choosing the supplier and variety of seeds for a certain crop. And at the fertilizing stage - choosing the dosage.

The chosen execution options for each of the stages $\Omega_1, \Omega_2, \ldots, \Omega_m$ affect the harvested crop and the total costs for technological processes. Then the model for finding the optimal strategy of the agricultural enterprise can be written as follows:

$$\sum_{i=1}^{n} \left(u_i(o_i^1, o_i^2, \ldots, o_i^{k_i}) s_i p_i - d_i(o_i^1, o_i^2, \ldots, o_i^{k_i})\right) \to max; \tag{3.6}$$

$$\sum_{i=1}^{n} s_i \leq S; \tag{3.7}$$

$$s_i \geq 0, i = \overline{1, n}. \tag{3.8}$$

The decision-making task of the enterprise in the agricultural sphere (3.6)-(3.8) consists of choosing the optimal set at each stage of cultivation and choosing the optimal set of crops.

The considered decision-making model of the enterprise in the agricultural sphere is a deterministic model. It lacks random or stochastic components. For constant input data, using a deterministic model always yields the same result. Natural processes, such as the cultivation of agricultural production, are not entirely deterministic. Unlike deterministic processes, where results can be precisely predicted from input data, natural processes include a significant level of randomness and unpredictability.

Let's consider the development of a stochastic decision-making model of the enterprise in the agricultural sphere.

Define the key variables and parameters that affect decisions in the agricultural sector. Assign a variable to each parameter. Examples of parameters are shown in Table 3.1.

Among the considered parameters, there are some whose values we can determine unambiguously, for example, the amount of fertilizers applied or the variety of the crop. Variables corresponding to parameters whose values we can determine unambiguously, such as o_i^{13}, o_i^{1}, will be clear variables in the model. Other parameters, such as temperature or damage from diseases, cannot be unambiguously determined at the decision-making stage.

However, there are certain historical data that can help estimate the values of these parameters. For this, it is necessary to collect historical data and perform their statistical analysis, which are fundamental stages in creating a stochastic decision-making model for an agricultural enterprise.

Data collection on weather, includes gathering data on temperature, precipitation, wind conditions, solar activity, etc. This data can be obtained from meteorological services or specialized databases.

It is also appropriate to analyze historical data on agricultural product prices, including price fluctuations, seasonal trends, etc. Gathering information about historical costs, including the cost of seeds, fertilizers, plant protection products, fuel, labor.

Table 3.1. Parameters Affecting Decision-Making in the Agricultural Sector

Group of Parameters	Variable	Indicator
Crop	o_i^1	Crop variety
	o_i^2	Planting date
	o_i^3	Harvest date
Weather Conditions	o_i^4	Temperature
	o_i^5	Humidity
	o_i^6	Precipitation
	o_i^7	Wind
Environmental Factors	o_i^8	Soil erosion
	o_i^9	Damage from disease
	o_i^{10}	Damage from weeds
	o_i^{11}	Damage from insects and other pests
Costs of Cultivation	o_i^{12}	Number of fertilizers applied
	o_i^{13}	Amount of irrigation
	o_i^{14}	Amount of applied plant protection products
	o_i^{15}	Costs of land treatment, e.g., weeding
Market Parameters	o_i^{16}	Market price of the crop
	o_i^{17}	Logistic costs
	o_i^{18}	Capital costs

Collecting data on threats from pests, diseases, and soil erosion to the agricultural enterprise is of great importance, as these factors can significantly affect the yield and quality of agricultural production. Gathering information about past cases of crops being infected by pests and diseases. Analyzing data about types of pests and diseases, their distribution, seasonality, and impact on yield. Regular observation of the condition of crops to detect signs of infection. Using sensors, drones, and other technologies to detect pests and diseases at early stages. Gathering information about past cases of soil erosion in relevant areas. Analyzing changes in soil quality and structure over time. Studying geological and geographical characteristics of lands that may affect erosion. Using maps of soil erosion created based on satellite images and other sources. Conducting field analyses to assess soil structure, permeability, organic matter levels, etc. are important stages.

After data collection, their analysis is carried out:

First, it is necessary to find descriptive statistics: Analysis of averages, medians, standard deviations, etc., to get a general idea of the data.

Next, a correlation analysis should be conducted to identify relationships between different variables, for example, between the amount of applied plant protection products and the damage from disease.

Constructing regression models for forecasting one variable based on others helps identify general trends, such as increases or decreases in yield or market prices over time.

This statistical analysis helps identify important patterns and dependencies that can be used to build a more accurate and effective stochastic decision-making model.

Variables corresponding to parameters whose values we cannot unambiguously determine at the decision-making stage, such as o_i^4, o_i^{12}, will be fuzzy variables in the stochastic decision-making model of the agricultural enterprise.

Consider a model in which variables from the groups of crops, cultivation costs, and market parameters are clear, and variables from the groups of weather conditions and environmental factors are fuzzy.

A fuzzy variable in the context of fuzzy logic and the theory of fuzzy sets is a key concept. It represents a variable whose value is not precisely or unambiguously defined but is described by a range of possible values with a certain degree of membership. A fuzzy variable can take a wide range of values, not limited to strictly defined states.

Each possible value of a fuzzy variable has a certain degree of membership, indicating how "true" or "characteristic" this value is for a given situation or object.

Fuzzy variables are widely used in fuzzy controllers, decision-making, forecasting, and other areas where there is a need to process ambiguity, subjectivity, or uncertainty. For example, in the agricultural sector, fuzzy variables can be used to model concepts like "soil productivity" or "risk of disease infection," where precise values may be difficult to determine.

Using fuzzy logic and fuzzy variables allows for more effective modeling and processing of complex, ambiguous, or dynamic systems, where traditional precise approaches may be limited or inadequate.

Membership functions in fuzzy logic define the degree to which a particular value corresponds to a fuzzy variable. They are the basis for defining and processing fuzzy variables. The results of the analysis show that there are several main types of membership functions:

1. Triangular Membership Function:
   - Has the shape of a triangle.
   - Easy to use and calculate.
   - Used for representing simple fuzzy sets.
2. Trapezoidal Membership Function:
   - Has the shape of a trapezoid.
   - Provides a more flexible representation, allowing for a range in which the variable fully corresponds to the fuzzy set.
   - Often used in cases where greater uncertainty needs to be accounted for.
3. Bell-Shaped Membership Function:
   - Has the shape of a bell or Gaussian curve.
   - Effective for modeling situations where variables change more smoothly.
   - Often used in examples where variables have a natural or biological basis.
4. Sigmoidal Membership Function:
   - Has the shape of a sigmoid or "S"-shaped curve.

- Useful for modeling processes where variables transition from one state to another in a smooth manner.

- Often used for modeling logistic processes.

5. Parabolic (Quadratic) Membership Function:

- Has the shape of a parabola.

- Used for modeling situations where variables have a quadratic dependence.

6. Hyperbolic Membership Function:

- Has the shape of a hyperbola.

- Can be used for modeling situations where variables have a hyperbolic dependence or relationship.

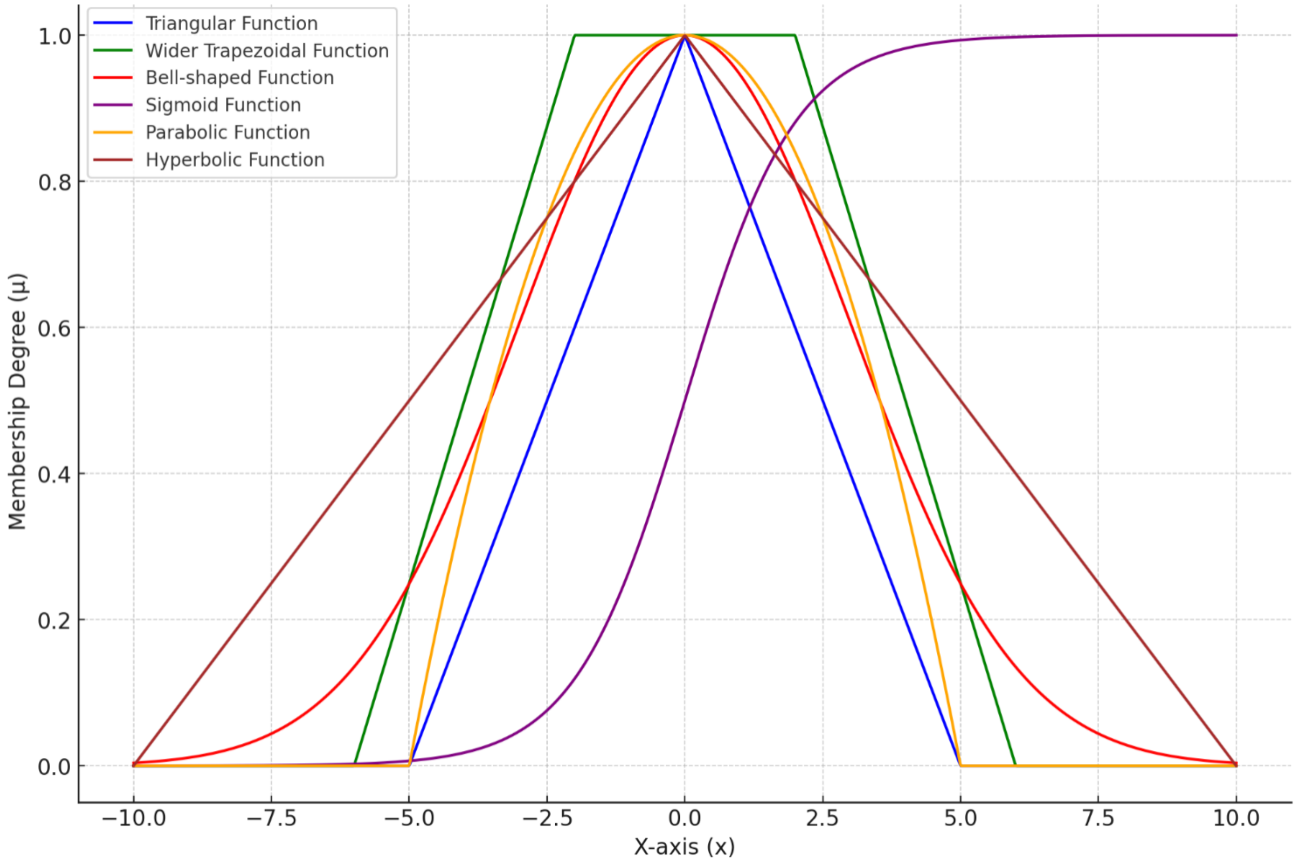


Figure. 3.2. Triangular Function: Shown in blue. Trapezoidal Function: Shown in green. Bell-shaped Function: Shown in red. Sigmoid Function: Shown in purple. Parabolic Function: Shown in orange. Hyperbolic Function: Shown in brown

Each type of membership function is chosen depending on the specific application and characteristics of the fuzzy variable that needs to be modeled. The choice of membership function affects the accuracy and efficiency of the fuzzy model, making it a critically important step in the development process of fuzzy systems.

Let μ_i^4 be the membership function of the variable o_i^4, then the pair o_i^4, u_i^4 (defines a fuzzy variable that determines temperature.

According to the analysis conducted for environmental uncertainties, the most appropriate choice is the use of a bell-shaped membership function.

The bell-shaped membership function, based on the Gaussian distribution, can be described by two key numerical parameters: the center (c) and the standard deviation (σ). The value corresponding to the center of the bell curve on the x-axis indicates the point where the membership function reaches its maximum value. The central position c determines where on the x-axis the "ideal" or most characteristic value for the fuzzy variable is concentrated.

The standard deviation (σ) defines the width of the curve. It shows how widely the values are distributed around the center c. A larger standard deviation makes the curve wider, indicating greater fuzziness or uncertainty. On the other hand, a smaller standard deviation makes the curve narrower, showing more confidence or accuracy in the assessment. In the Gaussian function form, these parameters are used as follows:

$$\mu_i^j = e^{-\frac{1}{2}\left(\frac{o_i^j - c_i^j}{\sigma_i^j}\right)^2} \tag{3.9}$$

o_i^j is the value of the parameter on the x-axis for which the degree of membership μ_i^j is determined.

Then replace all fuzzy variables in the decision-making model of the agricultural enterprise (3.4)-(3.6) with pairs of values for the center and standard deviation of the respective membership function.

Then the fuzzy decision-making model of the agricultural enterprise in the context of environmental uncertainty can be written as follows:

$$\sum_{i=1}^{n} (u_i(o_i^1, o_i^2, o_i^3,\ (\mathrm{c}_i^4, \mu_i^4), (\mathrm{c}_i^5, \mu_i^5), (\mathrm{c}_i^6, \mu_i^6), (\mathrm{c}_i^7, \mu_i^7), (\mathrm{c}_i^8, \mu_i^8), (\mathrm{c}_i^9, \mu_i^9), (\mathrm{c}_i^{10}, \mu_i^{10}), (\mathrm{c}_i^{11}, \mu_i^{11})$$

$$,$$

$$o_i^{12}, o_i^{13}, o_i^{14}, o_i^{15}, o_i^{15}, o_i^{16}, o_i^{17}, o_i^{18}) s_i p_i -$$

$$d_i(o_i^1, o_i^2, o_i^3,\ (\mathrm{c}_i^4, \mu_i^4), (\mathrm{c}_i^5, \mu_i^5), (\mathrm{c}_i^6, \mu_i^6), (\mathrm{c}_i^7, \mu_i^7), (\mathrm{c}_i^8, \mu_i^8), (\mathrm{c}_i^9, \mu_i^9), (\mathrm{c}_i^{10}, \mu_i^{10}), (\mathrm{c}_i^{11}, \mu_i^{11}),$$

$$o_i^{12}, o_i^{13}, o_i^{14}, o_i^{15}, o_i^{15}, o_i^{16}, o_i^{17}, o_i^{18})) \rightarrow max; \qquad (3.10)$$

$$\sum_{i=1}^{n} s_i \leq S; \qquad (3.11)$$

$$s_i \geq 0, i = 1, n. \qquad (3.12)$$

In Figure 3.3, the concept of a fuzzy decision-making model for an agricultural enterprise in conditions of environmental uncertainty is presented.

Using a fuzzy decision-making model in an agricultural enterprise under conditions of environmental uncertainty has several advantages:

Fuzzy logic allows for more effective modeling of real situations where there are ambiguous, inaccurate, or incomplete data, which is often encountered in environmental conditions.

Fuzzy models provide the flexibility to adjust parameters to adapt to different conditions and situations, which is especially useful in rapidly changing environmental conditions.

Thanks to a more accurate representation of reality, fuzzy models can help make more informed and effective decisions.

Fuzzy models can adapt and learn based on new data, which is useful in variable environmental conditions.

Overall, fuzzy decision-making models can significantly improve the management of agricultural enterprises under conditions of environmental uncertainty, providing flexibility, accuracy, and adaptability necessary for effective resource management and risk minimization.

If statistical parameters of historically collected data are used to define the membership function parameters in the fuzzy decision-making model of an agricultural enterprise under conditions of environmental uncertainty, we get a stochastic decision-making model for an agricultural enterprise under conditions of environmental uncertainty.

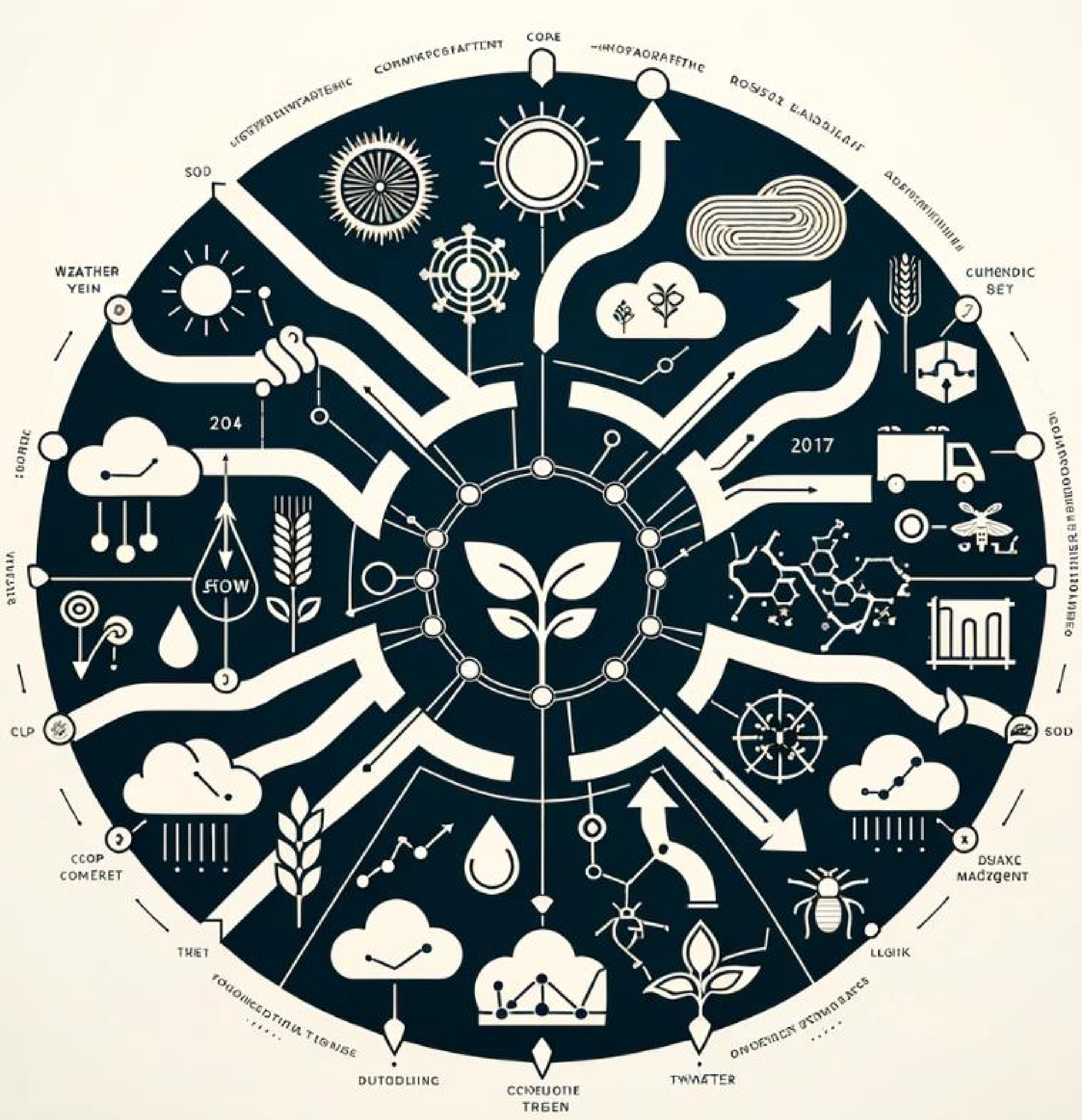


Figure 3.3 Concept of a Fuzzy Decision-Making Model for an Agricultural Enterprise in Conditions of Environmental Uncertainty.

Using a stochastic decision-making model in an agricultural enterprise under conditions of environmental uncertainty can bring several advantages and features for decision-making: increasing the accuracy of the model by using real historical data for calibrating membership functions can significantly improve the accuracy of the model, as it provides a more realistic representation of conditions and variables. Analyzing historical data allows identifying trends and patterns that can be integrated into the membership functions, providing a deeper understanding of the system's dynamics.

With the use of historical data, the model can be more flexible and adaptive to changes that have occurred in the past, which can be useful for predicting future changes.

Historical data can help in identifying risks and uncertainties that have previously affected the agricultural enterprise, and in incorporating them into decision-making.

