Chapter 9
Agricultural Decision-Making Methods and Systems

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Abstract Agricultural decision-making support system is a knowledge-enabled and computer-based system that supports and assists producers in decision-making. It is developed on the basis of agricultural information systems, agricultural simulation models, and agricultural expert systems. The system could assist decision-making with model combination and multiple scheme comparison. This chapter first analyzes the major problems in decision-making for production and discusses the decision-making methods and the development process of key technologies in the decision-making system. In addition, the typical agricultural decision-making support systems in each stage of production are introduced. In the future, the agricultural decision-making system will become modeled, precise, networked, and human-oriented.

Keywords Decision-making · Decision support system · Agricultural decision-making problems · Agricultural decision-making systems

9.1 Introduction

Decision-making refers to the strategy or method used to derive decisions. It is the process in which people formulate ideas and make decisions for various events. Decision-making is a complicated thinking operation process, encompassing information collection, processing, final judgment, and conclusion.

Decision support system (DSS) is a computer application system that helps decision-makers take semi-structured or unstructured decisions by means of human-computer interaction through data, models, and knowledge. It is a new type of computer information system for management that has become one of the most attractive

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Y. He et al. (eds.), *Agricultural Internet of Things*, Agriculture Automation and Control, https://doi.org/10.1007/978-3-030-65702-4_9

application in the field of computer management. Essentially, the theoretical development of DSS relates to a number of disciplines, including computer software, information theory, artificial intelligence, economics, management science, behavioral science, etc. As computer software and hardware technology continue to mature, the range of computer applications has expanded from the initial numerical calculations to include a number of management areas.

DSS is also a scientific tool that assists decision-making in a specific form. It provides decision-makers with a working environment that combines knowledge, initiative, creativity, and information processing capabilities. Moreover, DSS is also an integration of qualitative and quantitative methods through human-machine dialogue. It assists decision-makers in analyzing problems, exploring decision methods, evaluating, forecasting, and selection.

Agricultural production, subject to regions, seasons, and cycles, involves a wide range of issues related to decision-making. Agricultural decision-making refers to the process in which people make choices or decisions on goals, plans, policy strategies, and major measures of agricultural production.

The agricultural decision support system is developed on the basis of agricultural information systems, crop simulation models, and agricultural expert systems. In addition to furthering development in agricultural information decision support system, agricultural production management decision support system, and agricultural intelligent decision support system, the international agricultural decision support system has expanded to include group decision support system and network decision support system, thanks to the development of information and network technology. Group decision support system aims at integrating decision support systems in different aspects of the same field or related fields to form a more comprehensive decision support system. The network decision support system, also known as a distributed decision support system, decomposes a decision task into several subtasks and distributes it on each node of the network to complete it. In the foreseeable future, the agricultural decision support system will become an indispensable decision-making tool for sustainable development in agriculture.

9.2 Analysis of Agricultural Decision-Making Problems

Agricultural decision-making mainly takes place during production. Generally speaking, the agricultural production process can be divided into crop farming, aquaculture, transportation, and processing. The content and focus of decision-making in different links have their own characteristics.

9.2.1 Crop Farming

The system of crop farming, an objective complex, was formed under certain natural, economic, technological, and historical conditions. Therefore, there are apparent regional differences in species, quantity, quality, distribution and regional combination of agricultural resources, and socioeconomic and technological conditions. Challenges for decision-making in different aspects of crop farming vary.

The first problem we encounter is the choice of plant varieties. For example, for the control and management of planting systems in larger areas, it is necessary to separate the areas with different characteristics and place similar areas into one category for classification and guidance. Such process of classification is the division of the planting system. To put it more bluntly, whether a certain area is suitable for planting a crop is subject to the combined effects of many factors, including socioeconomic, technological, and natural factors. Appropriate and case-specific arrangements must be made, i.e., land suitability evaluation must be carried out. Models are playing an increasingly important role in the evaluation of land suitability. This is the case because, firstly, traditional geographic information system (GIS) models may no longer adapt to the requirements of land suitability evaluation. Secondly, when it comes to the application of models, most of the systems still rely on the original GIS model, lacking the ability of mathematical modeling and spatial simulation required for land suitability evaluation (Xia et al. 2005).

In addition to evaluating the suitability of the land, it is also critical to determine the economics of the crops planted. Local resources ought to be fully tapped into, and public demands should likewise be met, so that more economic benefits could be delivered. At present, decision-making in agriculture is usually based on the experience of growers or experts. Such highly subjective decision-making always involves the biases of decision-makers, thus leading to deviations.

In the process of planting, growers need to make decisions for a variety of problems. For example, the core of making decisions for pest control is to determine the amount of pesticide spray in different areas of farmland on the basis of clarifying the types, occurrence degree, and changing trend of pests and diseases, and the difficulty in this process is to identify the types and extent of pests and diseases. The occurrence of diseases and pests is a complex natural phenomenon, which has global and regional characteristics in space, disordered instability and ordered periodicity in time, and other complex and changeable characteristics, such as heterogeneity, diversity, suddenness, randomness, migration, and regularity (Gu 2015). It is quite challenging to diagnose diseases and pests, predict the trend of diseases, and make the decision of control methods. The relationship between the factors of decision-making is not clear, and sometimes a bad decision may occur because of the lack of information. Decision support systems of diseases and pests that currently exists usually adopt traditional rule-based knowledge representation method against a specific disease. This method can be limited by knowledge acquisition and knowledge base maintenance. Furthermore, it usually uses a single reasoning method, such as case-based reasoning or rule-based reasoning, thus its reasoning efficiency is not obvious.

Another important decision that growers have to make is that of fertilization. Often times, growers attempt to determine the amount of fertilizer to be applied based on crop growth, environmental information, and their experiences. There are significant regional differences in agricultural production; therefore, soil nutrients in different fields drastically vary, and the rules of growth and planting and fertilization management methods of different crops also present individual differences.

9.2.2 Breeding

Commonly divided, breeding can be sorted into aquaculture and livestock farming. Similar to crop farming, aquaculture and livestock farming are also troubled by issues relating to decision-making about suitability, the economics of farming, and the production process. Compared with the crop farming, breeding often comes in two different production modes: family-based small-scale farming, and factory-based large-scale farming.

Family-based small-scale aquaculture production usually features scattered production sites, low levels of automation, unclear breeding rules, and lack of effective process management. Furthermore, management of aquaculture often depends on the experience of breeders to determine the breeding status for making the corresponding breeding decisions. Such conditions lead to high labor costs, failure to improve production efficiency, and high rates of operational error (Gao 2016), thus increasing the risk of breeding operations. Family-based small-scale livestock farming is usually dominated by free-range farming. The retail farming production equipment, production technology, and production conditions are relatively inferior, especially in terms of management philosophy; thus they are not able to meet the needs of modern aquaculture. Most farmers rely entirely on experience to make farming decisions on various issues. In addition, family-based small-scale farming often causes environmental pollution that includes air pollution, soil pollution, and water pollution.