Using historical data to calibrate membership functions allows for more effective validation of the model, comparing its predictions with real historical events.

Instead of subjective determination of parameters, using statistical data provides a more objective basis for modeling.

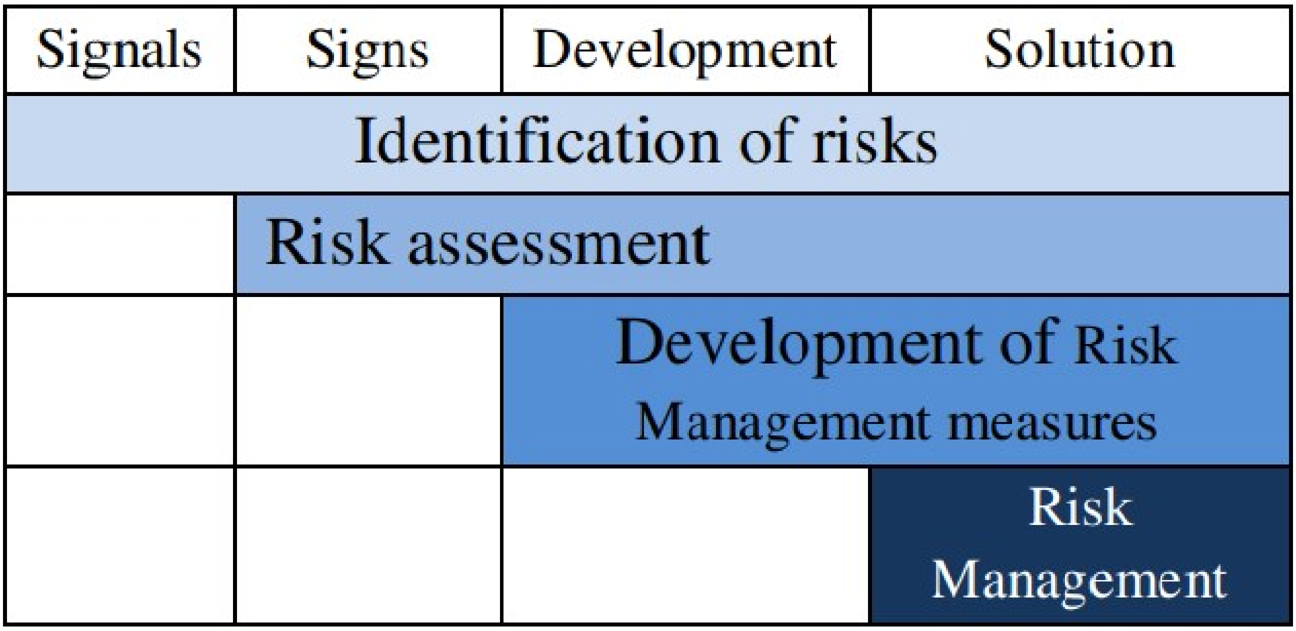
It is important to consider that while the use of historical data can significantly improve the model, it is also important to consider possible changes in conditions and make adjustments to adapt the model to current or future trends. Historical data should be used as a foundation, but with constant updating and adaptation of the model.

3.3. Fuzzy model for assessing the risks of an agricultural enterprise's activities under environmental uncertainty

For modeling economic phenomena and processes associated with a high level of uncertainty, it is appropriate to apply the theory of fuzzy sets. The use of fuzzy mathematics [69] is a tool for solving problems of aggregating ambiguous, subjective, and inaccurate evaluative judgments of experts about the state of a particular parameter or risk indicator of the enterprise. With the help of fuzzy set theory, it is possible to model complex systems in conditions of insufficient information and randomness of processes.

The process of risk management can be divided into the following four stages (Fig. 3.4):

1. Identification of risks.
2. Analysis and assessment of risks.
3. Development of risk management measures.
4. Monitoring and operational risk management.



Signals	Signs	Development	Solution
Identification of risks			
	Risk assessment		
		Development of Risk Management measures	
			Risk Management

Figure 3.4 Risk Management stages

In the first stage, risk criteria should be determined, risk identification methods should be developed, and a risk classification system should be formed.

In the second stage, it is necessary to form a list of possible risk situations, assess the degree and measure of risk for each case, and determine the priority of risks.

In the third stage, it is necessary to determine risk management methods, organize the risk management process and develop preventive measures for risks.

At the last stage, it is necessary to implement risk management methods, assess the effectiveness of risk management, and form a risk knowledge management system.

According to the estimates of "The World Economic Forum" [70]. The top global risks (Figure 3.5):

1. Geopolitical instability.
2. Problems of economic development.
3. Insufficient measures to combat climate change.
4. Negative consequences of loss of biodiversity.
5. Inefficient development management technologies.

Figure 3.5 Global risks [70]

When assessing risks, it should be recognized that it is impossible to ultimately get rid of risk in most situations. Hence, it is necessary to determine the acceptable risk level is the level at which the danger ceases to threaten the enterprise.

According to ISO standards [71], risk assessment results from two procedures – risk analysis and measurement.

Risk analysis can be divided into a priori strategic, operational-tactical, and a posteriori systemic.

Risk measurement is related to the evaluation degree, risk measure, and risk price.

The degree of risk assesses an adverse situation's possibility and statistical frequency.

The measure of risk is an assessment of the level of unfavourability of a risky situation in case of its realization, which reflects its possible negative consequences.

The price of risk is the ratio of the maximum possible result to the degree of risk.

The risk analysis algorithm [8] consists of seven steps and is shown in Figure 3.6.

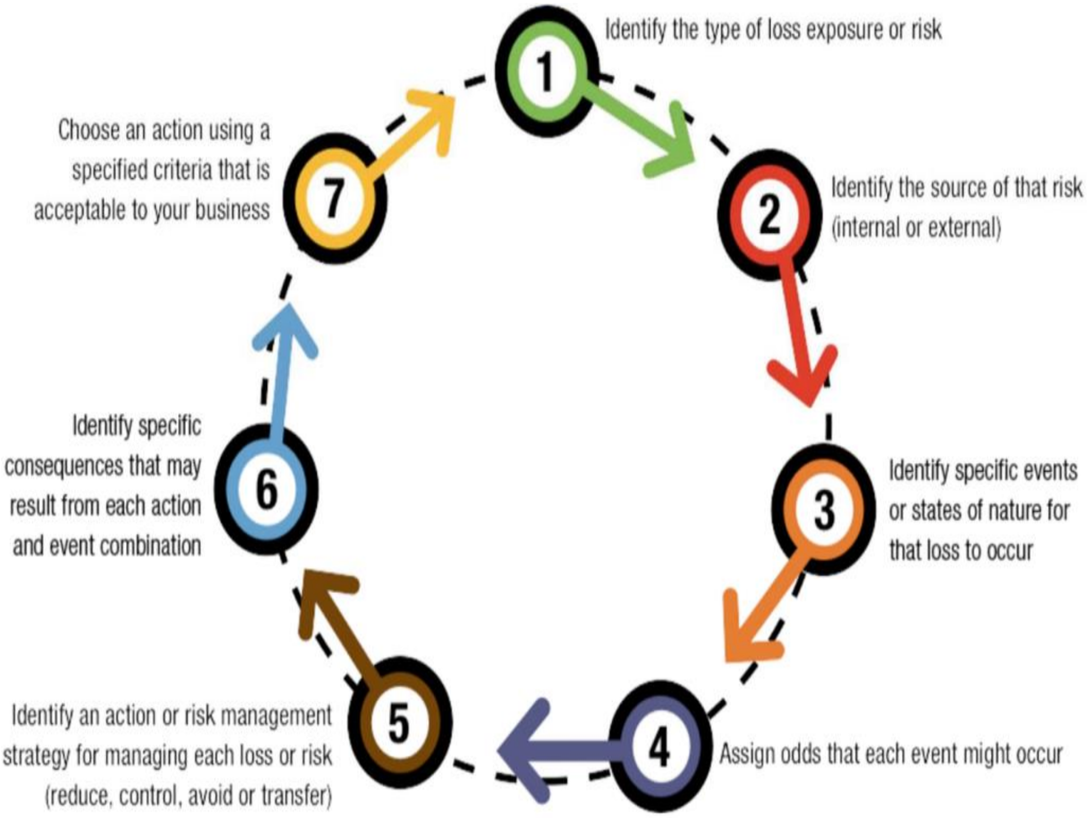


Figure 3.6. Risks analysis algorithm.

Considering the process approach to evaluating the factors of negative impact on an agricultural enterprise in conditions of environmental uncertainty, let’s consider a hierarchical model for quantitative assessment of integral risk:

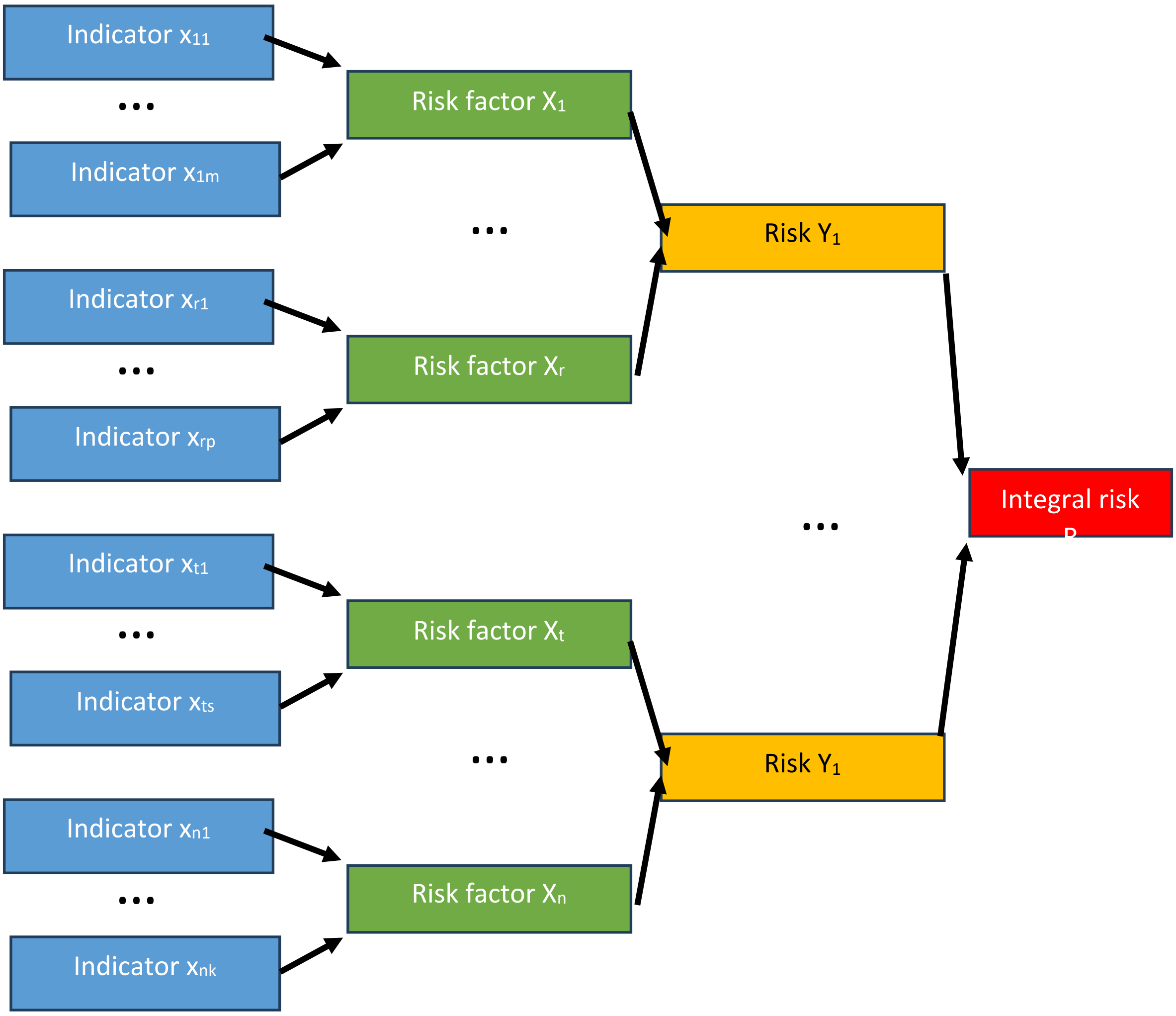


Figure 3.7. Hierarchical Model for Quantitative Assessment of Integral Risk

It is necessary to conduct a quantitative assessment of risks inherent to each process, according to their specific types of risks and corresponding factors. These factors can be assessed using appropriate indicators. Although the types of risks for short-term and long-term periods are identical, there are significant differences in the factors of these risks, their level of impact, and the overall level of risk. Especially in the long term, the level of impact increases due to increased uncertainty. These differences in risk factors will be accounted for by integrating additional or alternative indicators for long-term risks. The difference in the level of impact of the same risk factors and the same types of risks in different periods should be incorporated into the parameters of the mathematical model.

The proposed approach to quantitative risk analytics is the foundation of a fuzzy hierarchical model, which includes the following components: leaves, representing risk indicators (x_{11}, …, x_{nk}); nodes, representing specific process risks (X_1, …, X_n) and overall risks of each process (Y_1, Y_2); the root of the tree as an integral indicator of risk in crisis management (Z). The choice of approach to structuring the fuzzy hierarchical model, where fuzzy conclusions are formed on intermediate variables with subsequent transmission of precise values to fuzzy systems of the next level of hierarchy, has several advantages, as it allows assessing:

- Individual types of risks within each process;
- Overall risks of the processes of agricultural enterprise activities;
- Integral risk in enterprise management.

This approach facilitates making operational management decisions regarding all identified risks and their factors.

Conducting a quantitative assessment of risks in an agricultural enterprise using a fuzzy hierarchical model is a comprehensive approach that accounts for the variability and complexity of risk factors across different timeframes. This approach can significantly enhance the precision and effectiveness of risk management strategies.

The fuzzy hierarchical model for quantitative risk assessment in agricultural enterprises offers a nuanced and comprehensive framework. It effectively addresses the complexities of risk factors in the agrarian sector, considering the variability of these factors over different timeframes. This approach enhances the ability of an enterprise to make informed decisions, manage risks effectively, and maintain resilience in the face of environmental and market uncertainties (fig 3.8).

In the first stage of developing a fuzzy model, the main task is to define linguistic variables and their corresponding values. A linguistic variable in this context is defined as a variable whose values can be represented in the form of words or phrases used to qualify different phenomena, processes, or objects. All potential values of a linguistic variable form what is called a term-set, and its components are called terms.

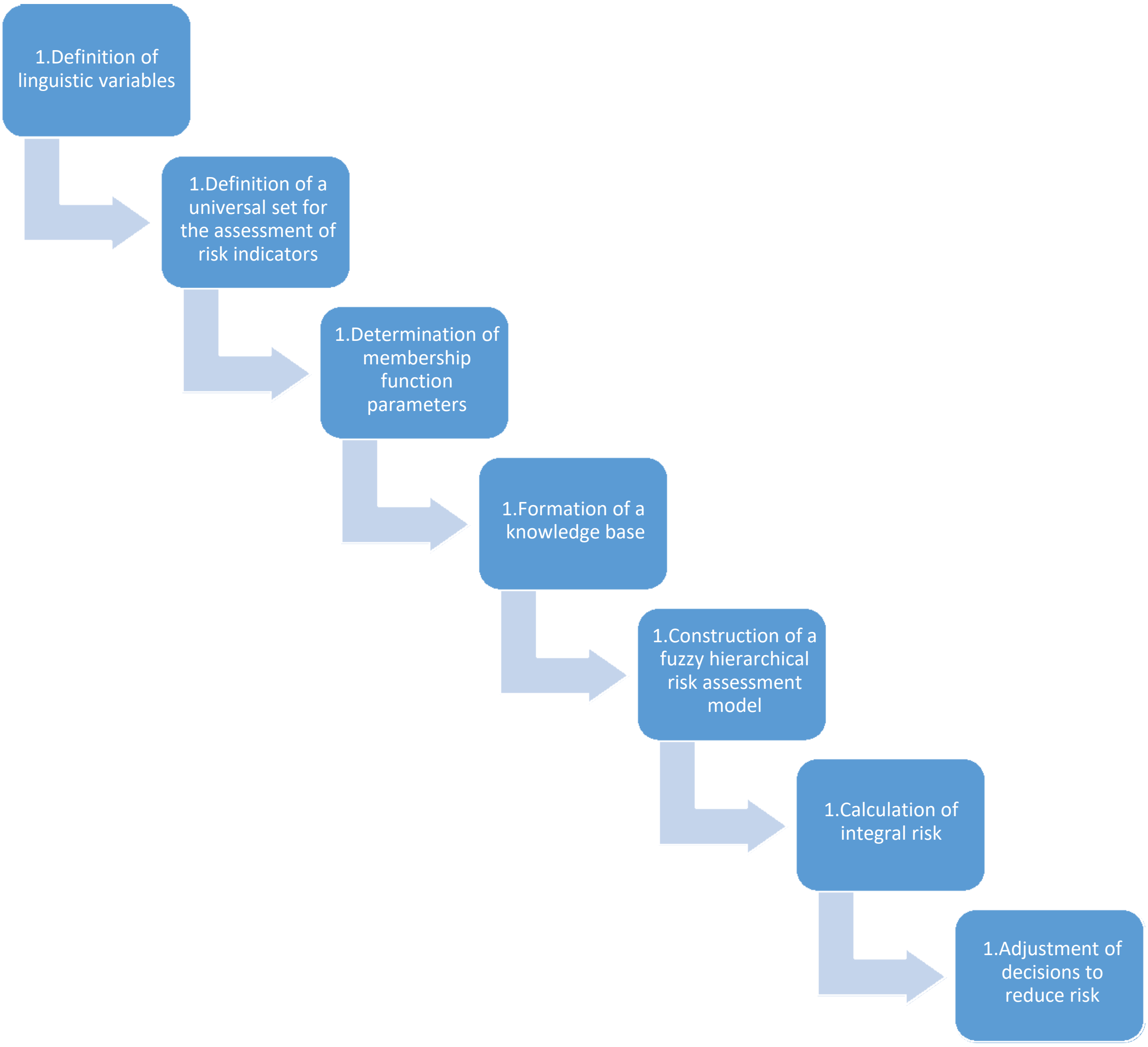


Figure 3.8. Stages for Quantitative Assessment of Integral Risk

For analyzing risk indicators, a linguistic variable "Indicator Level" with possible terms like "very low," "low," "medium," "high," "very high" can be introduced. Similarly, for assessing risk indicators, a linguistic variable "Risk Level" with terms such as "acceptable," "critical," "catastrophic" can be used.

The next step in the development process of the fuzzy model is establishing a universal set of numbers, the elements of which will serve to quantitatively express the assessments of indicators and risks. The optimal option for measuring the level of risks is the use of numbers in the range [0;1], where a higher numerical value reflects an increase in the level of risk. Regarding risk indicators, which can be both qualitative and quantitative, it is recommended to use a similar approach with a set of real numbers in the range [0;1] for qualitative indicators. The values of quantitative indicators are usually represented as decimal fractions that can exceed one. To align these values with the universal set of the fuzzy model, it is proposed to use percentage deviations of expected values from normative or planned ones, converting them into fractions of one. Thus, for both linguistic variables, the set of real numbers in the range [0;1] is chosen as the universal set.

In the process of creating a knowledge base, which analyzes the relationships between indicators and risks, it is critically important to consider that these relationships can have both a direct and inverse character. For most indicators and risks, an inverse correlation is observed: as the value of the indicator increases, the level of risk decreases. At the same time, there are specific categories of risks where a direct dependency is typical, such as risks associated with time constraints, levels of financial and operational leverage, and others. After establishing the term-sets and universal set, it is necessary to develop membership functions, which allow determining the degree of correspondence of any element of the universal set to a given fuzzy set. Membership functions are developed based on the statistical analysis of expert opinions on the presence of attributes in the elements of the universal set that are characteristic of the fuzzy set.