A variety of advanced technologies is adopted in factory-based large-scale farming. For example, most researches on information-based aquaculture process management are focused on the detection of water temperature, water level, dissolved oxygen, pH, and other water quality environmental factors via relevant hardware equipment, aiming at establishing real-time monitoring systems for aquaculture, such as intelligent aquaculture based on the IoT control system (Li et al. 2013; Manju et al. 2017; Raju and Varma 2017), wireless sensor network-based aquaculture multi-environmental factor monitoring system (Shi et al. 2018; Tai et al. 2012; Yang et al. 2015), smart ecological aquaculture system (Li et al. 2017), etc. These systems help realize such functions as real-time monitoring and monitoring data analysis of aquaculture water quality. In addition, concerning Israel's highly intensive aquaculture model (Guan and Lai 2006), industrial circulating water welfare aquaculture industry model (Huang et al. 2013), pneumatic propeller-driven aquaculture automatic operation vessels (Sun et al. 2014), and industrialized aquaculture automatic feeders (Yeoh et al. 2010), they mostly rely on advanced aquaculture equipment to achieve automation in single or multiple aquaculture stages. These advanced information technologies and automation provide massive information for the generation of decisions, and some simple decisions can be completed directly. However, decision-making for some complex issues, such as the causes of diseases of different aquatic products, remains complicated. Large-scale livestock farming also involves the application of multiple advanced information and automation technologies. Today, livestock farming has evolved into a modern, scientific, large-scale, and intensive industry and has gradually shifted to the garden-type development, which completely overcomes the problems of air pollution, soil pollution, water pollution, and other common problems in the traditional small-scale farming. Modern livestock farming, in addition to placing a focus on the diseases of the livestock, has begun to involve the mental state and humanitarian issues of livestock and is able to establish new decision models based on new information technologies.

9.2.3 Transportation

Agricultural products go through several layers of links from field to consumers, among which transportation is an essential link. It can be divided into three aspects: decision-making related to transportation mode, decision-making related to logistics center, and decision-making related to transportation risk assessment.

9.2.3.1 Transportation Mode

Transportation mode decision-making is the first major part of transportation. Scientific and reasonable decision-making can avoid, to a certain extent, the loss that may occur during transportation and improve the trade quantity of agricultural products. Agricultural products are perishable and difficult to store due to their regional and seasonal characteristics; thus, transportation must be timely, fast, and economical. At present, there are three modes of transportation: road, railway, and waterway. Most carriers only engage in a certain type of transport function, and only a few carriers offer transport functions that coordinate with several modes of transport.

Transportation requirements for agricultural products are met depending on multiple factors. In terms of the evaluation of the selection principle of transportation mode, most scholars focus on the macroscopic perspective of goods transportation, but few on the selection principle of agricultural products transportation mode. Due to the short life cycle of most agricultural products, there are also unique requirements for the mode of transportation. Only by choosing an appropriate transportation method can agricultural products be transported economically, quickly, safely, and conveniently. The evaluation of transportation methods should include consideration on the impact of many factors. Firstly, the choice of transportation methods ought to follow economic principles. Secondly, it is necessary to improve the response capacity of transportation and to shorten the time and distance of transportation according to the specific features of products. Thirdly, the risk of transportation should be reduced, which is mainly reflected in avoiding wastes of goods. Based on studies of various factors and the characteristics of agricultural product transportation, the evaluation criteria for agricultural product transportation methods are determined, which are evident in three aspects: economic capacity, agility, and risk control (Guo and Xi 2015).

Although extensive studies have been carried out on supply chain-related issues under different channel right structures, there are few studies which consider both the attenuation law of product freshness and consumer price sensitivity and the optimal ordering decision of different transportation modes and different decision-making bodies in supply chains.

The existing researches mainly start from a certain restricting factor that affects the transportation of fresh agricultural products, and they lack the perspective of comprehensive research on the relationship between various influencing factors. The studies focus on the analysis of objective restricting factors rather than the psychological behaviors of decision-makers. In terms of influencing factors of transportation mode, empirical analysis is rarely used in existing literatures. Among the few quantitative models, behavioral principles and appeals of different transportation means are seldom considered and compared. Moreover, the influence of cost, time, and safety on the selection of transportation mode are not systematically discussed.

9.2.3.2 Location of Logistics Center

An appropriate location of logistics center can improve the overall efficiency of businesses, reduce the losses in the circulation process, and step up with the efficiency of distribution and transportation. With the development of modern science and technology, computer, mathematics, biology, and other related disciplines have been integrated into the study of location model of logistics centers, so that the depth and breadth of studies on the location of logistics centers could be enhanced.

Part of the existing decision-making system performs a purely quantitative analysis of location without giving consideration to subjective weights. Such methods often fail to consider multiple factors, resulting in decision-makings that are neither practical nor effective, whereas considering the qualitative factors of the site selection method and quantifying the qualitative factors can get better decision-makings.

Although there have been breakthroughs in studies on the impact of external conditions, it remains the case that the variable cost and the immutable cost are quite complicated to calculate due to the large number of influencing factors in the logistics center. The current research is still limited to the distribution between logistics centers and retailers, with the aim of finding suitable locations for logistics centers to minimize the total cost of transportation between logistics centers and retailers. Location issues between the manufacturers and the retailers have not been studied.

9.2.3.3 Transport Risk Assessment

Logistics businesses of fresh agricultural cold chain are rarely wholly information-based. Even if a node on the cold chain is information-based, it is difficult to ensure that it can be applied to the entire cold chain. Cold chain interruptions occur frequently and have become a bottleneck restricting the development of cold chain logistics.

Most of the transportation optimization problems center on how to choose the best transportation route, the best transportation method, and how to get the goods to the customer in the shortest time with the least transportation cost under the premise of known transportation tasks. However, the goal of a transportation company that makes profits by undertaking transportation tasks is to undertake those transportation tasks that can achieve the maximum profit among the many transportation tasks according to the actual business situation.

In terms of research on transportation reliability, there is currently no specific refinement of the reliability of fresh agricultural product transportation systems. Most studies only consider reliability as one of the elements of transportation, without separately refining all attributes that are correlated with the reliability of transportation systems. Hence, a complete concept of transportation reliability system is not possible. Therefore, there is a lack of discussion on the relationship between the performance constraints of the overall transportation system and decision-making for transportation mode. This is particularly true in relation to decision-making for transportation mode under transportation risk constraints. In terms of transport risks in logistics links, researchers focus on the risk analysis of the whole process of logistics (including other links of logistics) and enterprise transaction risks in supply chain risks, while the relationship between transport risks and risks in other logistics links is not fully explored.

9.2.4 Processing

Agricultural product processing is the sum total of industrial production activities based on agricultural materials, artificial breeding, or wild animal and plant resources. It is noteworthy that agricultural products classification and quality testing are important links.