For assessing the presence in the elements of the universal set [0;1] of the properties of the fuzzy set (for indicators: very low, low, medium, high, very high; for risks: acceptable, critical, catastrophic), trapezoidal membership functions were chosen. The analytical expression of the trapezoidal function is as follows:

$$\mu(x) = \begin{cases} 0, x \leq a \\ \frac{x-a}{b-a}, a \leq x \leq b \\ 1, b \leq x \leq c \\ \frac{d-x}{d-c}, c \leq x \leq d \\ x \geq d \end{cases} \tag{3.13}$$

where μ(x) is the level of correspondence of the elements of the universal set [0;1] to the fuzzy set of values (a; d) - pessimistic assessment (the level of confidence of experts about the presence in the elements of the universal set of the properties of the fuzzy set is lower than 1); [b; c] - optimistic assessment (the level of confidence of experts about the presence in the elements of the universal set of the properties of the fuzzy set is equal to 1). The parameters of the trapezoidal membership function are set as follows: [a; b; c; d]. The general form of this function is shown in Fig.3.9.

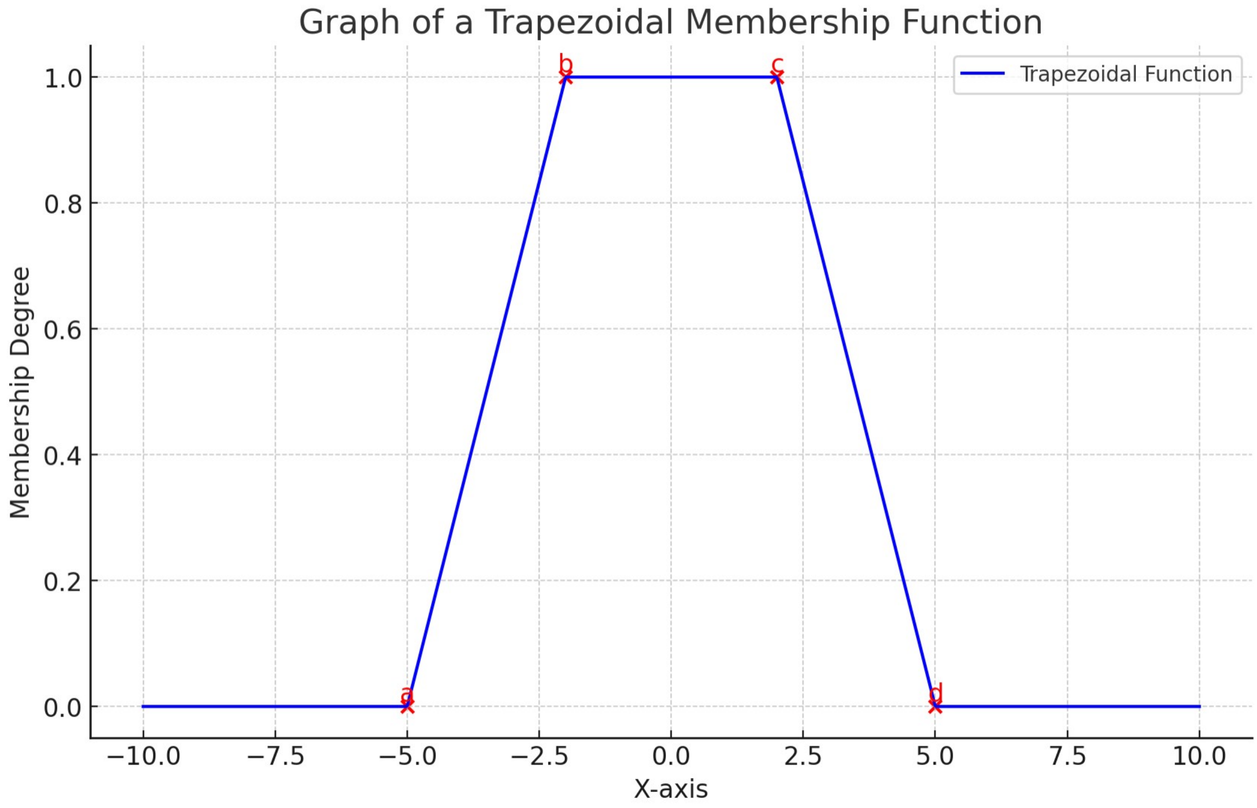


Figure 3.9. Graph of a Trapezoidal Membership Function.

The next step involves forming fuzzy knowledge bases. Considering the generalized risk assessment model (see Fig.3.4), fuzzy rules (if-then) about the following relationships need to be constructed between indicators and risks, between risks characteristic of the process and the overall risk of this process and between process risks and the integral risk of crisis management.

The developed model can be used both for risk assessment based on given indicator values and for studying the sensitivity of risks to changes in indicator values. This is important in conditions characterized by informational uncertainty and high dynamics.

Additionally, the proposed model is easily adaptable to other conditions, including the possibility of changing the parameters of this model: the list of indicators and risks, the type of membership functions and their parameters, logical rules, which allows for its application not only to agricultural enterprises but also to enterprises of other types of economic activity.

Risk factors can be classified as risk factors in the agricultural sector. They can be grouped into several main categories:

1. Environmental risk factors: deviations of temperature, moisture, precipitation, wind from optimal values affect plant development and yield. Soil erosion can negatively impact the quality and quantity of the harvest.

2. Biological risk factors: damage from disease, damage from weeds, damage from insects and other pests lead to reduced yield and quality of production.

3. Economic risk factors: Labor costs in land treatment, changes in market prices for crops, logistics costs: affect overall expenses and profitability. Insufficient capital expenditures on investments in equipment, machinery, soil improvement, etc., are also a risk factor.

4. Management factors: planning and managing the production process includes rational use of resources, effective activity planning is also a risk factor.

Table 3.2 lists indicators and risk factors. This list is not exhaustive and can be supplemented.

The Mamdani procedure is one of the fuzzy logic methods that can be applied to assess risk factors in an agricultural enterprise. It allows processing the uncertainty and fuzziness often encountered in agricultural activities. Here are the main stages of the Mamdani procedure

Table 3.2 Risk factors

Indicator	Variable	Risk	Risk function
Deviation of temperature from the optimal value	x_{11}	Environmental	X_1
Deviation of moisture from the optimal value of wind	x_{12}		
Deviation of the amount of precipitation from the optimal value	x_{13}		
Soil erosion	x_{14}		
Change in market price for crops	x_{21}	Economical	X_2
Change in logistic costs	x_{22}		
Deviation of capital expenditures on investments	x_{23}		
Damage from disease	x_{31}	Biological	X_3
Damage from weeds	x_{32}		
Damage from insects and other pests	x_{33}		
Management risk	x_{41}	Management	X_4

First, it is necessary to define variables that influence risk. Considering the previous analysis, we will use the previously defined risk indicators.

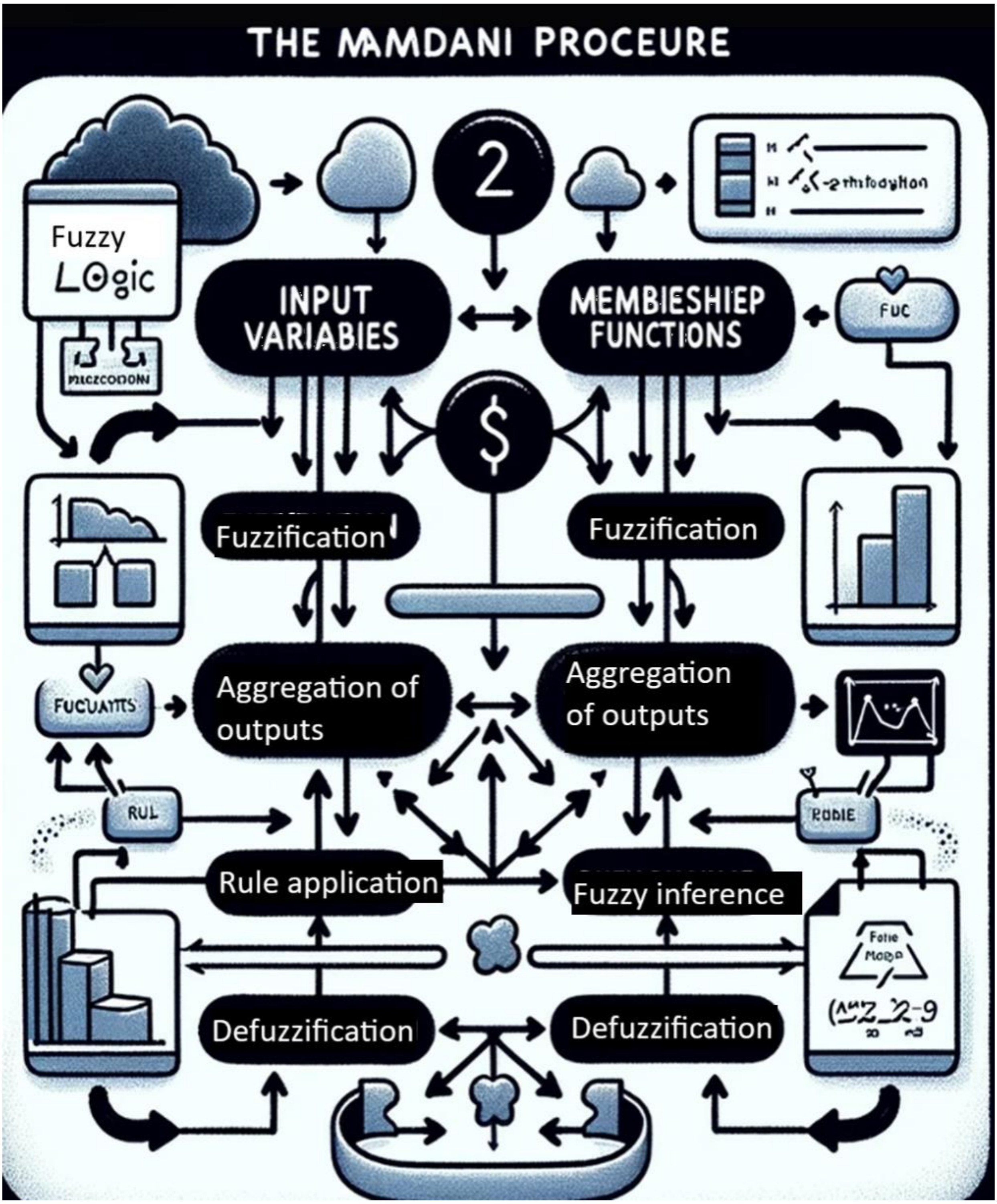


Figure 3.10 Mamdani algorithm scheme

For each variable, membership functions are created, which describe the degree to which a specific value corresponds to fuzzy sets. Membership functions describe how strongly a specific value corresponds to a fuzzy category. For example, for the deviation of moisture from the norm, categories such as "low," "medium," and "high" can be used.

A discrete membership function is a way of representing fuzzy sets where each possible value of the input variable (in this case, moisture) receives a specific degree of membership to fuzzy categories "low," "medium," "high." Suppose we have a deviation of moisture that can vary from 0% to 100%.

Table 3.3. Variables Influencing Risk

Deviation of temperature from the optimal value	x_{11}
Deviation of moisture from the optimal wind value	x_{12}
Deviation of the amount of precipitation from the optimal value	x_{13}
Soil erosion	x_{14}
Change in market price for crops	x_{21}
Change in logistic costs	x_{22}
Deviation of capital expenditures on investments	x_{23}
Damage from disease	x_{31}
Damage from weeds	x_{32}
Damage from insects and other pests	x_{33}

An example of a discrete membership function might look like this:

Low Moisture:

0% - 10%: 1 (full membership in the category "low")

11% - 20%: 0.8

21% - 30%: 0.6

31% - 40%: 0.4

41% - 50%: 0.2

Above 50%: 0 (no membership)

Medium Moisture:

30% - 40%: 0.2

41% - 50%: 0.4

51% - 60%: 0.6

61% - 70%: 0.8

71% - 80%: 1 (full membership in the category "medium")

Above 80% and below 30%: a gradual decrease in membership

High Moisture:

50% - 60%: 0.2

61% - 70%: 0.4

71% - 80%: 0.6

81% - 90%: 0.8

91% - 100%: 1 (full membership in the category "high")

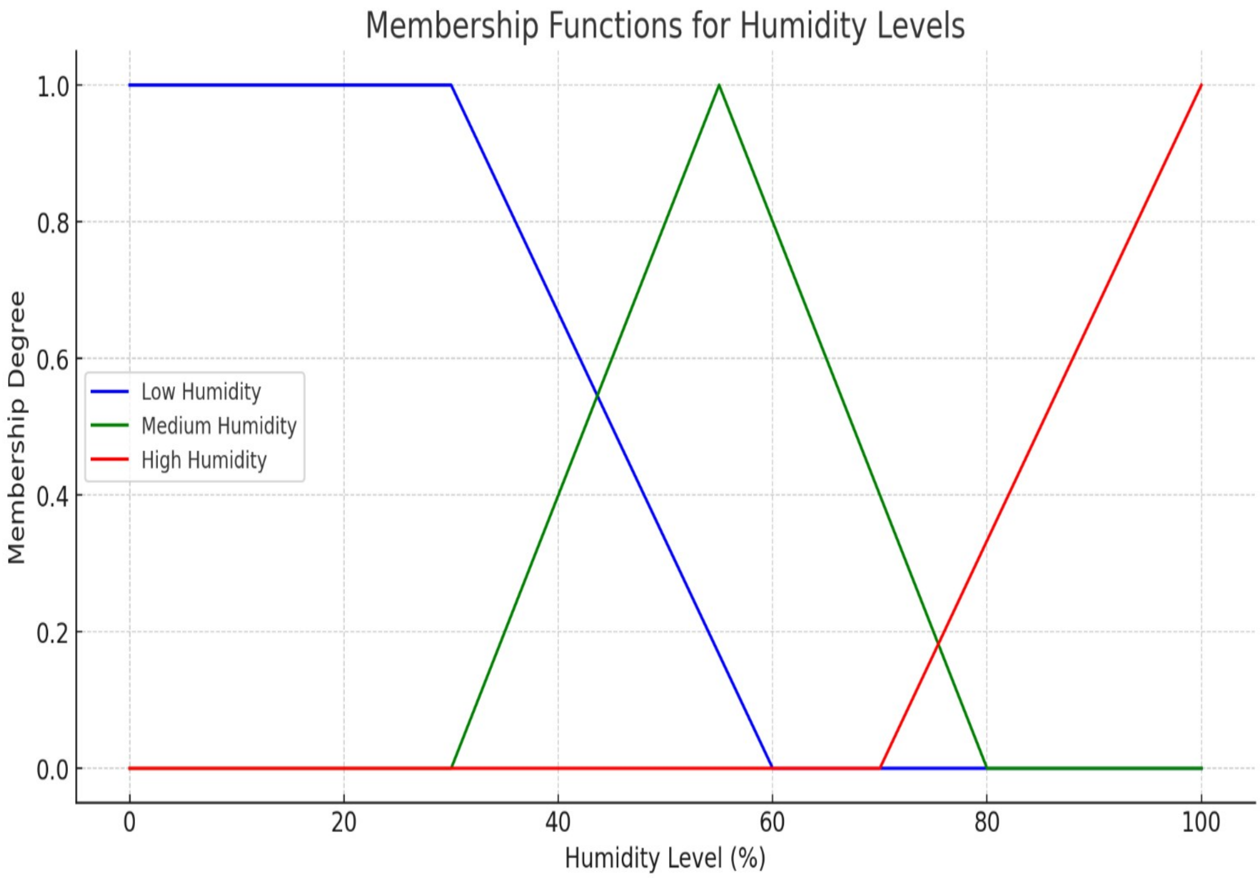


Figure 3.11. The membership functions for different levels of humidity

Development of Inference Rules:

The development of inference rules in fuzzy systems often involves using expert knowledge to formulate rules that describe relationships between different variables. These rules are used to determine how input data (e.g., weather conditions, crop status) influence conclusions (e.g., risks for an agricultural enterprise). Here are some examples of such fuzzy rules:

1. Drought Rule: "If the temperature is high and the humidity is low, then the risk of drought is high."

2. Yield Rule: "If the humidity is medium and the temperature is optimal, then the yield is high."

3. Frost Rule: "If the temperature is low in the spring period, then the risk of frost is high."

4. Pest Rule: "If the temperature is high and humidity is high for a prolonged period, then the likelihood of pests is high."

5. Irrigation Rule: "If the humidity is low and high temperature is forecasted, then additional irrigation is needed."

6. Fertilizer Use Rule: "If soil moisture is optimal and temperature is moderate, then the efficiency of fertilizer application is high."

7. Harvest Rule: "If humidity is low and dry weather is forecasted, then it is the optimal time for harvesting."

8. Plant Disease Rule: "If humidity is high and temperature is moderate for a long period, then the risk of plant diseases is high."

9. Soil Erosion Rule: "If the wind is strong and the soil is dry, then the risk of soil erosion is high."

10. Market Price Rule: "If the overall yield forecast is low, then the expected market price for the crop is high."

These rules use "if-then" logic to determine the influence of various factors on conditions or outcomes important to an agricultural enterprise. They allow the decision-making system to adapt to changing conditions and respond to potential risks.

4. Composition of Conclusions:

The aggregation process in fuzzy logic plays an important role as it allows combining the results from different inference rules into one aggregated fuzzy value. This step is where conclusions from each individual rule are combined to create an overall output that reflects all applied rules. Here are more details about this process:

1. Maximization of memberships is the choice of the highest degree of membership from all the rule conclusions. For example, if one inference rule gives a membership degree of 0.7 and another 0.5, the aggregated output will be 0.7.

2. Sum of all rule conclusions can exceed 1, as the membership degrees from different rules are summed. For example, if one inference rule gives a membership degree of 0.7 and another 0.5, the aggregated output will be 1.2.

Let consider the example of Application in the Agricultural Sector

Imagine we have two inference rules:

- Rule 1: "If the temperature is high, then the risk of drought is high."
- Rule 2: "If humidity is low, then the risk of drought is also high."

If current conditions give a high degree of membership for "high temperature" and a medium for "low humidity," each rule generates its conclusion about drought risk. Aggregation of these conclusions will allow forming a single assessment of drought risk that takes into account both these factors.

Aggregation of conclusions is key as it allows integrating the impact of different conditions or factors on the final outcome. It provides the flexibility of fuzzy logic, allowing the system to account for the complexity and multifaceted nature of the real world. The resulting aggregated output is used in the next step for defuzzification, giving a precise final value for decision-making.

5. Defuzzification is the process by which a fuzzy output (comprising several fuzzy conclusions) is converted into a single precise numerical value. It is the final step in the fuzzy logic process, allowing the results of fuzzy analysis to be used for decision-making in a clear, defined format.

One of the most common methods of defuzzification is the center of gravity (centroid) method. Its steps include:

- Forming an Aggregated Fuzzy Output Set: After applying all inference rules and aggregating the results, an overall fuzzy output set is formed.

- Determining the Center of Gravity: The center of gravity of this aggregated output set is determined as the balancing point if the area under the curve of the fuzzy output set were a physical area.

- Formally, it is the average of all possible output values, taken into account their degrees of membership.