In developed countries and regions, the quality classification of agricultural products is the key in agricultural administrative departments. The quality classification of agricultural products, the basis for the marketization of agricultural products, improves the efficiency of agricultural products markets and promotes agricultural modernization.

Based on machine vision, the fruit and vegetable quality detection and classification technology has yielded promising results. The indicators for detecting and grading the external quality of fruits and vegetables mainly include color, size, surface defects, shape, and texture. At present, the scope of various decision-making methods are relatively single, mostly focusing on fruits with similar appearance (Ying et al. 2000). The color, surface damage, size, shape, and various internal defects of fruits and vegetables play an extremely important role in their classification decision; hence, how to collect all-round information of products is vital in decision-making for the final classification.

In addition, the quality of agricultural products is difficult to classify due to factors that include region, time, and climate. The results, sizes, thicknesses, lengths, heights, fineness, leanness, and content of ingredients may differ even when it comes to products produced in the same variety, same region, and same season. Moreover, the quality of products varies significantly depending on the production technology deployed. Therefore, the classification and standardization of agricultural products is relatively difficult, and the grade and standard formulation come with obvious particularities, thus posing daunting challenges to the determination of decision-making methods for the final classification.

Though research on the application of machine vision in the field of agricultural product classification and grading is becoming increasingly extensive, there are still some deficiencies in the following areas: Many experimental studies are confined to the laboratory or static conditions; thus, it is difficult to put them into application. The range of agricultural products involved is not broad enough, and many agricultural products have not used machine vision to achieve classification. Computer vision technology is ideal when detecting a single index of food or using one index as the classification standard; however, if multiple indicators of the same food are used as the grading standard for testing and grading, the error of grading results ramps up, and the accuracy and time of testing fall below the ideal state. The detection adaptability is not strong, and the detection results are easily affected. Computer vision technology has a significant effect on the grading detection of a single kind of fruits and vegetables, but it is difficult to apply the same system and equipment to other kinds of fruits and vegetables. Moreover, sharing a set of computer vision equipment can be challenging even for the same type of different varieties of agricultural products. The current computer vision technology and supporting mathematical models are suitable for simple environments, while more errors may occur when working in complex environments.

The inspection of quality in processing holds great significance. Spectral technology has attracted the attention of many scholars because of its non-destructive features, short analysis time, zero pollution, low cost, and the fact that it does not require sample pretreatment. Although research based on spectroscopy has continued for a long time, similar problems related to the hierarchical application of machine vision exist. Let us take near-infrared spectroscopy as an example; the technology is easily affected by various factors (such as the temperature of the sample, the location of the sample, and the loading conditions). When the sample is moving, the near-infrared spectrum is more easily affected for online detection, and the acquisition of stable spectrum remains a problem. Most of the models used in online detection research are partial least-square method (PLS) or neural network models, which are abstract and undescriptive (Sun et al. 2009). The research on descriptive models and the application of descriptive models in online detection are not sufficient, most of which are only tentative; as a result, the detection model cannot be applied to agricultural products processing. Furthermore, the applicability is also limited because most models are for single agricultural products and designated spectrum acquisition equipment.

9.3 Decision-Making Methods

Decision-making, a purposeful thinking process of human beings, exists in all human activities and in the whole of human history. Since ancient times, human beings have altered their relationship with nature and society relying on their own unique decision-making capabilities in order to survive and develop.

Research on science-based decision-making began in the early twentieth century. After World War II, research on decision-making incorporated the results of behavioral science, systems theory, operations research, and computer science. By the 1960s, the discipline of decision-making, which specialized in researching and exploring the rules for making correct decisions, was formed. Among the relevant research programs, the prominent one is the modern decision-making theory proposed in the 1960s by the famous American economist and management scientist Herbert Alexander Simon, who pointed out that management is equivalent to decision-making (Simon 1977). Decision-making runs through the whole process of management that is actually composed of a series of decisions. The quality of decision-making plays a prominent role in the efficiency and effect of various functions of management. As research on decision theory and method furthers, decision-making is permeating into all fields, especially business undertakings.

In modern management science, decision-making is a conscious and selective action taken to achieve a predetermined goal. It can be treated as a process that involves asking questions, establishing goals, creating the design, and selecting solutions. Based on limited manpower, equipment, materials, technology, capital, and time, people put forward feasible schemes to achieve specific goals. A number of science-based methods and means are then adopted to compare, analyze, and evaluate the alternatives so as to obtain satisfactory results. The scheme will be modified according to the feedback of the plan until the goal is achieved. Scientific decision-making is the precondition that ensures the smooth progress of all kinds of undertakings, as well as a sign of leadership.

The extensive adoption of decision-making, and the diversity of human activities make decision-making diverse. According to the different conditions, decision-making can be divided into deterministic decision-making, risky decision-making, and uncertain decision-making.

Agricultural decision-making refers to the process in which people make choices or decisions on the development goals, discovery plans, action plans, policy strategies, and major measures of production. It generally includes strategic and tactical decisions, macro decisions and micro decisions, and group decisions of managers and individual decisions of producers.

9.3.1 Deterministic Decision Methods

In the decision-making process, several alternatives are proposed, each of which has only one result, so that the best choice can be made by comparing the results. A deterministic decision is a decision under a positive state. Decision-makers have a full understanding of the conditions, nature, and consequences of the problems relating to decision-making, and each alternative can only have one result. The key to this type of decision-making is to choose the best solution in a positive state. Common decision-making methods include differential analysis and cost-volume-profit analysis. The former is a method of selecting the optimal solution from the analysis of the differential income and the differential cost of each option by measuring the expected revenue and the expected cost of the two alternatives. The differential analysis also has certain limitations, in that it can only be used to choose between the two schemes. If the decision-maker is faced with three or more options, they can only seek alternative methods or use the differential analysis method to compare and finally select the best. The principle of differential analysis is simple, which is why it is widely used in production decision-making. The cost-volume-profit analysis aims to analyze the relationship between production cost, sales profit, and product quantity to grasp the law of profit and changes in loss and guide companies to determine a business plan that can produce the most products with the least cost and maximize profits. It can be used to calculate the breakeven point, also called the profit and loss divergence point and the income turning point, of the organization. The analysis principle is that when the output increases, the sales revenue increases in direct proportion without increasing the fixed cost. What is meant is that as the output increases, only the variable cost increases with it.

9.3.2 Uncertain Decision-Making Methods

In the process of decision-making with uncertain decision-making methods, various alternatives are proposed, each of which brings several different results, but the probability of occurrence in relation to each result cannot be determined in advance, so that the decision-making is uncertain. The difference between uncertain decision-making and risky decision-making is that in the latter, several possible outcomes are produced by each scheme, and their probability of occurrence are known, whereas uncertainty decision-making only offers the several possible outcomes produced by each scheme, with unknown probability of occurrence. This is the case due to insufficient understanding of the randomness rules of possible objective states of market demand, which increases the degree of uncertainty of decision-making.