Let Z be the fuzzy conclusion about the global risk obtained by the sum method, then the expected value is calculated as:

$$\mu M(x) = \int_0^1 Z(x)\mu(x)dx, \tag{3.14}$$

and the risk of activity is determined through the standard deviation:

$$\sigma(x) = \sqrt{\int_0^1 (f(x) - M)^2 \mu(x)dx}\,, \tag{3.15}$$

Since there are many risk factors, integration should be carried out for each risk factor.

To find the optimal solution in terms of risk management, the task is to minimize the coefficient of variation:

$$\frac{\sigma(x)}{M(x)} \to min, \tag{3.16}$$

The center of gravity method allows objectively and precisely determining the final decision based on fuzzy rules and input data. For example, in agriculture, this method can be used to determine the optimal time for irrigation or harvesting, where input data includes forecasted weather conditions, soil state, etc.

This method provides a clear numerical value that can be easily interpreted and used in decisions, providing a bridge between fuzzy logic and practical actions.

In the context of an agricultural enterprise, Mamdani can be used to assess risks such as crop losses, drought, economic damages from market price fluctuations, impact of pests and diseases, etc. This method allows agricultural managers to better understand potential risks and develop strategies for their minimization or management. The method can be applied to determine optimal times for critical agricultural activities like irrigation or harvesting, considering varying and uncertain factors such as weather conditions and soil states. It enables agricultural managers to quantify and understand risks like crop losses, drought, economic impacts of market fluctuations, pest infestations, and disease outbreaks.

The use of the center of gravity method for defuzzification in a fuzzy logic system is highly effective in the context of agricultural risk management. It allows for a nuanced understanding of various risk factors and provides a quantitative basis for making informed decisions to mitigate or manage these risks effectively

The approach to risk analysis using fuzzy logic and linguistic variables is methodologically sound and well-suited for dealing with the inherent uncertainties and subjective nature of risk assessment in complex systems like agrarian management. The model for risk assessment in the agrarian sector under environmental uncertainty is a sophisticated tool that effectively incorporates both quantitative and qualitative elements. By using linguistic variables and trapezoidal membership functions within a fuzzy logic framework, the model captures the complexity and subjective nature of risk assessment, providing a more nuanced and realistic approach to managing uncertainties in agricultural management.

Conclusions to chapter 3

1. It has been established that mathematical models allow for a quantitative assessment of the impact of various factors on the ecosystem and the environment, considering a wide range of uncertainties arising from randomness, incomplete data, or uncertainties in model parameters. Stochastic models use random variables to model uncertainty in parameters or impacts on the ecosystem. Models with fuzzy quantities allow for the modeling of situations with unknown exact values of parameters. Models can be combined to create more complex models that account for different aspects of uncertainty. Mathematical models of environmental uncertainty are an important tool for assessing and managing the impact of various environmental factors, allowing for the development of more effective strategies in conditions of uncertainty. However, they are only approximations of reality, and their results may be limited by the accuracy of input data and the choice of the model.

2. Decision-making models developed by an agricultural enterprise consider its activity as a controlled multi-stage process. A set of 20 parameters, which are input variables of the model, has been proposed. Conditional multi-criteria optimization methods are suggested for finding optimal values of control parameters. It has been established that a deterministic model with clear variables does not accurately describe the activity of an agricultural enterprise in terms of accounting for factors of environmental uncertainty. Therefore, 8 factors are proposed to be represented as fuzzy numbers. Since these factors represent natural processes, it is justified to choose a bell-shaped membership function, and parameters of mathematical expectation and standard deviation need to be calculated based on historical data. A stochastic approach combined with simulation modeling is proposed for finding a solution to the model.

3. A fuzzy hierarchical model for minimizing risk in the activities of an agricultural enterprise has been developed. For this, a method is presented that allows the fuzzification of parameters for which there is insufficient historical data. The method involves introducing linguistic variables based on expert assessments.

Linguistic variables can be combined with fuzzy ones by introducing a single space [0;1]. Also, the creation of a fuzzy knowledge base is proposed, which includes a set of rules. The Mamdani procedure is suggested for obtaining a clear assessment of the integral risk.

Developing a fuzzy model for risk assessment in agricultural enterprises involves a systematic approach to handling uncertainty and complexity in various risk factors. The Mamdani procedure is particularly effective in this context.

The Mamdani procedure, as applied to agricultural enterprises, offers a robust framework for risk assessment. It combines fuzzy logic's ability to handle uncertainty with practical decision-making tools, ensuring that agricultural managers can make informed decisions under complex and uncertain conditions.

CHAPTER 4. DECISION SUPPORT SYSTEM FOR AGRICULTURAL ENTERPRISE UNDER ENVIRONMENTAL UNCERTAINTY

4.1. Architecture of the decision support system for agricultural enterprise under environmental uncertainty

The term "Information System for Decision Support of an Agricultural Enterprise in Conditions of Environmental Uncertainty" defines a system that is created for the collection, processing, analysis, and provision of information necessary for decision-making in an agricultural enterprise, especially in conditions where environmental factors can be unpredictable or have a high degree of uncertainty.

Information System (IS): This is a complex of technological and organizational means designed for the collection, processing, storage, and transmission of information. In the context of an agricultural enterprise, this information may relate to the production of agricultural products, resources, finances, markets, and importantly, environmental parameters and factors.

Decision support is a set of processes designed to provide information and analysis that help the management of an agricultural enterprise make informed and optimal decisions. This can include the selection of crops, methods of cultivation, resource management, marketing strategies, and more.

Environmental uncertainty refers to the fact that in the agricultural sector, the environment and environmental conditions can be variable, difficult to predict, and require special attention in decision-making. For example, climate change, natural disasters, environmental pollution, the impact of pesticides and fertilizers on soil and water resources - all this can affect the success of agricultural activities and require adaptation and response.

Thus, the information system for decision support of an agricultural enterprise in conditions of environmental uncertainty is aimed at providing comprehensive analysis and information support for managing an agricultural enterprise, taking into account unusual environmental factors that may affect agriculture.

Modules for updating the architecture and adding new functions.

This modular architecture allows building a flexible and scalable system that can adapt to different situations of environmental uncertainty and provide effective decision support. Each module can evolve and update independently, which facilitates quick response to changes in the environmental conditions and user needs.

Special attention in this system is given to the use of the Cassandra database, which allows for efficient management of large volumes of data. This is critically important for storing and processing data on environmental uncertainties, such as series of temperatures, humidity, and other key agroclimatic indicators.

Cassandra offers several advantages for an information system like the one developed for the agricultural sector. Here are some of the key benefits:

Scalability: Cassandra is highly scalable, allowing it to handle large volumes of data with ease. This is crucial for agricultural systems where data from multiple fields, including temperature, humidity, and other environmental factors, is continuously collected and analyzed. Cassandra can scale horizontally, meaning you can add more nodes to the cluster to handle increased load, making it an ideal choice for growing data requirements.

High Availability and Fault Tolerance: Cassandra is designed for high availability and fault tolerance. It replicates data across multiple nodes, ensuring that the system can withstand node failures without data loss. This feature is particularly important for critical agricultural data, where the loss or unavailability of data can lead to incorrect decision-making.

Fast Write and Read Speeds: Cassandra provides fast write and read operations, which is essential for time-sensitive agricultural data processing. This allows for near real-time analysis of data, enabling quicker decision-making based on the latest information.

Flexible Data Storage: Cassandra supports a wide variety of data types and is schema-agnostic. This flexibility is beneficial for an agricultural system that needs to store diverse data types, from simple numerical temperature readings to more complex structured data.

Distributed Nature: Being a distributed system, Cassandra allows for data to be stored on multiple nodes across different physical locations. This distributed nature ensures that the system is resilient to regional failures, which can be crucial for agricultural enterprises operating in multiple geographic locations.

Ease of Management: Despite its powerful capabilities, Cassandra is relatively easy to manage. It automates many of the tasks that are typically labor-intensive in database management, such as replication, scaling, and ensuring consistency across nodes.

Strong Community and Support: Cassandra [94] has a robust community and is well-supported, with numerous resources available for troubleshooting and optimization. This makes it a reliable choice for systems where ongoing support and development are critical.

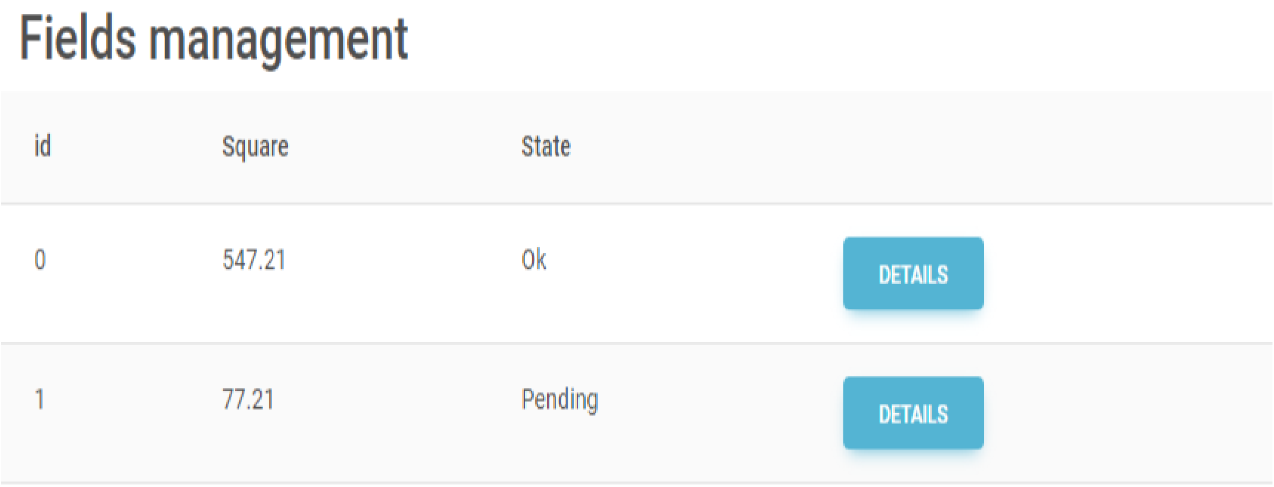
In summary, Cassandra's scalability, high availability, fast performance, flexibility, distributed nature, ease of management, and strong community support make it a highly suitable database choice for a decision support system in the agricultural sector, especially when dealing with large volumes of diverse and critical data.

The Information System for Decision Support of an Agricultural Enterprise in Conditions of Environmental Uncertainty" is a comprehensive solution designed to assist agricultural enterprises in navigating the complexities and variabilities of environmental factors. This system integrates various technological and organizational tools to facilitate informed decision-making.

The Information System for Decision Support of an Agricultural Enterprise in Conditions of Environmental Uncertainty is an advanced tool that synergizes data management, environmental understanding, and decision support. By leveraging the capabilities of Cassandra and a modular architecture, it offers a robust platform for agricultural enterprises to optimize their operations in the face of environmental challenges and uncertainties. This system not only enhances operational efficiency but also supports sustainable agricultural practices in an ever-changing environmental landscape.

Let's consider the main features of the system:

Page for Viewing Data on All Company Fields (Fig. 4.1): On this page, users can view the collected data on all fields belonging to the company. This provides a comprehensive understanding of the state of all agricultural resources.

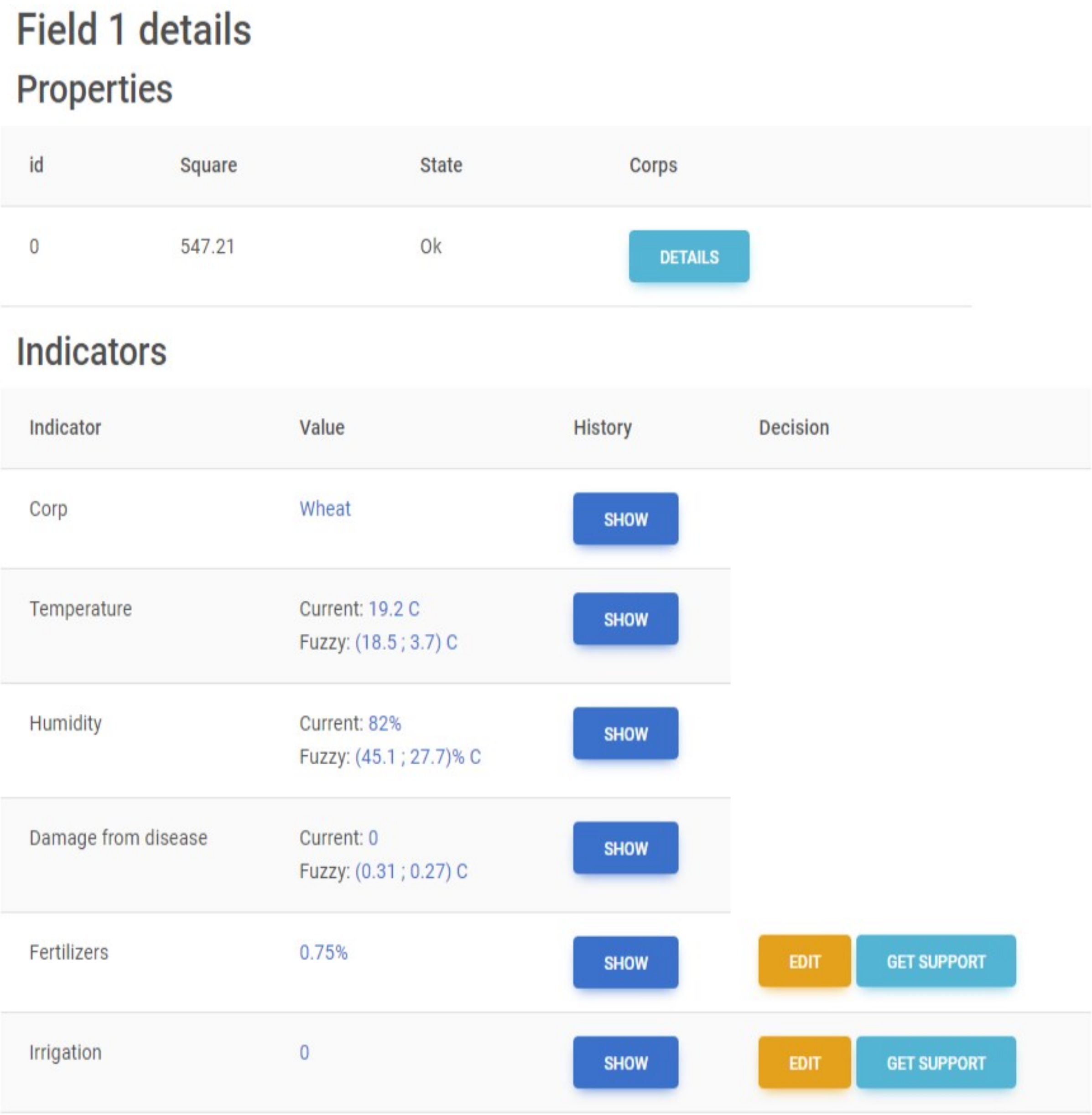


Fields management

id	Square	State	
0	547.21	Ok	DETAILS
1	77.21	Pending	DETAILS

Figure 4.1. Fields list

Page for Viewing Indicators of a Single Field (Fig 4.2): On this page users can thoroughly examine all agrometeorological and other indicators for a specific field, allowing for a deeper analysis of a particular agricultural asset.



Field 1 details

Properties

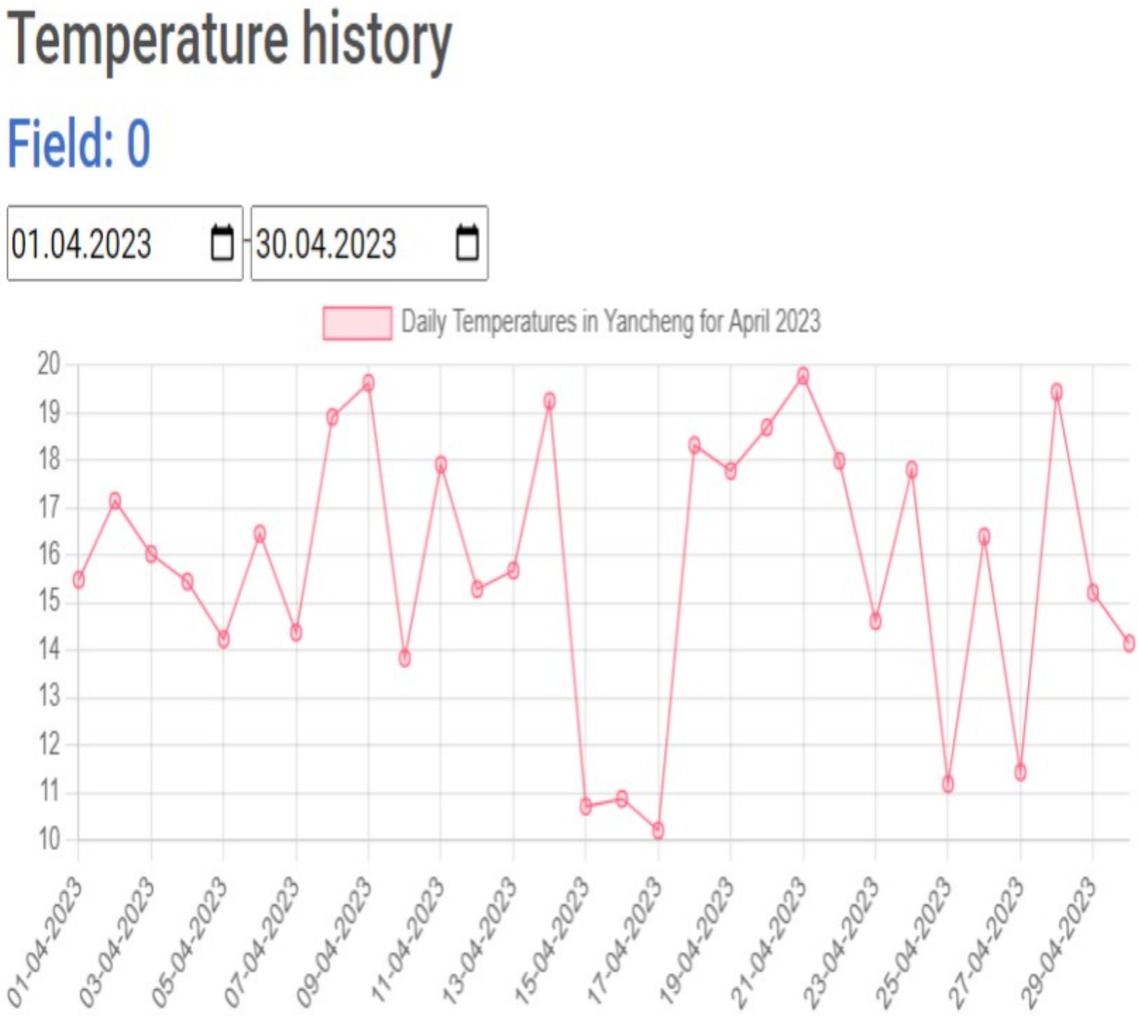
id	Square	State	Corps
0	547.21	Ok	DETAILS

Indicators

Indicator	Value	History	Decision
Corp	Wheat	SHOW	
Temperature	Current: 19.2 C Fuzzy: (18.5 ; 3.7) C	SHOW	
Humidity	Current: 82% Fuzzy: (45.1 ; 27.7)% C	SHOW	
Damage from disease	Current: 0 Fuzzy: (0.31 ; 0.27) C	SHOW	
Fertilizers	0.75%	SHOW	EDIT GET SUPPORT
Irrigation	0	SHOW	EDIT GET SUPPORT

Figure 4.2. Field details

Page for Viewing the History of Changes in a Particular Indicator (Figure 4.3): This page provides a historical overview of changes in a particular indicator, such as temperature or humidity. This is important for analyzing trends and forecasting future changes.