The criteria of uncertain decision-making include pessimistic decision-making criteria, optimistic decision-making criteria, compromise decision criteria, regret-value decision criteria, and equal probability decision criteria. In the decision-making process, the selection of different plans depends largely on the experience, preference, judgment of natural state, psychological quality, attitude to risk, and other factors concerning the decision-making subject, hence making the decision-making process highly subjective. For the same decision-making problem, different decision-makers will adopt different decision-making criteria that correspond to different decision-making methods, leading to different decision-making results. Since there is no unified evaluation standard, we cannot determine the advantages and disadvantages of various decision-making methods. In order to better cope with the problems of uncertain decision-making, the decision-makers must conduct in-depth investigation and study, strive to improve their own quality, and accumulate decision-making experience extensively.

9.3.2.1 Criteria of Pessimistic Decision-Making

When dealing with uncertain decision-making problems, decision-makers may pursue foolproof decisions out of cautiousness. At this point, to be safe, we must assume the worst scenario, which is to say that one should first consider the worst results of each alternative, and then choose the best one among them, and draft the corresponding plan. That is, when the goal is to maximize the income, one ought to choose the plan with the largest profit value from the minimum income of each action plan as the decision plan, whereas when the goal is to minimize the loss, one should choose the plan with the lowest loss value from the maximum loss of each action plan as the decision plan.

The basic idea is to first calculate the minimum return value that various plans may have in their natural states and then choose the plan that corresponds to the largest value among these minimum return values as a decision plan.

9.3.2.2 Criteria of Optimistic Decision-Making

The criteria of optimistic decision-making require the decision-makers to adopt a sound and optimistic attitude – choosing the most satisfying decision plan when they are unable to determine the possible results of each plan. The basic idea of the code is that the decision-makers should always take an optimistic attitude toward the natural state of objective occurrence and hope that the most favorable state would occur with an optimistic spirit of adventure. For decision-makers aiming at maximization of benefits, they should first identify the maximum benefits of each scheme and then choose the scheme corresponding to the largest of the maximum benefits as the optimal scheme. Therefore, the optimistic decision criteria here is also called the maximum expected value decision criteria. Similarly, for decision-makers who aim at minimizing loss, the scheme corresponding to the one with the least loss should be selected as the optimal scheme from the minimum loss value of each scheme. The optimistic decision criteria here is also known as the minimum loss value decision criterion.

The basic idea is to first calculate the maximum possible benefits of various schemes in their natural states and then choose the scheme corresponding to the maximum benefits of these schemes as the decision scheme.

9.3.2.3 Criteria for Compromise Decision-Making

The guiding principle of this method is to seek steady development, meaning that decision-makers should be neither too optimistic nor too pessimistic and that a more stable plan is preferable. The specific steps of such decision-making are as follows: first, identify the minimum value and maximum value of each scheme in all states. Secondly, decision-makers should set the maximum coefficient a ($0 < a < 1$) according to their degree of risk preference, and the minimum coefficient is determined as 1-a. a, also known as the optimism factor, which is a measure determining the aversion to risks of policymakers. Then, the weighted average value of each scheme is calculated by the given optimism coefficient, and the corresponding maximum and minimum profit and loss value of each scheme are likewise determined. Finally, the scheme corresponding to the maximum profit and loss value of the weighted average is taken as the selected scheme.

9.3.2.4 Criteria for Minimum Regret Decision-Making

Ideally, decision-makers choose the solution with the largest gain or the smallest loss as the optimal solution. However, decision-makers may not take the optimal solution under ideal circumstances but adopt other solutions due to the influence of future uncertainty. Moreover, they would regret it if it were to be found that they missed the chance to reap the biggest rewards. Based on the idea of avoiding to regret in the future by choosing now, researchers put forward the criteria for regret decision-making, quantifying the subjective feeling of "regret," and the value so determined is the basis for the decision.

This method uses the minimum value of the maximum regret value as the decision plan. The difference between the maximum return value in each natural state and the return value of each scheme is called the regret value, also known as opportunity loss.

9.3.2.5 Criteria for Equal Probability Decision-Making

When information about the emergence of future natural states is unclear, the criteria introduced in the previous sections make bold assumptions from different perspectives, hence simplifying the solution of uncertain decision problems. Viewed from the perspective of their respective starting points, all of them are justified, but their inherent shortcomings and limitations are also apparent. For instance, the criteria for pessimistic decision-making assume that the natural state that obtains the minimum benefit must occur, and the probabilities of other states are zero, whereas the idea of optimistic decision-making is exactly the opposite. The criteria for compromise decision-making introduce the concept of optimistic coefficient, which overcomes extreme thoughts but also only considers the best and worst natural state returns, assuming that the probability of other intermediate states occurring is zero. The common disadvantage of these criteria is that they do not make full use of all the information contained in the revenue function, which will significantly affect the accuracy of the decision. In the nineteenth century, Laplace, a well-known mathematician, proposed rules of equal probability decision-making, which overcomes the shortcomings of insufficient use of the above criteria. These criteria hold that when the probability of occurrence of each natural state is unclear, the probability of occurrence of each state can only be considered as equal. The expected return of each plan is obtained with equal probability, and the plan corresponding to the maximum expected return value is the optimal decision plan.

9.3.3 Methods for Decision-Making Under Risks

In the decision-making process of decision-making under risks, multiple alternatives are proposed, each of which has several different results, and the probability of their occurrence can also be calculated. The reason why decision-making under risk exists is that various market factors affecting the prediction target are complex and changeable, and the implementation result of each scheme is highly random. Therefore, no matter which action plan the decision-maker chooses, certain risks are inevitable. The main methods involved in decision-making under risks are revenue matrix method, decision tree method, and Bayesian decision method.

9.3.3.1 Payoff Matrix Method

The payoff matrix generally consists of three parts: feasible schemes, natural states and their probability of occurrence, and possible outcomes of various action schemes. The presentation of these three parts on a table is known as the return matrix. Decision-making under risks is based on the decision payoff matrix, which calculates the returns of each plan in different natural states and then calculates the expected return of each plan according to the weighted average of the objective probability, among which the best scheme is selected.

9.3.3.2 Decision Tree

As a diagram of the decision-making situation and a method commonly used in risky decision-making, a decision tree can be used to visualize the problems relating to decision-making. It draws various alternatives, possible natural states, and multiple profit and loss values on a chart. It is convenient for decision-makers to review the decision-making situation and analyze the decision-making process, especially for decision-makers who lack mathematical knowledge and are not sufficiently competent.

The criteria for decision-making under risk are expectations, which is an average of weighted properties in various states. The expected value of a scheme is the sum of the probabilities of its gains and losses in various states. The decision tree uses several branches to represent the expected value of various schemes, and if the branches with lower expected values cut out, the remaining scheme would be the optimal scheme. Decision tree consists of decision node, scheme branch, scheme node, probability branch, and result point.

Decision trees can be divided into single-stage decision trees and multistage decision trees. The former means that only one decision-making activity is required before an ideal solution can be selected. Single-stage decision trees generally have only one decision node. If the problem is more complicated and cannot be solved by one decision, and the most satisfactory solution can be selected through a series of interconnected decisions. This decision is called multistage decision. The goal of multistage decision-making is to optimize the overall effect of each decision.

When applying decision tree to decision-making, the following processes are usually involved:

- Drawing a decision tree. The given problem gradually expands from the decision point into scheme branch, state node, probability branch, and the result point. When drawing a decision tree, one should do it step by step (from left to right).
- Calculating expectations. The calculation of the expected value is performed gradually from right to left, that is, the expected value and the expected result of the scheme are determined according to the profit and loss value on the right side and the probability of the probability branch.
- Pruning plan. Based on the expected results of different schemes, the schemes with lower expected values are discarded successively from right to left and marked with symbols. This process can be figuratively called pruning. The last decision point leaves a branch, which is the optimal scheme.

When the problem only demand one decision, it is called a single-stage decision-making problem. If the problem is more complex and requires a series of decisions to resolve it, it is called a multistage decision problem. It is noteworthy that multistage decision problems are more intuitive and easier to operate using a decision tree decision method.

9.3.3.3 Bayesian Decision-Making Method

When dealing with risky decision-making problems, it is essential to determine the probabilities of various states. They are unconditional probabilities based on experience that are called prior probabilities. The method of expected value for decision-making chooses the best scheme according to the prior probability of various events. Such a decision carries certain risks because the prior probability is determined by historical data or subjective judgment and has not been tested in practice. In order to minimize this risk, we need to accurately determine and estimate these prior probabilities. It is critical to obtain accurate intelligence information through scientific experiments, surveys, statistics, and other methods to modify the prior probability, so that the posterior probability and the expected value of each scheme are determined, allowing decision-makers to make accurate choices.

The Bayesian formula gives the relationship between prior and posterior probabilities:

$$P\left(\theta_i|A\right)=\frac{P\left(A|\theta_i\right)P\left(\theta_i\right)}{\sum_{j=1}^{n}P\left(A|\theta_j\right)P\left(\theta_j\right)} \tag{9.1}$$

where $P(\theta_i)$ is the prior probability of event; $P(\theta_i|A)$ is the posterior probability of event θ_i; and A is any event and satisfies $P(A) \neq 0$. The basic steps of a Bayesian decision are as follows:

- Prior analysis: Decision analysts first collect supplementary statistical data and information, and apply state analysis methods to calculate and estimate the prior distribution of state variables in accordance with their own experience and judgment, and calculate the conditional results of each feasible solution under different natural states using this information. According to some decision-making criteria, the feasible solutions are evaluated and selected to find the most satisfactory solution, which is called pre-analysis. Due to objective conditions, such as time, human, material, and financial constraints, it is impossible to fully collect market information. Decision analysts can only complete the pre-analysis step.
- Pretest analysis: If the problem of decision-making is very important, and provided that time, manpower, financial resources, and material resources allow, it should be considered whether to conduct market research to supplement and collect new information. The basis of such consideration is to balance the benefit that supplementary information may bring and the cost of supplementary information. If the value of the information is higher than the cost, indicating that the advantages of supplementary information outweigh the disadvantages, it should

be supplemented. If the opposite is true, then supplementary information would not be unnecessary. This comparative analysis of the value and cost of supplementary information is called a pretest analysis. If the cost of obtaining the supplement is small or even negligible, this step can be omitted, and the investigation and collection of information can be directly carried out, and the next step based on the obtained supplementary information can proceed accordingly.

- Posterior analysis: After the pretest analysis, decision-makers make the decision relying on supplementary information and prepare for the post-test analysis by market research and analysis of supplementary information. The key to posterior analysis is to use supplementary information to modify the prior distribution, thus deriving a more realistic posterior distribution. Then, the posterior distribution is used for decision analysis to select the most satisfactory feasible plan. The value of information and the cost of comparative analysis are taken into consideration to make a reasonable explanation of the economic benefits of decision analysis. It is worth mentioning that both the posterior analysis and the pretest analysis use Bayesian formula to modify the prior distribution. The difference between them is that the latter is based on the possible investigation results, and focused on the judgment derived from supplementary information, while the former is based on the actual survey results, and focused on selecting the most satisfactory solution. In practice, the two are sometimes carried out simultaneously only with different emphasis because they are indistinguishable.

9.3.3.4 Agricultural Application of Decision-Making Under Risks

Agricultural production is an incompletely measurable activity that uses multiple natural and artificial inputs to obtain agricultural products. Owing to the randomness of the activity, there is the risk that it may not be possible to carry out crop production according to the ideal deterministic model, and the same is true for pest control, as the occurrence of pests shows a certain randomness. Implementation of a control measure, such as the layout of resistant varieties, naturally bears certain risks. In this case, it is necessary to scientifically estimate and quantify the risk probability and to identify the least risk prevention measures. This kind of quantitative method counts as decision-making under risks. At present, the dominant method of decision-making under risks for pest control is the Bayesian analysis. Zhang and Gu (1996) introduced multi-objective decision-making technology into the field of decision-making under risks and proposed a multi-objective decision-making algorithm and a comparative method to determine risk probability, hence providing research and application values in pest control decision-making. As IoT technology matures, agricultural decision support systems need to process increasingly diverse types of data. Combining various methods to improve the reliability of decision-making is a big data solution for modern agricultural decision support systems. The decision system designed by Guo (2018) enables real-time monitoring and perception of important parameters that include soil moisture, temperature, and light intensity in the agricultural production environment. This system adopts the Bayesian statistical inference to establish a multidimensional Gaussian statistical model of various indicators of smart agriculture. Based on machine learning, the decision threshold of environmental parameters is optimized, so that electrical equipment can be controlled more accurately and reasonably, and the goal of rational planting can be achieved. The system software platform features real-time monitoring and display of agricultural production environmental parameters, trend change of corresponding parameters, query and analysis of historical data, and map display and monitoring of greenhouse environmental parameters.

9.4 Decision Support System and Its Key Technologies

9.4.1 Decision Support System

Decision support system (DSS) was first proposed in 1971 by M. S. Scott Morton of the United States in an article titled *Management Decision System*. Essentially, DSS is developed at the basis of management information systems and management science (Cao 1997). Management information system is used to process a large amount of data and complete management tasks. Management science (or operations research) relies on models to aid decision-making. The decision support system combines a large amount of data with multiple models and supports decision-making through human-computer interaction. DSS is a human-computer interaction information system based on computer processing that can comprehensively utilize various data, information, knowledge, artificial intelligence, and model technologies. It can assist decision-makers at all levels to implement scientific decisions. Moreover, DSS comes with better flexibility and adaptability, quick responses, and a friendly, interactive user interface used to support the decision-making process. Though DSS may be helpful in solving semi-structured and unstructured decision-making problems, it cannot replace decision-making at higher levels.