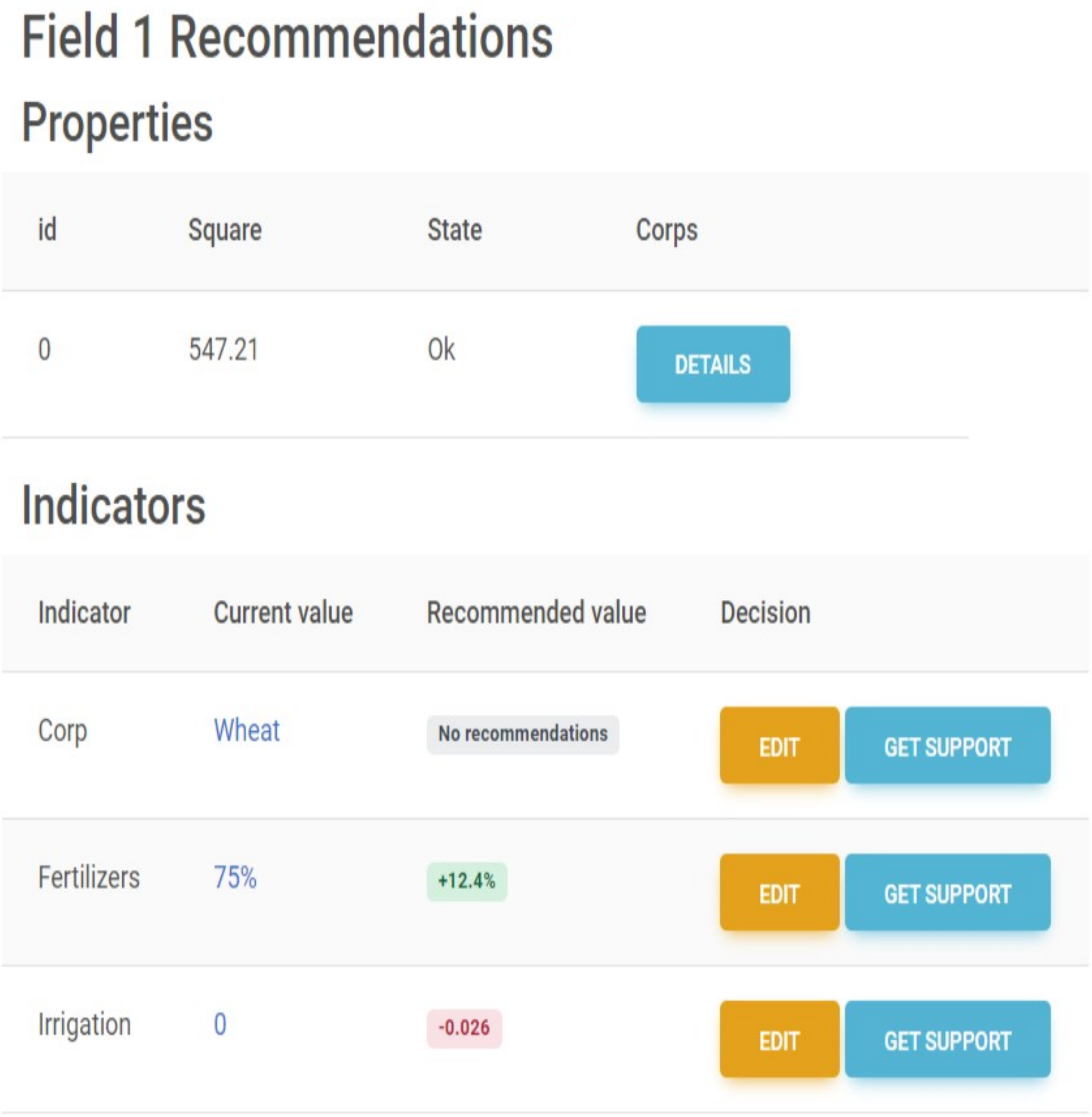
Temperature history

Field: 0

01.04.2023 - 30.04.2023

Figure 4.3. Temperature history

Page for Receiving Decision Support Regarding the Change of Indicator Values to Improve Company Profits (fig 4.4). This page uses artificial intelligence algorithms to provide recommendations for optimizing agricultural processes to maximize profits. The system analyzes current data and proposes strategies for the optimal use of resources depending on the current environmental situation.



Field 1 Recommendations

Properties

id	Square	State	Corps
0	547.21	Ok	DETAILS

Indicators

Indicator	Current value	Recommended value	Decision
Corp	Wheat	No recommendations	EDIT GET SUPPORT
Fertilizers	75%	+12.4%	EDIT GET SUPPORT
Irrigation	0	-0.026	EDIT GET SUPPORT

Figure 4.4. Recommendations

This innovative system will provide agricultural enterprises with the necessary tools for effective management in the complex conditions of modern agribusiness, allowing them to quickly adapt to environmental changes and optimize their activities to increase profitability.

4.2 Validation of the decision support system for agricultural enterprise under environmental uncertainty

To validate the fuzzy decision-making model of an agricultural enterprise under environmental uncertainty, which considers the cultivation of crops as a sequence of stages, the following numerical experiment can be performed:

1. Collection and Analysis of Historical Data: Collect historical data on weather, humidity, temperature, light exposure, soil composition, and other environmental parameters for your region. These data can be obtained from meteorological stations or specialized agricultural research centers.
2. Determination of Model Parameters: Describe the key parameters of your optimization model, such as types of crops, planting seasons, duration of the vegetation period, irrigation needs, etc.
3. Development of Experiment Scenarios: Create different scenarios of changing environmental conditions (for example, dry year, rainy year, temperature fluctuations) and determine how these conditions can affect crop cultivation.
4. Cultivation Simulation: Apply the model to simulate crop cultivation in different environmental conditions. Monitor how the model predicts yield, resource utilization (water, fertilizers), and potential risks.
5. Comparison with Real Data: Compare the simulation results with actual data on yield and resource use for similar periods. This will help to identify deviations and the accuracy of the model.
6. Analysis of Results and Model Adjustment: Analyze the results and identify weaknesses in the model. For example, if the model inadequately responds to extreme weather conditions, make the necessary adjustments.
7. Repetition of the Experiment: After making changes to the model, repeat the experiment to check its improved accuracy.

This approach will not only validate the model but also identify potential directions for its improvement and adaptation to the specific conditions of the agricultural enterprise.

For validation, two sources of weather data were considered.

1. China Meteorological Data Service Centre (CMDC): This service is an upgraded system of the meteorological data sharing network and an important component of China's National Science and Technology Infrastructures Platform. It offers a unified shared service platform for meteorological data in China and includes data retrieval and download services for various types of meteorological data. The CMDC provides datasets like daily timed data from automated weather stations in China, the near-real-time and real-time product datasets of the China Meteorological Administration Land Data Assimilation System (CLDAS-V2.0), and data from global surface and upper air stations [95].

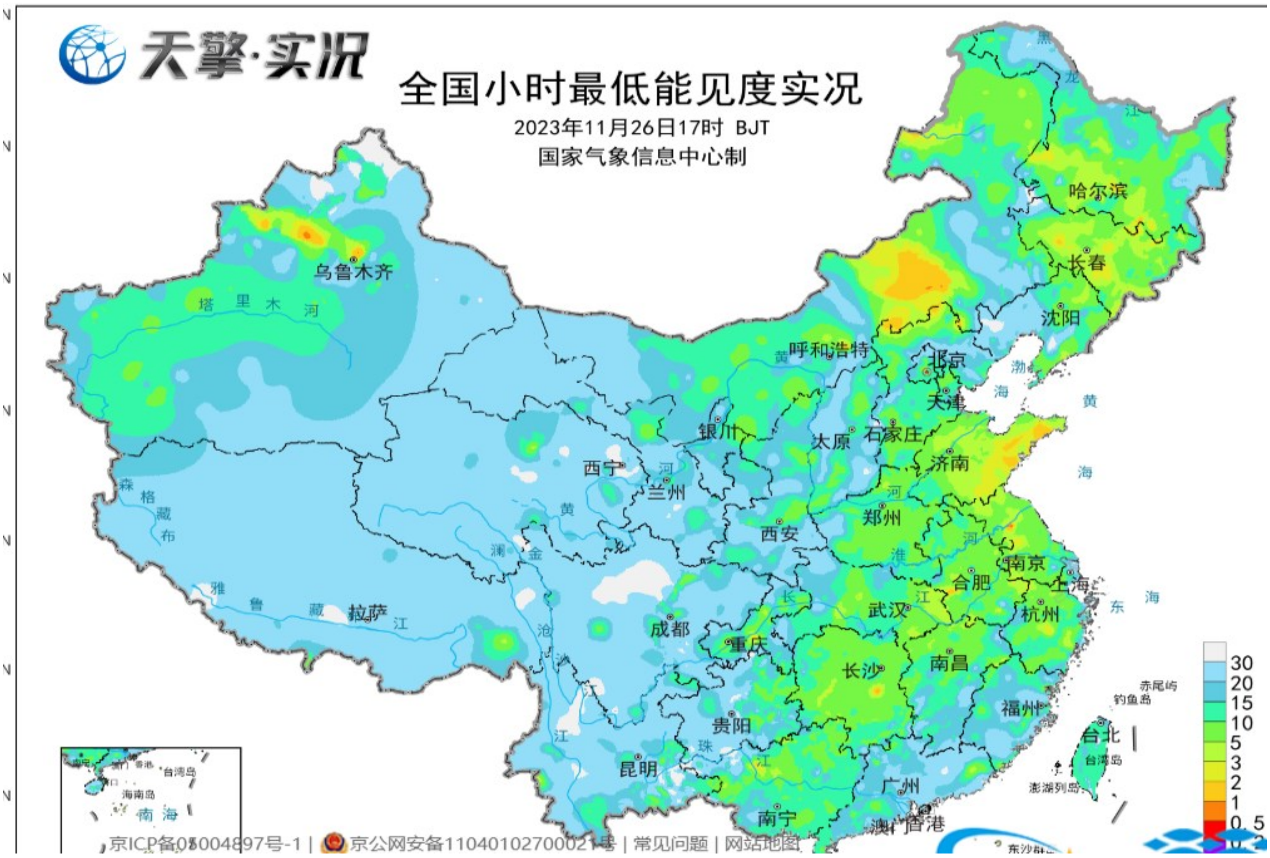


Figure 4.5 Example of the temperature distribution

2. Meteoblue: This service offers hourly historical weather data since 1940 for Yancheng, which can be purchased through their "history+" feature. The downloadable variables include temperature, wind, clouds, and precipitation, available as CSV files [96] An example of data obtained from the Meteoblue service is presented in Fig. 4.6. This service provides various indicators that are updated every minute.

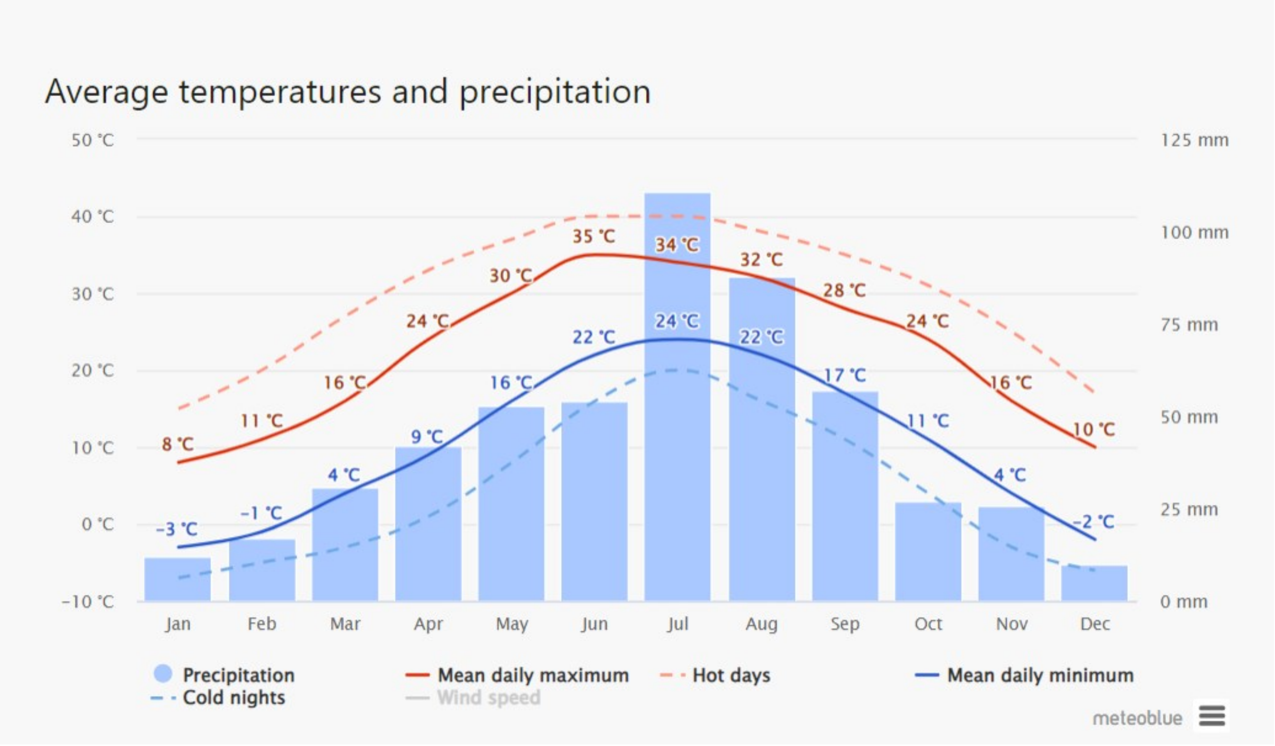


Figure 4.6 Example of the temperature distribution

Figure 4.6 illustrates the temperature distribution in Yancheng throughout 2022, showing variations in temperature across different seasons.

The graph may indicate higher temperatures during the summer months and cooler temperatures in winter, reflecting Yancheng's typical climate patterns.

Such data is crucial for understanding seasonal temperature trends, which can significantly impact agricultural planning and crop management in the region.

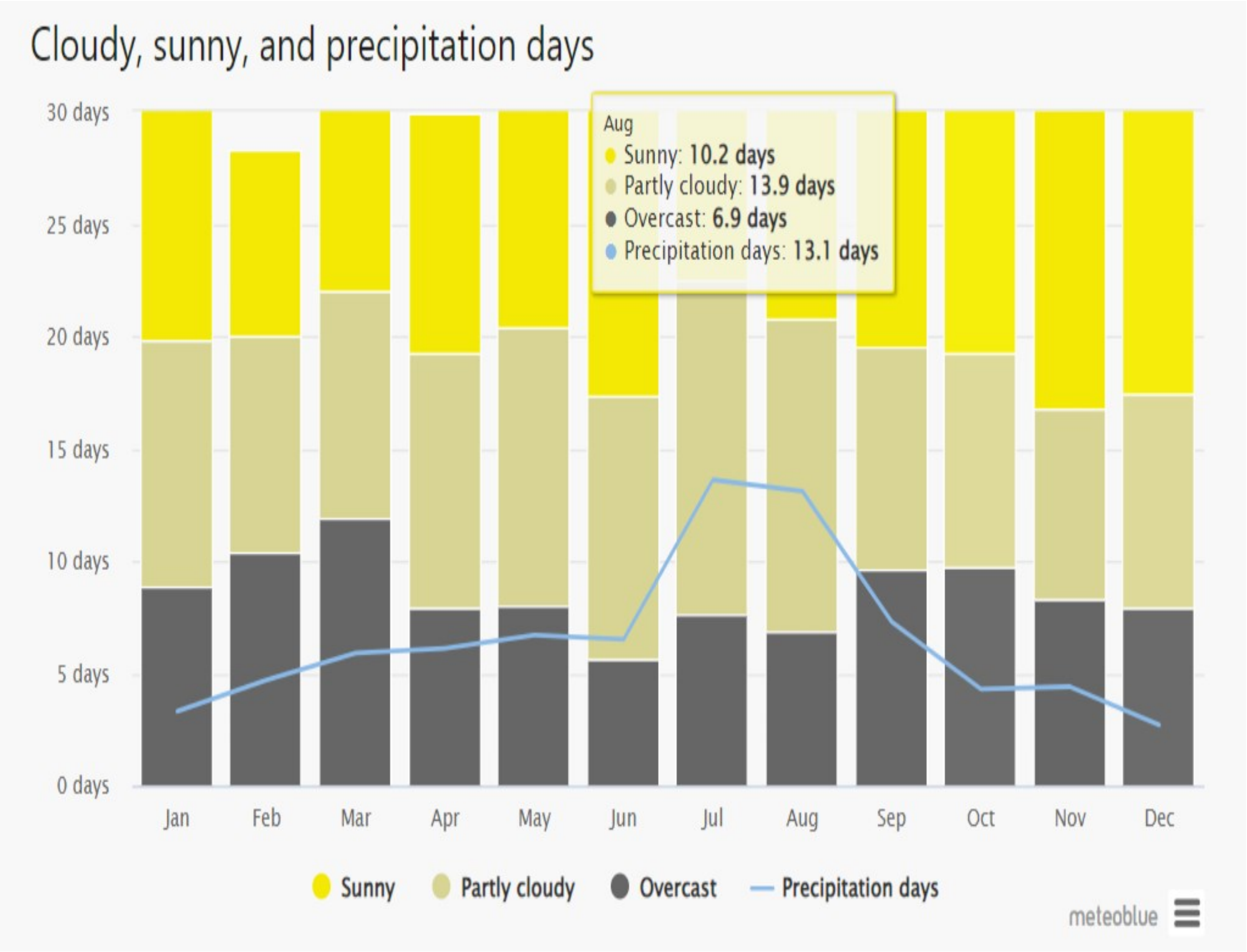


Figure 4.7 Example of the sunny days distribution

Figure 4.7 presents the distribution of sunny days in Yancheng for the year 2022, highlighting the frequency of clear, cloudless days.

This information could be instrumental in agricultural planning, especially for crops that require a certain amount of sunlight for optimal growth.

The chart might show variations in sunny days, perhaps with more sunny days in certain months, which can aid in determining the best times for planting and harvesting.

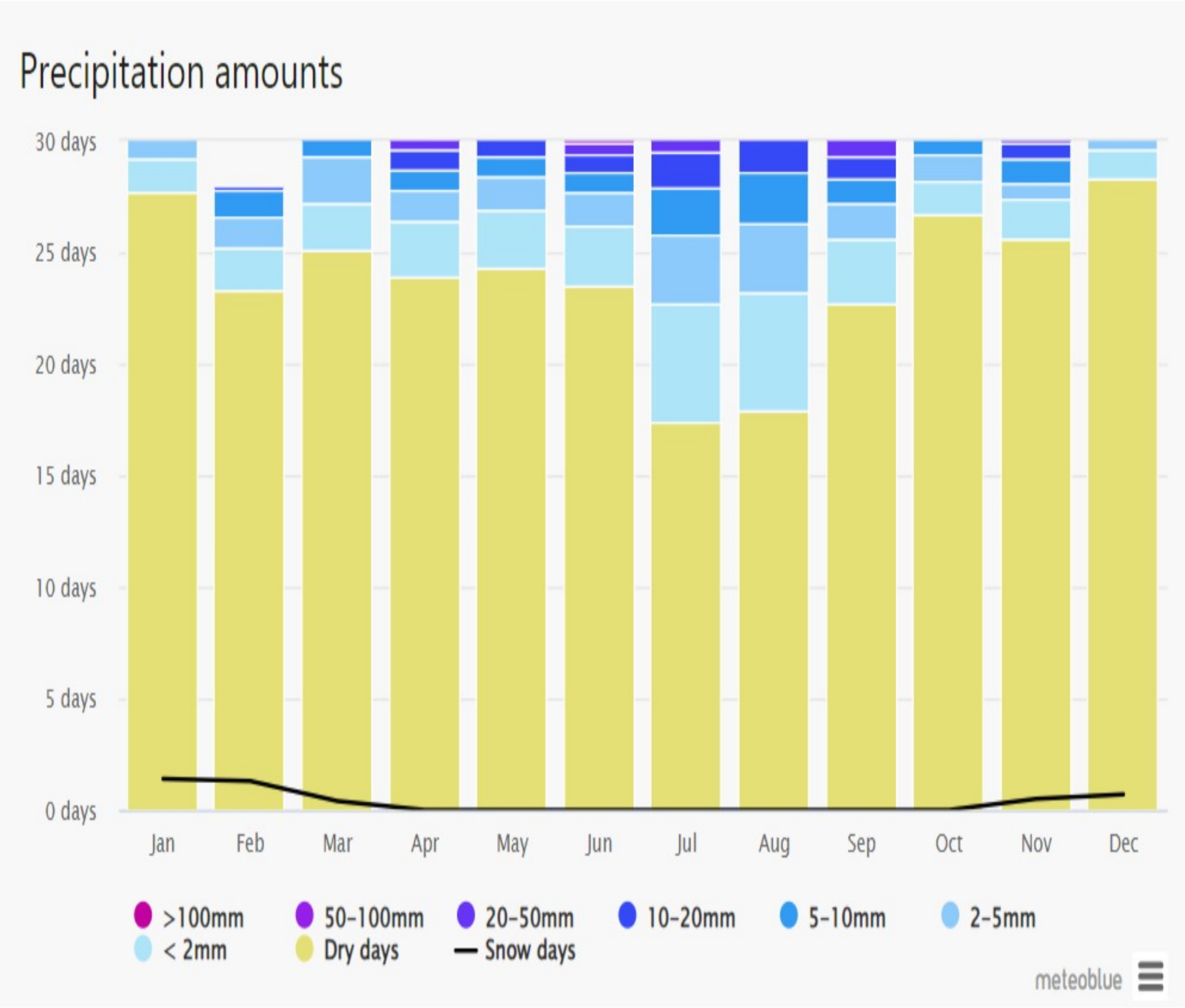


Figure 4.8 Example of the precipitation distribution

Figure 4.8 show cases the precipitation distribution in Yancheng over 2022, detailing the amount and frequency of rainfall received throughout the year.

Such data is essential for water resource management in agriculture, helping to plan for irrigation needs and understand potential flooding or drought conditions.

The distribution may reveal a monsoon influence, with certain periods having significantly higher precipitation, critical for farming decisions.

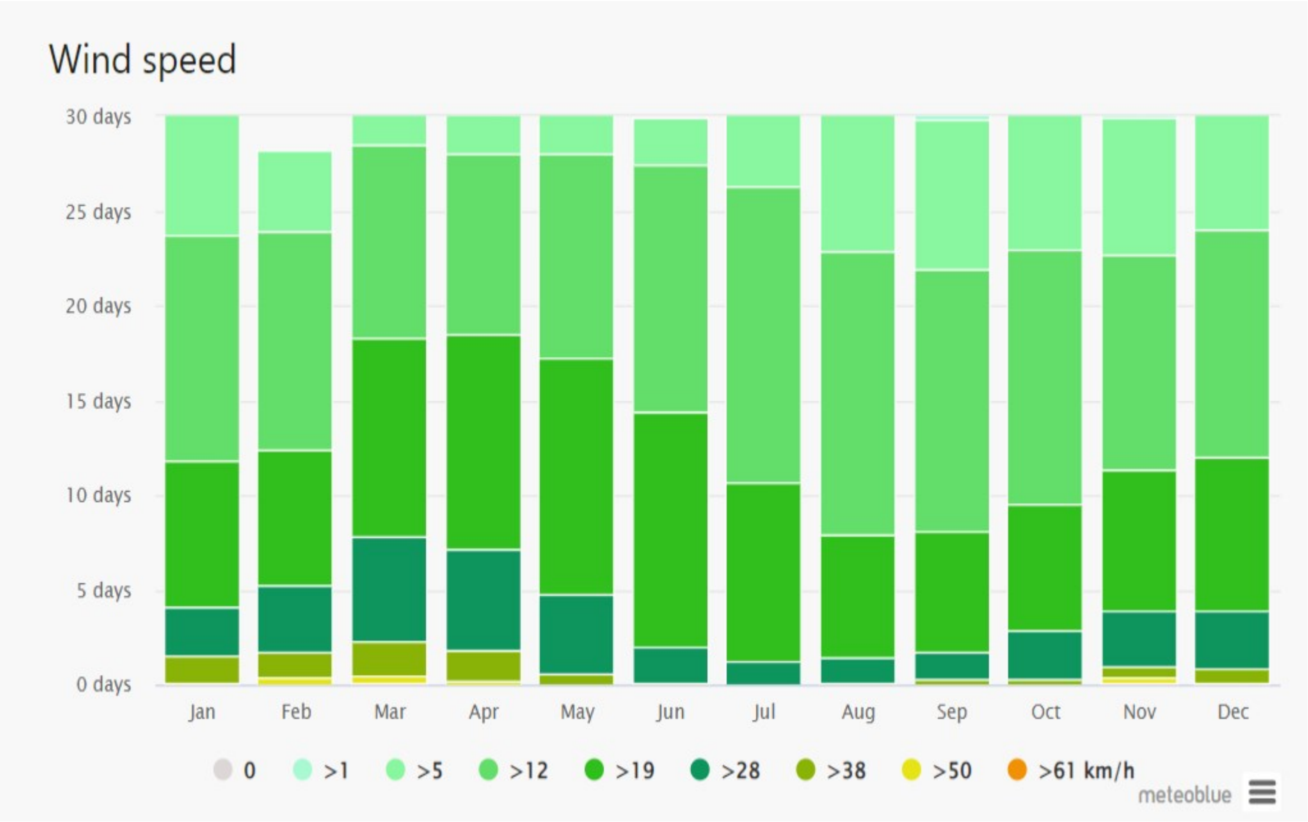


Figure 4.9 Example of the wind distribution

Figure 4.9 depicts the wind distribution in Yancheng for 2022, showing wind speed and direction patterns over the year.

This information can be valuable for various agricultural activities, including the application of pesticides and understanding potential wind-related erosion or damage to crops.

Patterns in wind distribution may indicate prevailing winds or seasonal changes in wind behavior, which can influence various aspects of farm management.

In Yancheng, China, the major grain crops grown include maize, paddy rice, and wheat. These crops are among the most important staple cereal crops in China and contribute significantly to the nation's cereal production. In China, maize, paddy rice, and wheat accounted for approximately 97% of the national cereal areas in 2020[97]. Specifically, in regions like the Middle-lower Yangtze River plain, where Yancheng is located, multiple cropping systems involving these crops are prevalent.

In China, several agricultural regions are distinguished: QTP: Qinghai-Tibet Plateau; HHHP: Huang-Huai-Hai Plain; LP: Loess Plateau; SB: Sichuan Basin; MLYR: Middle and Lower Yangtze Plain; SC: South China; NeCP: Northeast China Plain; YGP: Yunnan-Guizhou Plateau; and NaR: Northern Arid and Semi-Arid Region. Yancheng belongs to the Middle and Lower Yangtze Plain.

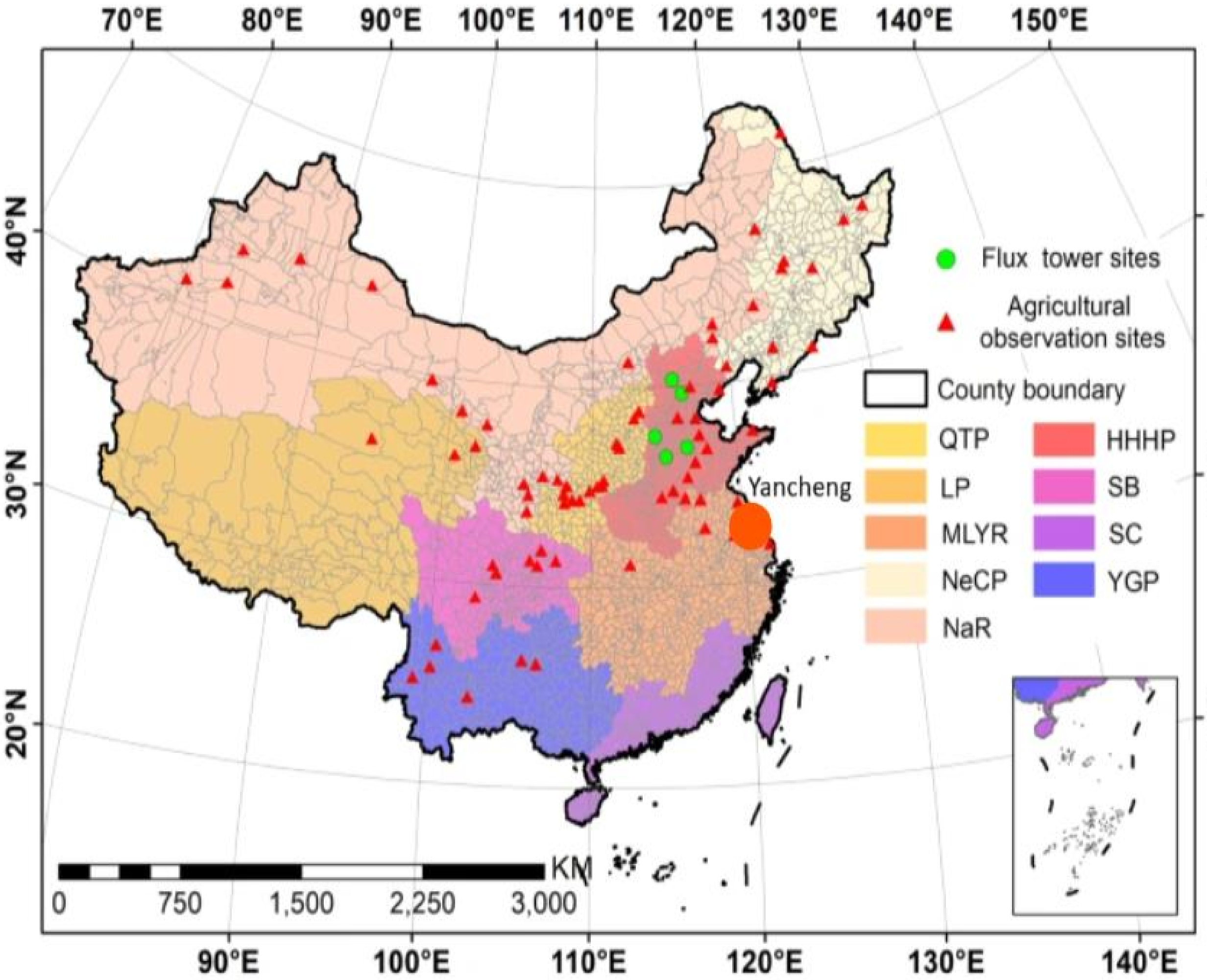


Figure 4.10. Example of the temperature distribution

The comprehensive approach to analyzing cereal crop yields in China, as outlined in your description, integrates several sophisticated datasets and models. This multi-faceted analysis is crucial for understanding the complex interplay between environmental factors and agricultural productivity. Here's a breakdown of the key components of this analysis.

For datasets regarding the yield of these crops consider the following datasets:

1. High-Resolution Crop Yield and Water Productivity Dataset: This dataset, which covers maize and wheat, was generated using a random forest algorithm and multiple remotely sensed indicators. It offers high-resolution (1 km) data on crop yield and crop water productivity (CWP) for maize and wheat across China. This dataset includes data from 2001 to 2015 and uses various indicators like Gross Primary Productivity (GPP), Evapotranspiration (ET), land surface temperature, and leaf area index for estimating yields [98].

2. ChinaWheatYield30m: This is a high-resolution (30 m) annual winter wheat yield dataset covering the period from 2016 to 2021. The dataset was generated using a semi-mechanistic model that combines satellite observations with regional meteorological information. It provides highly accurate estimates of wheat yield, validated with in situ measurements and census statistics. This dataset is particularly useful for analyzing small-scale spatial heterogeneity, which is a significant characteristic of the Chinese farmers' economy [99].

To determine the impact of changing weather parameters on crop yields, a model was considered that analyzes the dependence of yield on climate change [100].

This model recognizes the significant impact of precipitation and temperature on cereal yield, revealing a nonlinear relationship between these climatic factors and yield. To address this complexity, the study created a comprehensive climatic factor and applied an eco-climatic model that connects natural sciences with socioeconomic analysis. The model uses the Cobb-Douglas production function [101], including inputs such as rural labor, cereal crop area, agricultural fertilizers, and meteorological elements like temperature and precipitation. The study uses historical climatic and economic data from 1981 to 2018, obtained from China's National Meteorological Information Center and National Statistical Center of China. The analysis of these data is enhanced using the Principal Component Analysis (PCA) method for dimensionality reduction and representation of most interrelated indices through a few complex indicators.

he Cobb-Douglas production function is used economic model that represents the relationship between two or more inputs and the amount of output produced. It is a specific form of a production function that is used to describe how inputs are transformed into outputs in production processes, particularly in the context of national production or individual firms. In agricultural economics, the Cobb-Douglas function can be used to model the impact of various inputs on agricultural output. For instance, it can help determine how changes in labor (e.g., manual work or skilled labor), capital (e.g., machinery, tools), land (area of cultivation), and other inputs like water, fertilizers, and pesticides affect the overall production of crops. This model helps in understanding the optimal allocation of resources to maximize output

The study [102] shows that cereal yield in China significantly depends on the use of fertilizers and other factors. The analysis revealed that cereal yield increased from 38.3 million metric tons to 53.2 million metric tons in the period from 2000 to 2018, corresponding to an increase of approximately 28.0%. Fluctuations in cereal yield are related to various potential factors, including technological advancements, nitrogen fertilizer usage, irrigation, agricultural labor, agromechanization, and urbanization development. A study conducted on the Loess Plateau of China showed that improving agricultural conditions, such as irrigation and fertilizers, can increase crop yields by 20%.

A spatial regression model was also considered to assess the impact on cereal yield of such independent factors: investments in irrigation, additional fertilizer application, additional agricultural labor, and cereal sowing area. It was shown that these factors have a positive effect on cereal yield, with the degree of this influence decreasing relatively. Additional fertilizer application has a coefficient of 0.351, indicating the significant role of chemical fertilizers in improving cereal yields.

A significant limitation of this study is that increasing the amount of fertilizer can compensate for the decrease in yield from climate change only within certain limits (up to 20%), and the modeling was conducted without considering this limitation.

To develop experimental scenarios investigating the impact of different environmental conditions on grain cultivation in China, the following scenarios were used:

- Dry Year: Modeled conditions with limited precipitation randomized within a range of 10% to 30%. This scenario is useful for assessing the impact of irrigation.

- Rainy Year: Modeled conditions with increased precipitation levels randomized within a range of 10% to 30%, to assess the risks associated with soil overmoisture, the development of diseases and mold, and the impact on the quality and quantity of the harvest.

- Simulate conditions with sharp temperature changes, including unexpected frosts and heatwaves. Analyze how these changes affect the growth phases of cereal crops, such as germination, flowering, and grain ripening. These scenarios will help identify potential risks and opportunities to improve strategies for cultivating cereal crops under changing climate conditions in China.

Table 4.1. Experiment Results

Year	Real yield	Dry year	Wet Year	Temperature disease	DSS
2012	4.67	4.972996	4.353258	2.848113	4.697327
2013	4.70	4.945807	4.480222	3.046226	4.599967
2014	5.00	5.237360	4.225764	4.840496	5.080376
2015	4.79	5.095142	3.911811	4.697055	4.450842
2016	4.36	4.473343	4.160950	4.155120	4.439740
2017	4.36	4.446952	3.600607	2.837104	4.151030
2018	4.63	4.757318	4.389493	4.117974	4.775015

The modeling shows that the scenario of sudden temperature changes, particularly frosts, has the most negative impact on yield. However, the scenario of a year with high humidity shows even better results. On average, the yield in this scenario is 4.31% higher than the actual data. In the modeling of a dry year, the yield decreases by -10.35%, and with random temperature changes by -18.57%. The application of a decision support information system in conditions of environmental uncertainty allows reducing the yield loss to -0.98%.

This study offers a comprehensive understanding of the various factors affecting cereal crop yields in China, particularly under differing environmental conditions. The results demonstrate the critical role of DSS in agricultural management, helping to minimize the negative impacts of environmental uncertainties and optimize crop production. The insights gained from this analysis can inform strategic decisions and policy-making to enhance agricultural resilience and productivity in the face of changing environmental conditions.

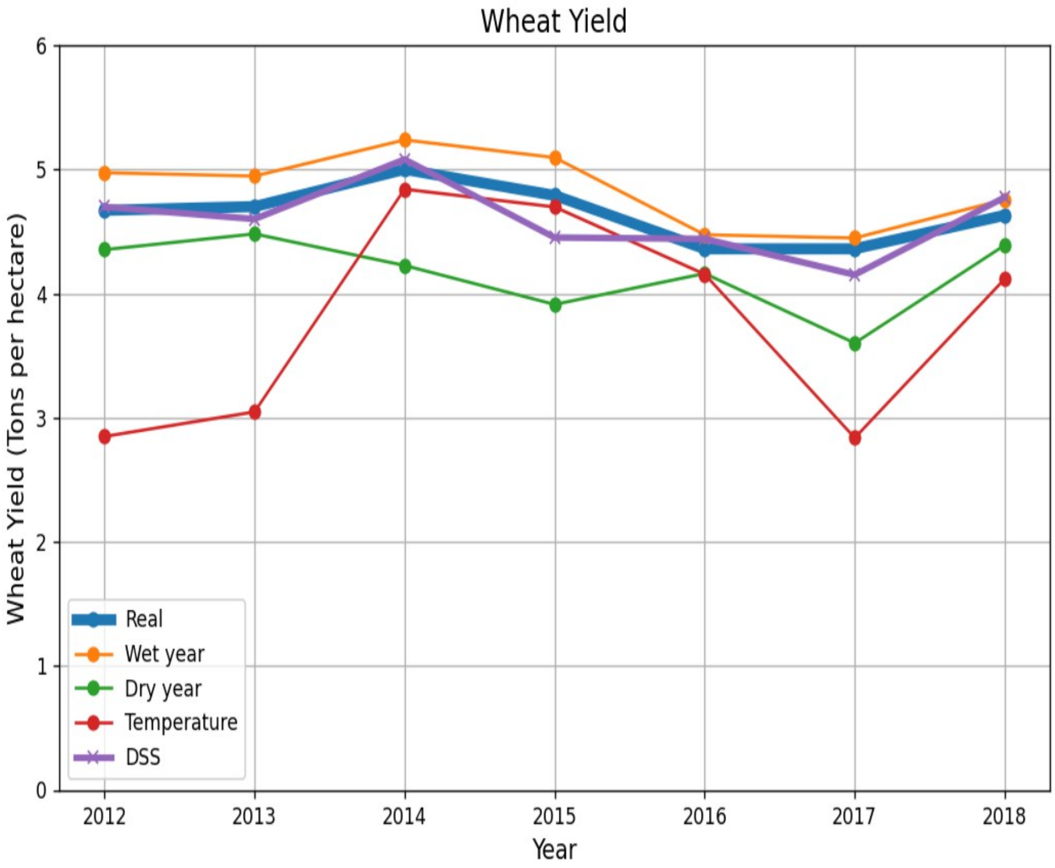


Figure 4.11 Example of the temperature distribution

The analysis of the results demonstrates the validity of the fuzzy decision-making model for agricultural enterprises in conditions of environmental uncertainty. However, weaknesses in the model have been identified, particularly in modeling the dependency of yield. The model inadequately responds to extreme weather conditions; therefore, it requires additional adjustment in terms of parameter selection and improvement of yield models, but these issues require collaboration with scientists - agronomists and go beyond the scope of the research.