The framework of the decision support system is shown below (Fig. 9.1):

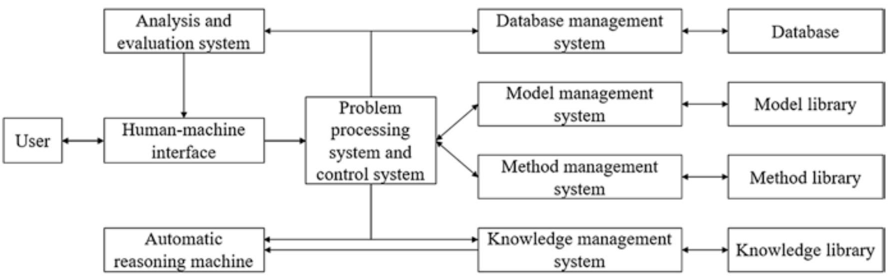

Fig. 9.1 The framework of the decision support system

- Human-machine interface: the bridge between the user and the system.
- Database system: storing the information needed to support decision-making. The data in the database has been properly processed and concentrated. In addition to the internal data of the enterprise, a large amount of external data is also required.
- Model library system: flexibly completing the storage and management functions of the model. Model library: storing various models used for decision-making, including strategic models, tactical models, operational models, and various model components and subroutines. Model library management system: responsible for the establishment and management of model library and model dictionary, model operation, model operation control, and interface management with database. Model dictionary: presenting the descriptive information about the model and data abstraction of the model.
- Method library system: a software system that provides algorithms for solving models. Method library: including methods and programs that make up various mathematical models, such as ranking algorithms, classification algorithms, minimum spanning tree algorithms, shortest path algorithms, linear programming, dynamic programming, various statistical algorithms, and so on. Method library management system: responsible for the establishment and management of methods, the building of the interface between method library and model library, and method dictionary management.
- Knowledge library system: solving semi-structured and unstructured problems. Including knowledge library, knowledge library management system, and reasoning machine. Knowledge library: storing various rules, causality, and experience of decision-makers. Reasoning machine: primarily responsible for selecting and implementing knowledge, and the common method used is searching method.

9.4.2 Key Technologies of Decision Support System

9.4.2.1 Data Warehouse

As market competition intensifies, and the needs of the information society rises, the quickly extraction of information from a large amount of data has become increasingly important. Doing so requires online services and a large amount of data for decision-making. Traditional database systems are complicated due to massive historical data. Plus, data of different systems is difficult to integrate, and the ability to access massive data is limited, thus traditional database systems are no longer able to meet market demands. In the early 1990s, the emergence of data warehouses solved these problems.

A data warehouse is a topic-oriented, integrated, stable, and different-time data collection used to support the decision-making process in business management. Data-oriented themes in a data warehouse correspond to traditional databaseoriented applications. Topics are a standard for classifying data at higher levels, and each topic corresponds to a macro analysis area. The integration characteristics of the data warehouse means that data must be processed and integrated before entering the data warehouse, a key step in establishing a data warehouse. First, we must unify the contradictions in the original data and transition the original data structure from application-oriented to topic-oriented. The stability of the data warehouse refers to the fact that the data warehouse reflects the content of historical data, not the data generated daily. After the data is processed and integrated into the data warehouse, it is rarely modified. Additionally, the data warehouse is a collection of data at different times. It is required that the time limit of data storage in the data warehouse should meet the needs of decision analysis and the data in the data warehouse must indicate the historical period of the data.

The data warehouse cleans, extracts, and transforms a large amount of traditional database data used for transaction processing and reorganizes them according to the needs of decision-makers. Such highly concentrated data provides a useful basis of analysis for various decision-making needs.

9.4.2.2 Data Mining

Data mining technology is capable of the identification and extraction of hidden, unexplored information, knowledge and business models, and related factor association rules from a large amount of fuzzy, incomplete, and noisy random data.

Data mining technology involves many fields, such as database technology, data warehouse, fuzzy logic, artificial intelligence, statistics, machine learning, information retrieval, high-performance computing, visualization, and artificial neural networks. The scope of data mining encompasses structured databases, semi-structured hypertext files, and even unstructured multimedia data.

Data preparation, data collection, and interpretation evaluation constitute the three main components of general data mining. The data mining process, iterating in three stages, is shown in the figure below (Fig. 9.2).

The two basic goals of data mining are prediction and description. Prediction refers to using certain variables or several known fields in the database to predict unknown or future values of other variables or fields of interest, while description refers to finding understandable patterns that describe data.

Data mining methods include:

- Clustering: the data is divided into different classes, so that the data within the same class is as similar as possible and the difference between classes can be

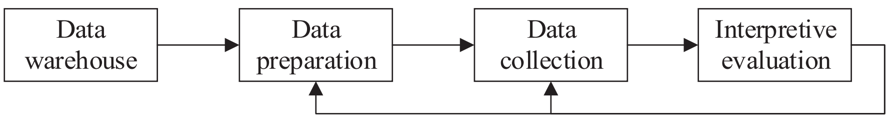

Fig. 9.2 The processing diagram of data mining

significant. The k-means algorithm is one of the most commonly used clustering algorithms. First, k objects are arbitrarily selected from n data objects as the initial clustering centers, and the remaining objects are assigned to the ones that are most similar to them according to their similarity (distance) with these clustering centers (represented by the cluster center). Then the cluster center (mean of all objects in the cluster) of each new cluster obtained is calculated, and this process is repeated until the standard measure function starts to converge.

- Artificial neural network: a mathematical or computational model that imitates the structure and function of a biological neural network (animal's central nervous system, especially the brain). It is used to estimate or approximate functions. Self-organizing map (SOM) or self-organizing feature map (SOFM) is a training sample space used to generate low-dimensional (usually two-dimensional) discretized representations using unsupervised learning. It is a method for reducing dimensions. Alkahtani et al. (2019) and others used SOM as a data mining tool to map high-dimensional distributions to regular low-dimensional grids in order to convert complex, nonlinear statistical relationships between high-dimensional data items into low-dimensional simple geometry relationships.
- Data visualization: data visualization integrates automated and visual analysis techniques to obtain visual knowledge from the data. Ellouzi et al. (2017) and others described the function of visual data mining as: in a decision support system, before applying visualization or automatic analysis, complex time data needs to be cleaned, preprocessed, and transformed. This data preparation is designed to export the appropriate temporal data representation for data mining.
- Classification: predicting which category a customer or event belongs to. The Bayesian method, based on the Bayesian principle, taps into probability statistics to classify the sample dataset. The feature of the Bayesian method is to combine the prior probability and the posterior probability, i.e., to avoid the subjective bias using only the prior probability. Moreover, the Bayesian method also avoids overfitting using sample information alone.
- Regression: regression analysis is based on a series of known or accessible correlations between independent and dependent variables to establish regression equations between variables. The regression equation is adopted as an algorithm model and used to connect the dependent variables on the new independent variable. Linear regression is the simplest and the most common used type of regression model. The data is modeled using a linear prediction function, and unknown model parameters are also estimated from the data. These models are called linear models.

9.4.2.3 Online Analytical Processing

Online analytical processing (OLAP) has rapidly developed in line with data warehouse technology. As an information analysis and processing process based on the data warehouse, OLAP is the user interface of the data warehouse. Data warehouses focus on storing and managing decision-oriented data, whereas OLAP focuses on data analysis in data warehouses and on transforming them into information to aid decision-making. When OLAP is used as a stand-alone application, sufficient data for analysis must be provided, and its data organization should correspond to that of the data warehouse. When combined with a data warehouse, OLAP draws data from the data warehouse. The large amount of data stored in data warehouse is organized in a multidimensional manner, which is the most suitable data organization method for OLAP.

OLAP technology is cross-sectoral and topic-oriented. Typical applications of the technology include slicing and dicing of multidimensional data, drilling, rotation, etc. Such applications facilitate users to extract relevant data from different angles. Another major feature of OLAP is the analysis of multidimensional data. Relying on OLAP, a mutual and complementary relationship with the multidimensional data organization of the data warehouse is formed.

The technical features of OLAP are as follows:

- Multidimensionality: Multidimensionality is the soul of OLAP. The system must provide multidimensional views and analysis of data analysis, including full support for hierarchical and multiple hierarchical dimensions. In fact, multidimensional analysis is the most effective way to analyze corporate data.
- Real-time response: Users expect strong response capabilities from OLAP. The system should be able to respond to most of the user's analysis requirements in a very short time.
- Targeting: The data in OLAP is prepared for the needs of decision analysis, thus eliminating the interference of a lot of redundant data that is not related to the subject.

9.4.2.4 Model Generation

Model generation refers to the establishment of a set of models in the system that can reflect the movement patterns of entities. This model is not necessarily a mathematical model, or it is not entirely a mathematical model.

The model generation process has four characteristics:

- The main storage mode of the model in the system is non-programmatic. Both data-based and knowledge-based model representations can be used as the basic form of the model. Of course, programmatic representation models may still be used in some areas.
- In the process of model generation, a combination of quantitative modeling and inference analysis is adopted. Quantitative modeling is used to determine the mathematical form and related parameters of the model, while inference analysis works before, during, and after modeling.

- The model is built via human-computer interaction. In the traditional modeling process, the boundary between the role of humans and the role of machines is clear-cut, but in the decision support system model generation technology, this boundary is ambiguous.
- Model generation should be a dynamic process. In particular, when the environment in which the entity is located changes, the environment in which the model is created should change accordingly. Even if the same steps are followed, the generated models will not be exactly the same.

The premise of model generation is that a simulation system of a solid environment must be constructed inside the system, which is called solid simulation environment. The simulation environment consists of two parts. One is a quantitative factor system, which is placed in the database, and the other is a non-quantitative factor system, which is placed in the knowledge base. It is obvious that the simulation environment cannot be independent of the usage context.

The model generation environment studied by the decision support system is not the specific content of the physical simulation environment; rather, this environment covers the conditions and software framework that should be included in the decision system in order to construct the simulation environment, which is called the framework environment of the model. There are five questions to consider when designing such a framework environment.

- Interactive mode: Natural language interface is an ideal way of interaction, and when it is not applicable, composite interface is often used instead.
- Model expression: When the model is expressed as a kind of knowledge, knowledge representation used to describe the model should be suitable for both quantitative calculations and inference analysis.
- Quantitative computing power: When determining the structure and parameters of the mathematical model, and when testing the generated model, a number of problems may occur in relation to quantitative calculation, most of which can be placed in the method library as subroutines. The algorithm as a subroutine should be independent of the specific application background.
- Reasoning analysis framework: Reasoning outside the context of the application struggles to go deeper. The framework generated as a model mainly refers to the basic structure of the inference system, the way of learning of knowledge, and the ability to acquire. If the designed decision system has a clearer background, the core knowledge embedded in the background would be able to bring great convenience to users.
- Management of the framework environment: Management function refers to the organization and coordination of the system. Powerful management functions are the key to the success of the system, especially when the system is actual use.

9.5 Typical Agricultural Decision-Making Systems

9.5.1 Suitability Evaluation Decision-Making System

In terms of crop suitability evaluation, many typical decision-making systems have been created. For instance, geographic information system (GIS), a basic platform for multidisciplinary integration of computers, geography, surveying, mapping, information, and management, can collect, store, manage, analyze, and display information related to geospatial space. Compared with traditional analysis methods, it transforms the past manual, single, static, and qualitative analysis methods into the multidimensional, multi-element, time-space integration, and qualitative and quantitative integration of comprehensive analysis technology. GIS has become one of the critical means of planning, environmental monitoring, and departmental decision-making in agriculture. The use of GIS technology for land suitability evaluation can make full use of existing data resources for comprehensive quantitative and qualitative analysis, achieve the systematization and automation of the land evaluation process, and provide accurate and reliable quantitative basis for land management and planning. Su et al. (2005) established a spatial analysis model of regional classification index based on three decades of climatological data and 1:250 000 basic geographical data from 90 meteorological stations in Guangxi, which provided the scientific basis for rational distribution of Shatian pomelo, seeking advantages and avoiding hazards and improving yield and quality of Shatian pomelo. Qiu et al. (2005) made comprehensive use of the "3S" technology to analyze and evaluate the suitable distribution status and utilization potential of fruit trees in Zhangzhou, Fujian Province. Yang et al. (2007) designed an ecological agriculture monitoring and decision support system based on WebGIS for tobacco planting in Honghe Prefecture, Yunnan Province. Cao et al. (2012) developed a precision corn planting decision-making system based on "3S" technology. The system provides accurate production information services for farmers and workers in the field of agricultural science and technology according to the basic situation of corn farming. In addition, it also features related functions such as query, modification, report, authority, and analysis of various related data. Qin (2018) chose 12 evaluation factors and soil management to construct a farmland suitability index evaluation system based on four aspects: soil nutrients, site conditions, and physical and chemical properties. A 16 m × 16 m grid was used as the evaluation unit, the analytic hierarchy process was used to determine the weight of the evaluation index, and remote sensing and geographic information system technology were used to establish a model for comprehensive evaluation. The suitability of cultivated land in the research area was divided into ten grades.