The use of a decision support system appears crucial in managing these impacts, with modeling scenarios indicating varying effects on yield due to different environmental conditions:

1. Sudden temperature changes that had the most negative impact on yield, leading to substantial decreases.
2. High Humidity Year. Interestingly, this condition resulted in a yield increase of 4.31% compared to actual data, suggesting that certain crops may benefit from increased humidity.
3. Dry Year. A decrease in yield by -10.35% was observed, reflecting the challenges of drought conditions.
4. Random Temperature Changes: This scenario had the most detrimental effect, with a -18.57% decrease in yield, highlighting the vulnerability of crops to unpredictable temperature fluctuations.

The implementation of a decision support information system under these varying conditions mitigated yield loss to just -0.98%, underscoring the effectiveness of such systems in reducing the negative impacts of environmental uncertainties.

The effectiveness of the fuzzy decision-making model in agricultural enterprise management under uncertain environmental conditions. However, it identifies limitations in modeling yield dependency and responding to extreme weather. Further refinement of the model, including parameter selection and yield model improvements, is suggested, requiring collaboration with experts in agronomy.

These findings emphasize the critical role of DSS in agricultural management for minimizing the impacts of environmental uncertainties and optimizing crop production. The insights can be instrumental in guiding strategic decisions and policy-making to enhance agricultural resilience and productivity amidst changing environmental conditions.

Conclusions to chapter 4

1. An information system for decision support in agricultural enterprises has been developed. This system has a modular structure and implements the models and methods described in this study. An analysis was conducted, and an optimal set of technologies for implementing the decision support information technology was selected. A distinctive feature of the information system is the large volume of data that needs to be stored for processing historical changes in weather parameters, soil conditions, and other factors of environmental uncertainty. Therefore, the Cassandra DBMS was chosen as the main data storage, optimized for storing a large amount of time series data. The information system offers a convenient web interface for viewing data on all the company's fields and viewing the values of parameters for each field. Using a decision-making method based on a fuzzy multi-criteria optimization task and a hierarchical fuzzy risk management model, the information system generates recommendations for changing management parameters.

The information system appears to be a robust tool for agricultural enterprises, enhancing their ability to make informed decisions in the face of environmental uncertainties. By leveraging advanced data management technologies and sophisticated modeling techniques, the system offers a means to improve agricultural productivity and resilience.

2. The decision support information system for agricultural enterprises under environmental uncertainty has been validated using simulation modeling methods. For validation, weather data from the China Meteorological Data Service Centre and data

on wheat, rice, and corn yields in the Yancheng region, which belongs to the middle-lower Yangtze plain, were used. An economic-climatic model based on the Cobb-Douglas production function was used to model the impact on crop yields. The consideration of 3 classes of scenarios showed that they could worsen the results of the agricultural enterprise's activities from 4.31% to 18.57%. The use of the information system for decision support allows mitigating the negative impact of scenarios to 0.98%. The analysis of the results shows the validity of the fuzzy decision-making model for agricultural enterprises in conditions of environmental uncertainty.

CONCLUSIONS

In this work, an important task is addressed, namely: the development of mathematical models and methods for forming strategies of activity and supporting the making of optimal decisions by agricultural enterprises, taking into account the incompleteness and fuzziness of data caused by the uncertainty of environmental conditions (scientific component), as well as the development of an information system for decision support in the agricultural sector, especially under conditions of environmental uncertainty, which allows for the automation of decision-making, as well as predicting and minimizing risks associated with environmental changes (practical component).

The practical significance of the obtained results lies in the fact that the main scientific positions of the dissertation have been brought to the level of methodological generalizations and applied tools, which enables the support of decision-making activities of enterprises in the agricultural sector.

The conducted research provides grounds for several conclusions:

1. As a result of the analysis of the general theoretical principles of decision-making in the agricultural sector, it has been established that there are two most common approaches. The first approach involves the use of multi-criteria optimization methods to maximize key factors of the enterprise's activities by choosing the right strategy. It has been shown that to apply this approach, it is necessary to develop scales of quantitative or qualitative assessments of the enterprise's activities. The second approach involves finding the optimal balance between the level of income for the farmer and the total level of risks threatening effective agricultural activity. It is shown that agriculture significantly affects the state of the environment. At the same time, environmental factors are the basis of agriculture. An approach to considering the system of agricultural production - external environment has been proposed. The main factors of mutual influence that affect the choice of the Decision Support System (DSS) have been highlighted.

2. A conceptual model for the development of an information system for decision-making under conditions of environmental uncertainty, which includes four components, has been developed. The Goal-setting component defines the basic objects and subjects of the environment in which the information system operates. It also contains requirements for the properties of the final product and expected outcomes from the implementation of the decision support system. The Principles component determines the principles that should be used in the development of the Decision Support System, with special importance placed on following the principles of open science and data. The Functionality component defines mathematical models for multi-criteria optimization and a risk minimization model. The Diagnostic component establishes criteria for evaluating the effectiveness of the decisions made. The considered components form a coherent system that supports the process in the development of the decision support system.

3. Decision-making models developed by an agricultural enterprise consider its activity as a controlled multi-stage process. A set of 20 parameters, which are input variables of the model, has been proposed. Conditional multi-criteria optimization methods are suggested for finding optimal values of control parameters. It has been established that a deterministic model with clear variables does not accurately describe the activity of an agricultural enterprise in terms of accounting for factors of environmental uncertainty. Therefore, 8 factors are proposed to be represented as fuzzy numbers. Since these factors represent natural processes, it is justified to choose a bell-shaped membership function, and parameters of mathematical expectation and standard deviation need to be calculated based on historical data. A stochastic approach combined with simulation modeling is proposed for finding a solution to the model.

4. A fuzzy hierarchical model for minimizing risk in the activities of an agricultural enterprise has been developed. For this, a method is presented that allows the fuzzification of parameters for which there is insufficient historical data. The method involves introducing linguistic variables based on expert assessments. Linguistic variables can be combined with fuzzy ones by introducing a single space

[0;1]. Also, the creation of a fuzzy knowledge base is proposed, which includes a set of rules. The Mamdani procedure is suggested for obtaining a clear assessment of the integral risk.

5. Approaches for evaluating the effectiveness of economic decisions are described. Managerial decisions are the result of the interaction of formal and informal processes, requiring a deep understanding of both theoretical and practical aspects of management. It has been established that the assessment of the effectiveness of a management system depends on the determination of basic criteria for comparison or establishing a normative level of efficiency. The ability of the system to achieve its final goals with minimal operational costs is a key criterion of its effectiveness. Indicators of the efficiency of the management apparatus and its structure can be divided into three groups that reflect different aspects of efficiency, including final results, the management process, and the rationality of the organizational structure. There are various approaches to decision-making, including mathematical (normative), qualitative-subjective (descriptive), and integrated approaches, each with its own features and importance in the context of managerial decisions. Mathematical modeling and information technologies contribute to a scientifically grounded approach to decision-making, although it is also important to consider informal aspects, such as intuition and emotions.

6. An information system for decision support in agricultural enterprises has been developed. This system has a modular structure and implements the models and methods described in this study. An analysis was conducted, and an optimal set of technologies for implementing the decision support information technology was selected. A distinctive feature of the information system is the large volume of data that needs to be stored for processing historical changes in weather parameters, soil conditions, and other factors of environmental uncertainty. Therefore, the Cassandra DBMS was chosen as the main data storage, optimized for storing a large amount of time series data. The information system offers a convenient web interface for viewing data on all the company's fields and viewing the values of parameters for each field.

Using a decision-making method based on a fuzzy multi-criteria optimization task and a hierarchical fuzzy risk management model, the information system generates recommendations for changing management parameters.

7. The decision support information system for agricultural enterprises under environmental uncertainty has been validated using simulation modeling methods. For validation, weather data from the China Meteorological Data Service Centre and data on wheat, rice, and corn yields in the Yancheng region, which belongs to the middle-lower Yangtze plain, were used. An economic-climatic model based on the Cobb-Douglas production function was used to model the impact on crop yields. The consideration of 3 classes of scenarios showed that they could worsen the results of the agricultural enterprise's activities from 4.31% to 18.57%. The use of the information system for decision support allows mitigating the negative impact of scenarios to 0.98%. The analysis of the results shows the validity of the fuzzy decision-making model for agricultural enterprises in conditions of environmental uncertainty.

REFERENCES

1. Ji, C., & Andrashko, Y. V. (2019). Conceptual model of information system for supporting decision making in the agrarian sphere. Scientific Bulletin of Uzhhorod University. Series of Mathematics and Informatics, 2(35), 156–161. https://doi.org/10.24144/2616-7700.2019.2(35).156-161
2. Ji, C. (2019). Management of the activity of agrarian enterprises for accounting risk management and multicriteria decision making, 38, 151–155, https://doi.org/10.6084/m9.figshare.9788633
3. Ji, C. (2019). Decision making in agricultural sector in view of the environment. Management of development of complex systems, 37, 160–163, https://doi.org/10.6084/m9.figshare.9783224
4. Ji, C. (2022). Risk management for the functionality component of an agricultural enterprise’s decision-making support information system. Management of Development of Complex Systems, (52), 35–38. https://doi.org/10.32347/2412-9933.2022.52.35-38
5. Ji, C. (2020). formation of requirements for the information system of environmental monitoring. Science Journal Innovation Technologies Transfer, 4, 31-34. https://doi.org/10.36381/iamsti.4.2020.31-34.
6. Ji, C. (November 20-21, 2018). Decision making in the activities of agrarian enterprises. V International Scientific and Practical Conference "Information Technologies and Interactions" (IT&I-2018), Kyiv, Ukraine, 56
7. Ji, C. (2019). View on the problem of decision-making in the agaricultural sector as a risk management task. I International Scientific and Practical Conference (IMTCK2019), Chernivtsi, Ukraine, 7.
8. Ji, C. (December 20, 2019). Development of the information system for supporting decision making in the agrarian sphere. VI International Scientific and Practical Conference "Information Technologies and Interactions" (IT&I-2019), Kyiv, Ukraine, 95-96.

9. Цзі, Ч. (March 25-26 2020). Формування вимог до інформаційної системи підтримки прийняття рішень в умовах екологічної невизначеності. Seventh international scientific practical conference «Management of the development of technologies», Kyiv, Ukraine, 135-136.

10. Ji, C. (2021). The impact of environmental factors on the decision making in agriculture. Information Technology and Implementation (IT&I-2021), 16-17.

11. Ji, C., Andrashko, Y., Biloshchytska, S. & Tsiutsiura, S. (2021). Conceptual Research Model of Developing the Decision Support System for Agriculture Under Uncertainty, 2021 IEEE International Conference on Smart Information Systems and Technologies (SIST), Nur-Sultan, Kazakhstan, 1-5, doi: 10.1109/SIST50301.2021.9465888. [abstracts Scopus, Web of Science]

12. The state of food security and nutrition in the world. (2018). Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/3/i9553en/i9553en.pdf

13. Gueririni, F. (2015) The future of agriculture? Smart Farming. Retrieved from: https://www.forbes.com/sites/federicoguerrini/2015/02/18/the-future-of-agriculture-smart-farming/#84d0ef13c42c

14. Cherevko G.V. (2006). State regulation of economic in agricultural sector. Kyiv: Znannya, 339.

15. Zhan, S. (2017). Riding on self-sufficiency: Grain policy and the rise of agrarian capital in China. Journal of Rural Studies, 54, 151-161.

16. Developing a Circular Economy in China: Highlights and Recommendations. http://documents.worldbank.org/curated/en/212741468019235369/489170REPLACEM10BOX338934B01PUBLIC1.doc

17. Gurr, G. M., Lu, Z., Zheng, X., Xu, H., Zhu, P., Chen, G., ... & Villareal, S. (2016). Multi-country evidence that crop diversification promotes environmental intensification of agriculture. Nature Plants, 2(3), 16014.

18. Joshi, P. K., Birthal, P. S., & Minot, N. (2015). role of diversification towards high-value crops.

19. Agrosector: Letter of MinFin on PDV. (2014). Analytical department of UAK Agroweek of Ukraine. – [Електронний ресурс]. Avaiable: http://a7d.com.ua/analtika/16801-agrosektor-listumnfnu-pro-pdv-plgiprisvyachuyetsya.html

20. Jiang, M. (2012). Introduction to Ecological Safety. World Affairs Press, 491.

21. Shkuratov, O.I. (2010). Assessment of ecological factors influence on economical characteristics of agricultural production. Bulletin of agricultural Science, 3 (780), 51-55.

22. Tesla, Yu.M., Biloshitskii A.A., & Tesla., N.Yu. (2010). Informative technology of project management on the ERPP basis (enterprise resources planning in project) and APE (administrated projects of the enterprise) system. Management of development of complex systems,1, 16-20.

23. Gevko, I.B. (2009). Methods of management solution. Textbook. Oscow:Finances and statistics, 187.

24. Mescon, M.H., Albert Michael, & Khedouri Franklin (1988). Management. Addison-Wesley Educational Publishers, Incorporated, 777.

25. Schmitt, A.J., Sun, S.A., Snyder, L.V. & Shen, Z.J.M. (2015). Centralization versus decentralization: Risk pooling, risk diversification, and supply chain disruptions. Omega, 52, 201-212.

26. Shpak, Y., Melnyk, O., Sroka, W., Adamiv, M. (2017). Information Diagnostic Support of Enterprise Under the Conditions of Uncertainty. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 65 (4), 1403-1414.

27. Kuchansky, A., Biloshchytsjyi, A., Andrashko, Yu., Biloshchytska, S., Shabala, Ye., Myronov, O. (2018). Development of adaptive combined models for predicting time series based on similarity identification. Eastern-European Journal of Enterprise Technologies, 1/4 (91), 32–42. DOI: 10.15587/1729-4061.2018.121620.

28. Kuchansky, A., Biloshchytskyi A., Andrashko, Yu., Vatskel, V., Biloshchytska, S., Danchenko, O., Vatskel, I. (2018). Combined models for forecasting the air pollution level in infocommunication systems for the environment state monitoring. 2018 IEEE 4th International Symposium on Wireless Systems within the International Conferences on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS-SWS). Lviv, 2018, P. 125–130. DOI: 10.1109/IDAACS-SWS.2018.8525608.

29. Patiro, S. P. S., Hendarto, K. A., Hasan, R. A., Nur, A., Ariawan, K., Wisudayati, T. A., & Simanjuntak, T. M. (2021, November). The challenge for Aik Nyet Nature Tourism in the new normal era. In IOP Conference Series: Earth and Ecological Science (Vol. 917, No. 1, p. 012038). IOP Publishing.

30. Liang, J., Zhong, M., Zeng, G., Chen, G., Hua, S., Li, X., & Gao, X. (2017). Risk management for optimal land use planning integrating ecosystem services values: A case study in Changsha, Middle China. Science of the Total Environment, 579, 1675-1682.

31. John Maynard Keynes. (1921). A Treatise on Probability. London: Macmillan and co.

32. Willer, H. (2010). Organic Agriculture World-wide: Current Statistics. In: The World of Organic Agriculture - Statistics and Emerging Trends 2010. FiBL and IFOAM, Frick and Bonn, chapter 1, pp. 28-51. Retrieved from www.fibl.org

33. Quality management systems — Fundamentals and vocabulary. (2015). ISO 9000:2015(en). Retrieved from https://www.iso.org/obp/ui/#iso:std:iso:9000:ed-4:v1:en

34. Wang, B., Wu, C., Reniers, G., Huang, L., Kang, L., & Zhang, L. (2018). The future of hazardous chemical safety in China: Opportunities, problems, challenges and tasks. Science of the total environment, 643, 1-11.

35. Morhenshtein, O., Neiman D. (2012). Game Theory and Economic Behavior. Moscov: Book on Demand, 2012, 708 c.

36. Vitlinsky, V, & Velikoivanenko, H. (2004). Riskology in Economics and Business: Monograph. Kyiv: KNEU, 480.

37. Vilenchuk O.M. (2013). Conceptual approaches to identification, assessment and risk management in the agrarian sector. Journal of Zhytomyr National Agroecological University, 1-2(2), 137-147. Retrieved from http://nbuv.gov.ua/UJRN/Vzhnau_2013_1-2%282%29__20

38. Troccoli, A., Harrison, M., Anderson, D.L.T., & Mason, S.J. (2008). Seasonal Climate: Forecasting and Managing Risk. Springer, 484.

39. Zadeh, L. (1965). Fuzzy sets. Information and Control, 8(3), 338-353.

40. Saaty T. (1980). The analytic hierarchy process: Planning, priority setting, resource allocation. McGraw-Hill, New York, 287.

41. Velasquez, M., Patrick, T., & Hester, An. (2013). Analysis of multi-criteria decision making methods. International Journal of Operations Research, 10/2, 56–66.

42. Konidari, P., & Mavrakis, D. (2007). A multi-criteria evaluation method for climate change mitigation policy instruments. Energy Policy, 35(12), 6235-6257.

43. Fishburn, P. (1967). Conjoint measurement in utility theory with incomplete product sets. Journal of Mathematical Psychology, 4(1), 104-119.

44. Ananda, J., & Herath, G. (2005). Evaluating public risk preferences in forest land-use choices using multi-attribute utility theory. Ecological Economics, 55(3), 408-419.

45. Zabeo, A., Pizzol, L., Agostini, P., Critto, A., Giove, S., & Marcomini, A. (2011). Regional risk assessment for contaminated sites Part 1: Vulnerability assessment by multi-criteria decision analysis. Environment International, 37(8), 1295-1306.

46. Loetscher, T., & Keller, J. (2002). A decision support system for selecting sanitation systems in developing countries. Socio-Economic Planning Sciences, 36(4), 267-290.

47. Chauhan, N., Mohapatra, P., & Pandey, K. (2006). Improving energy productivity in paddy production through benchmarking-An application of data envelopment analysis. Energy Conversion and Management, 47(9-10), 1063-1085.

48. Qin, X., Huang, G., Chakma, A., Nie, X., & Lin, Q. (2008). A MCDM-based expert system for climate-change impact assessment and adaptation planning – A case study for the Georgia Basin, Canada. Expert Systems with Applications, 34(3), 2164-2179.

49. BI Intelligence. The Internet of Everything. (2016). Available: http://bewiser.eu/admin/resources/internetofeverything 2016 -2.pdf

50. Guerrini, F. (2015). The future of agriculture? Smart Farming. Forbes Investing. Available: https://www.forbes.com/sites/federicoguerrini/ 2015/02/18/the-future-of-agriculture-smartfarming/#84d0ef13c42c

51. De Oliveira, T. H. M., Painho, M., Santos, V., Sian, O., & Barriguinha, A. (2014). Development of an agricultural management information system based on Open-Source solutions. Procedia Technology, 16, 342-354.

52. Liu, Y., Wang, H., Wang, J., Qian, K., Kong, N., Wang, K., ... & Engels, D. W. (2015). Enterprise-oriented IoT name service for agricultural product supply chain management. International Journal of Distributed Sensor Networks, 11(8), 308165. doi:10.1155/2015/308165

53. Li, M., Fu, Q., Singh, V. P., Ji, Y., Liu, D., Zhang, C., & Li, T. (2019). An optimal modelling approach for managing agricultural water-energy-food nexus under uncertainty. Science of the Total Environment, 651, 1416-1434.

54. Chavas, J. P., & Nauges, C. (2020). Uncertainty, learning, and technology adoption in agriculture. Applied Economic Perspectives and Policy, 42(1), 42-53.

55. Mons, B., Neylon, C., Velterop, J., Dumontier, M., da Silva Santos, L. O. B., & Wilkinson, M. D. (2017). Cloudy, increasingly FAIR; revisiting the FAIR Data guiding principles for the European Open Science Cloud. Information services & use, 37(1), 49-56.

56. Bonino, L. O., Gavai, A., Kuzniar, A., Kaliyaperumal, R., & Burger, K. FAIR data point software specification–FAIR Data point–Confluence. Available at https://dtl-fair.atlassian.net/wiki/display/FDP/FAIR+Data+Point+Software+Specification

57. Roche, D. G., Kruk, L. E., Lanfear, R., & Binning, S. A. (2015). Public data archiving in ecology and evolution: how well are we doing?. PLoS biology, 13(11), e1002295.

58. Azar, A. T., & Vaidyanathan, S. (Eds.). (2016). Advances in chaos theory and intelligent control (Vol. 337). Springer.

59. Lenka, S. K., & Mohapatra, A. G. (2016). Hybrid Decision Model for Weather Dependent Farm Irrigation Using Resilient Backpropagation Based Neural Network Pattern Classification and Fuzzy Logic. In Proceedings of First International Conference on Information and Communication Technology for Intelligent Systems: Volume 1 (pp. 291-302). Springer International Publishing.

60. He, Y. (2019). Fomalization of the problem of evaluation of pollution of the environment, Management of development of complex systems, 38, 168 – 172. dx.doi.org\10.6084/m9.figshare.978870

61. Kuchansky, A., Biloshchytskyi, A., Andrashko, Y., Vatskel, V., Biloshchytska, S., Danchenko, O., & Vatskel, I. (2018, September). Combined models for forecasting the air pollution level in infocommunication systems for the environment state monitoring. In 2018 IEEE 4th International Symposium on Wireless Systems within the International Conferences on Intelligent Data Acquisition and Advanced Computing Systems (IDAACS-SWS) (pp. 125-130). IEEE. 10.1109/IDAACS-SWS.2018.8525608

62. Morozov, V., Kalnichenko, O., & Bronin, S. (2018). Development of the model of the proactive approach in creation of distributed information systems. Eastern-european journal of enterprise technologies, 94(2). 10.15587/1729-4061.2018.139668

63. Velasquez, M., & Hester, P. T. (2011). An analysis of multicriteria decision making methods," International Journal of Operations Research, vol. 10(2), 56–66, 201

64. Van Dinh, N., & Thao, N. X. (2018). Some measures of picture fuzzy sets and their application in multi-attribute decision making. Int. J. Math. Sci. Comput.(IJMSC), 4(3), 23-41.3.

65. da Cruz Neto, J. X., Da Silva, G. J. P., Ferreira, O. P., & Lopes, J. O. (2013). A subgradient method for multiobjective optimization. Computational Optimization and Applications, 54(3), 461-472.

66. Aarts, E. H., Korst, J., & van Laarhoven, P. J. (1997). Local Search in Combinatorial Optimization, chapter 4, Simulated Annealing. John Wiley & Sons Litd, 30, 91-120.

67. Xu, G., Feng, J., Chen, F., Wang, H., & Wang, Z. (2019). Simulation-based optimization of control policy on multi-echelon inventory system for fresh agricultural products. International Journal of Agricultural and Biological Engineering, 12(2), 184-194.

68. Antón, J., Kimura, S., & Martini, R. (2011). Risk management in agriculture in Canada., OECD Food, Agriculture and Fisheries Working Papers, 40, OECD Publishing, 2011. doi: 10.1787/5kgj0d6189wg-en.

69. Zhao, X., Hwang, B. G., & Low, S. P. (2013). Developing fuzzy enterprise risk management maturity model for construction firms. Journal of construction engineering and management, 139(9), 1179-1189..

70. McLennan, Marsh, SK Group & Zurich Insurance Group. (2021). The Global Risks Report 2021. https://www.weforum.org/reports/the-global-risks-report-2021/

71. ISO Standards. (2018). Risk management: Principles and guidelines (ISO 31000:2018). https://www.iso.org/iso-31000-risk-management.html

72. Rosegrant, M. W., & Cline, S. A. (2003). Global food security: challenges and policies. *Science*, *302*(5652), 1917-1919.

73. Zuo, L., Zhang, Z., Carlson, K. M., MacDonald, G. K., Brauman, K. A., Liu, Y., ... & West, P. C. (2018). Progress towards sustainable intensification in China challenged by land-use change. *Nature Sustainability*, *1*(6), 304-313.

74. Qiu, B., Li, H., Tang, Z., Chen, C., & Berry, J. (2020). How cropland losses shaped by unbalanced urbanization process?. *Land Use Policy*, *96*, 104715.

75. Niu, Y., Xie, G., Xiao, Y., Liu, J., Wang, Y., Luo, Q., ... & Huang, M. (2021). Spatiotemporal patterns and determinants of grain self-sufficiency in China. *Foods*, *10*(4), 747.

76. Liu, F., Zhang, Z., Zhao, X., Wang, X., Zuo, L., Wen, Q., ... & Liu, B. (2019). Chinese cropland losses due to urban expansion in the past four decades. *Science of the Total Environment*, *650*, 847-857.

77. Song, W., Pijanowski, B. C., & Tayyebi, A. (2015). Urban expansion and its consumption of high-quality farmland in Beijing, China. *Ecological Indicators*, *54*, 60-70.

78. Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., ... & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *science*, *327*(5967), 812-818.

79. Zhou, L., & Turvey, C. G. (2014). Climate change, adaptation and China's grain production. *China Economic Review*, *28*, 72-89.

80. Tian, X., Yi, F., & Yu, X. (2020). Rising cost of labor and transformations in grain production in China. *China Agricultural Economic Review*, *12*(1), 158-172.

81. Zhou, B. B., Aggarwal, R., Wu, J., & Lv, L. (2021). Urbanization-associated farmland loss: A macro-micro comparative study in China. *Land Use Policy*, *101*, 105228.

82. Laborde, D., Martin, W., Swinnen, J., & Vos, R. (2020). COVID-19 risks to global food security. *Science*, *369*(6503), 500-502.

83. Li, S., Zhang, D., Xie, Y., & Yang, C. (2022). Analysis on the spatio-temporal evolution and influencing factors of China’s grain production. *Ecological Science and Pollution Research*, 1-13.

84. Pan, J., Chen, Y., Zhang, Y., Chen, M., Fennell, S., Luan, B., ... & Wang, J. (2020). Spatial-temporal dynamics of grain yield and the potential driving factors at the county level in China. *Journal of Cleaner Production*, *255*, 120312.

85. Liu, Y., Zou, L., & Wang, Y. (2020). Spatial-temporal characteristics and influencing factors of agricultural eco-efficiency in China in recent 40 years. *Land Use Policy*, *97*, 104794.

86. Li, S., Zhang, D., Xie, Y., & Yang, C. (2022). Analysis on the spatio-temporal evolution and influencing factors of China's grain production. *Ecological Science and Pollution Research*, 1-13.

87. Li, Y., Zhang, W., Ma, L., Wu, L., Shen, J., Davies, W. J., ... & Dou, Z. (2014). An analysis of C hina's grain production: looking back and looking forward. *Food and Energy Security*, *3*(1), 19-32.

88. Chai, J., Wang, Z., Yang, J., & Zhang, L. (2019). Analysis for spatial-temporal changes of grain production and farmland resource: Evidence from Hubei Province, central China. *Journal of cleaner production*, *207*, 474-482.

89. Shi, P., Feng, Z., Gao, H., Li, P., Zhang, X., Zhu, T., ... & Xiao, L. (2020). Has “Grain for Green” threaten food security on the Loess Plateau of China?. *Ecosystem Health and Sustainability*, *6*(1), 1709560.

90. Zhang, Q., Dong, W., Wen, C., & Li, T. (2020). Study on factors affecting corn yield based on the Cobb-Douglas production function. *Agricultural Water Management*, *228*, 105869.

91. Xu, X., Wang, L., Cai, H., Wang, L., Liu, L., & Wang, H. (2017). The influences of spatiotemporal change of cultivated land on food crop production potential in China. *Food Security*, *9*, 485-495.

92. Cao, X., Wang, Y., Wu, P., Zhao, X., & Wang, J. (2015). An evaluation of the water utilization and grain production of irrigated and rain-fed croplands in China. *Science of the Total Environment*, *529*, 10-20.

93. Chuan, L., He, P., Zhao, T., Zheng, H., & Xu, X. (2016). Agronomic characteristics related to grain yield and nutrient use efficiency for wheat production in China. *PLoS One*, *11*(9), e0162802.

94. Ghesini, S., Magagnoli, S., & Marini, M. (2018). Biology and conservation of Zerynthia cassandra (Lepidoptera, Papilionidae) in semi-natural environments and agricultural landscapes. Journal of insect conservation, 22(1), 151-161.

95. China Meteorological Data Service Centre. https://data.cma.cn/en

96. Simulated historical climate & weather data for Yanchen https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/yancheng_china_10405443

97. Qiu, B., Hu, X., Chen, C., Tang, Z., Yang, P., Zhu, X., ... & Jian, Z. (2022). Maps of cropping patterns in China during 2015–2021. Scientific Data, 9(1), 479.https://doi.org/10.1038/s41597-022-01589-8

98. Cheng, M., Jiao, X., Shi, L., Penuelas, J., Kumar, L., Nie, C., ... & Jin, X. (2022). High-resolution crop yield and water productivity dataset generated using random forest and remote sensing. Scientific Data, 9(1), 641. https://doi.org/10.1038/s41597-022-01761-0

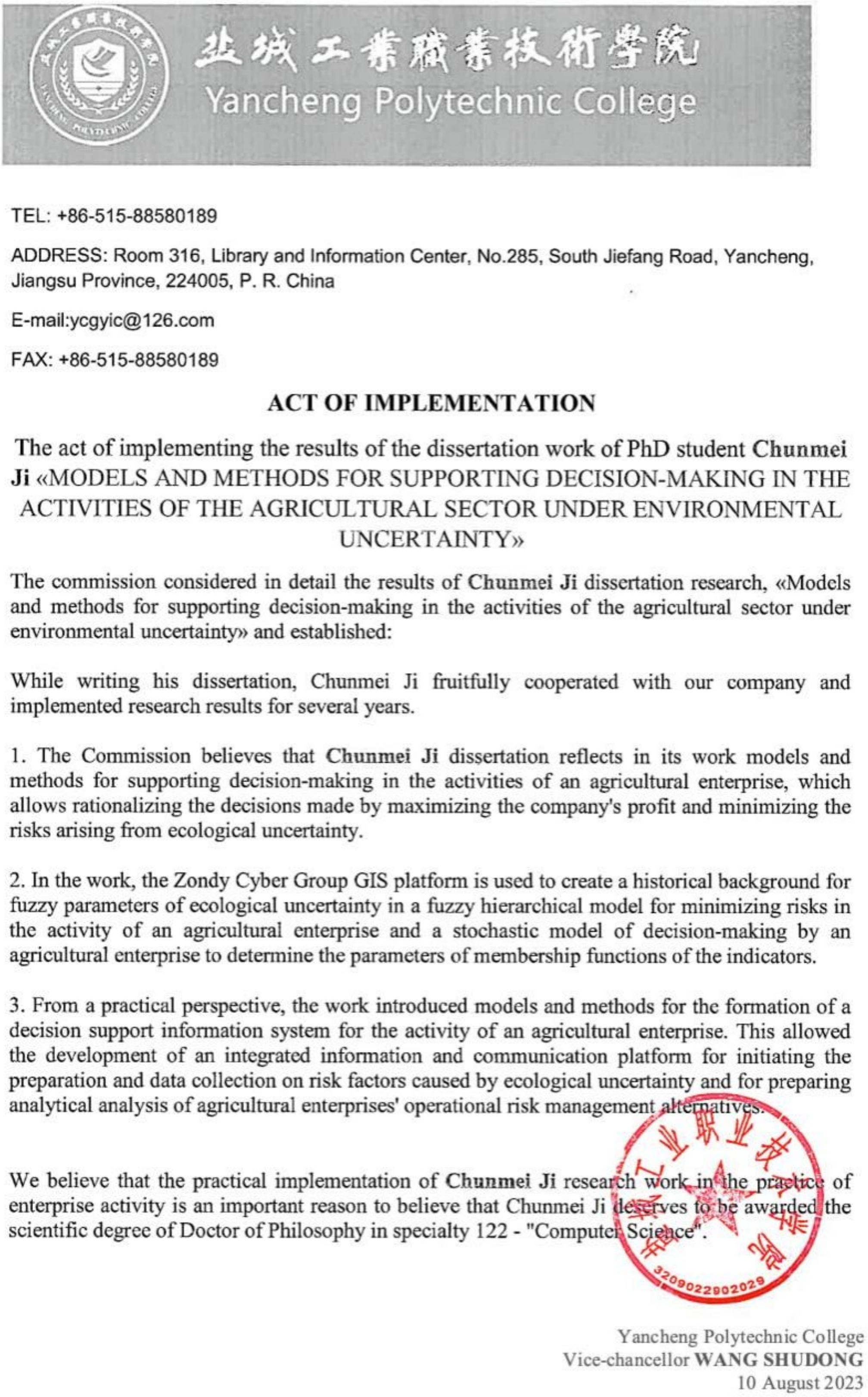
99. Zhao, Y., Han, S., Zheng, J., Xue, H., Li, Z., Meng, Y., ... & Yang, G. (2023). ChinaWheatYield30m: a 30 m annual winter wheat yield dataset from 2016 to 2021 in China. Earth System Science Data, 15(9), 4047-4063. https://doi.org/10.5194/essd-15-4047-2023 .

100. Chou, J., Sun, M., Xu, Y., Yang, F., Li, J., & Zhao, W. (2021). Resilience of grain yield in China under climate change scenarios. Frontiers in Ecological Science, 9, 641122.

101. Goldberger, A. S. (1968). The interpretation and estimation of Cobb-Douglas functions. Econometrica: Journal of the Econometric Society, 464-472.

102. He, H., Ding, R. & Tian, X. (2022). Spatiotemporal characteristics and influencing factors of grain yield at the county level in Shandong Province, China. Sci Rep 12, 12001 https://doi.org/10.1038/s41598-022-14801

APPENDIX A. ACT OF IMPLEMENTATION



盐城工業職業技術學院
Yancheng Polytechnic College

TEL: +86-515-88580189

ADDRESS: Room 316, Library and Information Center, No.285, South Jiefang Road, Yancheng, Jiangsu Province, 224005, P. R. China

E-mail:ycgyic@126.com

FAX: +86-515-88580189

ACT OF IMPLEMENTATION

The act of implementing the results of the dissertation work of PhD student **Chunmei Ji** «MODELS AND METHODS FOR SUPPORTING DECISION-MAKING IN THE ACTIVITIES OF THE AGRICULTURAL SECTOR UNDER ENVIRONMENTAL UNCERTAINTY»

The commission considered in detail the results of **Chunmei Ji** dissertation research, «Models and methods for supporting decision-making in the activities of the agricultural sector under environmental uncertainty» and established:

While writing his dissertation, Chunmei Ji fruitfully cooperated with our company and implemented research results for several years.

1. The Commission believes that **Chunmei Ji** dissertation reflects in its work models and methods for supporting decision-making in the activities of an agricultural enterprise, which allows rationalizing the decisions made by maximizing the company's profit and minimizing the risks arising from ecological uncertainty.

2. In the work, the Zondy Cyber Group GIS platform is used to create a historical background for fuzzy parameters of ecological uncertainty in a fuzzy hierarchical model for minimizing risks in the activity of an agricultural enterprise and a stochastic model of decision-making by an agricultural enterprise to determine the parameters of membership functions of the indicators.

3. From a practical perspective, the work introduced models and methods for the formation of a decision support information system for the activity of an agricultural enterprise. This allowed the development of an integrated information and communication platform for initiating the preparation and data collection on risk factors caused by ecological uncertainty and for preparing analytical analysis of agricultural enterprises' operational risk management alternatives.

We believe that the practical implementation of **Chunmei Ji** research work in the practice of enterprise activity is an important reason to believe that Chunmei Ji deserves to be awarded the scientific degree of Doctor of Philosophy in specialty 122 - "Computer Science".

3209022902029

Yancheng Polytechnic College
Vice-chancellor **WANG SHUDONG**
10 August 2023

APPENDIX B. LIST OF THE APPLICANT'S PUBLICATIONS ON THE THEME OF THE DISSERTATION AND INFORMATION ON THE APPROVAL OF THE RESULTS OF THE DISSERTATION

Articles in professional publications of Ukraine (included in the list of the Ministry of Education and Science of Ukraine))

1. **Ji, C.,** & Andrashko, Y. V. (2019). Conceptual model of information system for supporting decision making in the agrarian sphere. Scientific Bulletin of Uzhhorod University. Series of Mathematics and Informatics, 2(35), 156–161. https://doi.org/10.24144/2616-7700.2019.2(35).156-161 [category «B»]
2. **Ji, C.** (2019). Management of the activity of agrarian enterprises for accounting risk management and multicriteria decision making, 38, 151–155, https://doi.org/10.6084/m9.figshare.9788633 . [category «B»]
3. **Ji, C.** (2019). Decision making in agricultural sector in view of the environment. Management of development of complex systems, 37, 160–163, https://doi.org/10.6084/m9.figshare.9783224 . [category «B»]
4. **Ji, C.** (2022). Risk management for the functionality component of an agricultural enterprise's decision-making support information system. Management of Development of Complex Systems, (52), 35–38. https://doi.org/10.32347/2412-9933.2022.52.35-38 [category «B»]

Articles in professional publications of Ukraine (not included in the list of the Ministry of Education and Science of Ukraine)

5. **Ji, C.** (2020). formation of requirements for the information system of agricultural monitoring. Science Journal Innovation Technologies Transfer, 4, 31-34. https://doi.org/10.36381/iamsti.4.2020.31-34.

Approbation works:

6. **Ji, C.** (November 20-21, 2018). Decision making in the activities of agrarian enterprises. V *International Scientific and Practical Conference "Information Technologies and Interactions" (IT&I-2018),* Kyiv, Ukraine, 56

7. **Ji, C.** (2019). View on the problem of decision-making in the agricultural sector as a risk management task. . *I International Scientific and Practical Conference (IMTCK2019)*, Chernivtsi, Ukraine, 7.

8. **Ji, C.** (December 20, 2019). Development of the information system for supporting decision making in the agrarian sphere. *VI International Scientific and Practical Conference "Information Technologies and Interactions" (IT&I-2019)*, Kyiv, Ukraine, 95-96.

9. **Цзі, Ч.** (March 25-26 2020). Формування вимог до інформаційної системи підтримки прийняття рішень в умовах екологічної невизначеності. *Seventh international scientific practical conference «Management of the development of technologies»*, Kyiv, Ukraine, 135-136.

10. **Ji, C.** (2021). The impact of environmental factors on the decision making in agriculture. Information Technology and Implementation (IT&I-2021), 16-17.

11. **Ji, C.,** Andrashko, Y., Biloshchytska, S. & Tsiutsiura, S. (2021). Conceptual Research Model of Developing the Decision Support System for Agriculture Under Uncertainty, *2021 IEEE International Conference on Smart Information Systems and Technologies (SIST)*, Nur-Sultan, Kazakhstan, 1-5, doi: 10.1109/SIST50301.2021.9465888**.** [abstracts Scopus, Web of Science]