There are many more applications of this type of decision-making system. "3S" technology can be used to quickly and accurately obtain multidimensional information in agricultural production systems and manage and analyze spatial data. Global positioning system (GPS) can accurately locate the geographic location and review the results of agricultural zoning at fixed points to ensure that the results are true and reliable, while geographic information system (GIS) technology can simplify the processing and operation of data. The advantage of remote sensing (RS) technology is that it can quickly and accurately obtain information on the growth and environmental distribution of crops on the ground and identify non-agricultural land. The introduction of “3S” technology can provide a large amount of basic data and dynamic data for agricultural expert systems and offer data support for the establishment of expert system databases and model libraries, hence facilitating decision-making.

9.5.2 Cultivation Decision System

The rice cultivation simulation-optimization decision-making system (RCSODS) of the Jiangsu Academy of Agricultural Sciences in China combines rice simulation technology with the principles of rice cultivation optimization, so that the system is able to propose recommendations of decision-making for high-yield cultivation measures that correspond to different varieties and different environments. Each subsystem is based on the combination of the two models, and a decision model with strong mechanism and versatility is established for various cultivation measures. Moreover, the RCSODS system is not limited by the experience of regional experts. The system can effectively provide decision-making recommendations for measures of high-yield rice cultivation according to environmental conditions, such as climate and soil, and crop growth conditions, including previous crops, sowing dates, cultivation methods, and rice varieties. Therefore, the RCSODS system has a wide range of applications, and it clearly outperforms other agricultural decision-making systems based on expert systems.

The RSCODS system consists of more than 100 sets of mathematical models, which are mainly divided into two categories, the first of which are rice simulation models, including rice bell models, photosynthetic production models, stem borer dynamic models, nitrogen dynamic models, and yield formation models. Each model contains several sub-models. The second type is the rice cultivation optimization model, covering the best season model, the best leaf area dynamic model, the best stem borer dynamic model, the best yield model, the best fertilizer model, etc. The above models all use day as the simulation time unit.

The rice bell model includes four sub-models related to rice morphological development, namely, the development stage model, leaf age model, total leaf age model, and organ formation model. As the core of the RCSODS system, the development stage model features a time scale function, which controls the adjustment of the sub-models and corresponding parameters during the simulation of the entire system. At the same time, the formulation of various optimized cultivation decisions also serves a specific growth period. The fertility period model has successfully been applied, and it has further promoted the concept of fertility day in modern plant physiology. The model defines a diurnal cycle as a developmental physiological day under optimal temperature and light conditions and assumes that the number

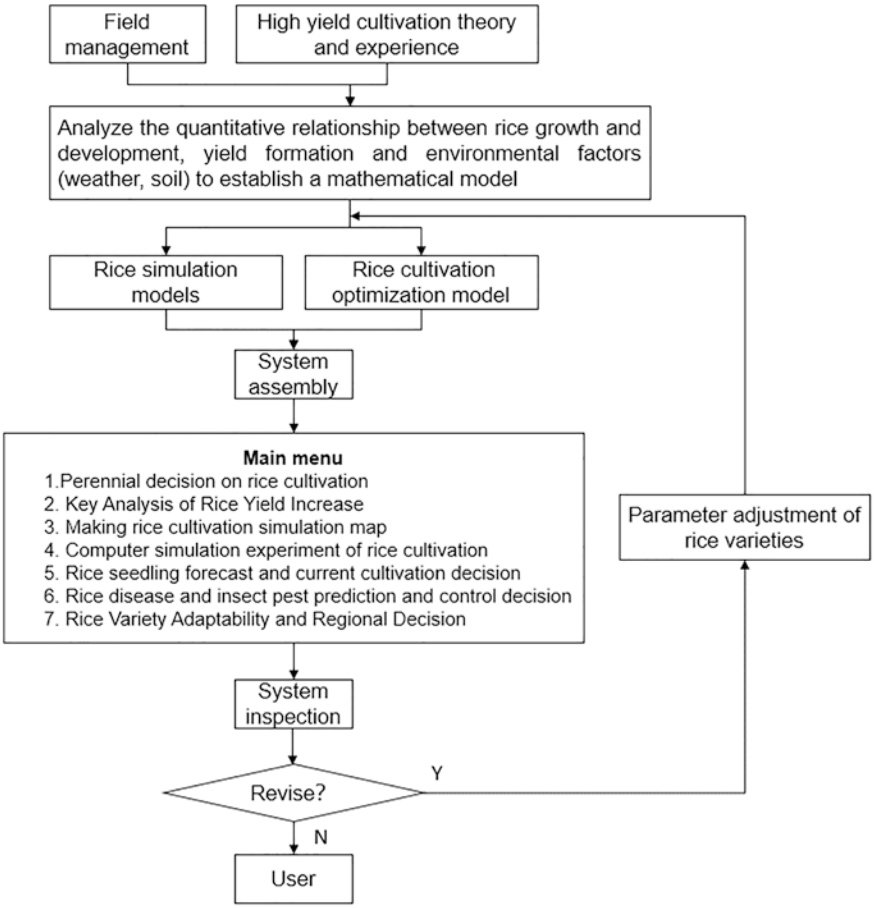

Fig. 9.3 The flowchart of RCSODS

of developmental physiological days required to complete a specific growth period is constant for a given rice variety. The proposal of the "constant physiological days" has been well-received globally. The main flowchart is shown below (Gao and Jin 1993) (Fig. 9.3).

The Expert System of Wheat Cultivation Management (ESWCM) of Beijing Academy of Agricultural and Forestry Sciences combines model technology and expert system technology. The organizational structure consists of natural and socioeconomic database systems (DBS), knowledge base systems (KBS), model base systems (MBS), inference engine (IE), human-machine interface (HMI), and system maintenance procedures. The system can make timely predictions on the growth and development of wheat and improve the ability of human foresight. When in use, decisions on the wheat field can be made block by block. According to the original production basis, environment and material input conditions, and management and scientific and technological level, the yield target can be formulated, the optimal combination can be determined according to local conditions, and the best plan for managing seedlings and decisions of classification guidance can be drafted. In order to improve the yield, adaptability and stability of crops, the appropriate varieties are recommended according to sowing time and different conditions of fertilizer and water; the appropriate sowing density is recommended according to the soil productivity and the sowing time of each point; the appropriate amount and method of fertilizer application are recommended based on soil fertility foundation and target yield; and the reasonable irrigation frequency, time and amount of water are recommended according to the seedling situation, soil moisture dynamics and conditions of weather and precipitation. ESWCM system can predict and actively regulate and control the population structure and ideal plant type of wheat to promote effective growth and to bring increase in effective accumulation. Relying on ESWCM, all links in wheat production are coordinated, and planned production is achieved (Zhao et al. 1997) (Fig. 9.4).

Developed by American scientists, the COMAX/GOSSYM cotton production management system, based on cotton growth models, and combined with cotton production expert knowledge, has been successfully used to provide guidance for cotton production management. The system consists of a knowledge base, an inference engine, a weather station, and a data file set (soil, variety parameters, weather data, agronomic measures, etc.). The growth model GOSSYM is essentially a model

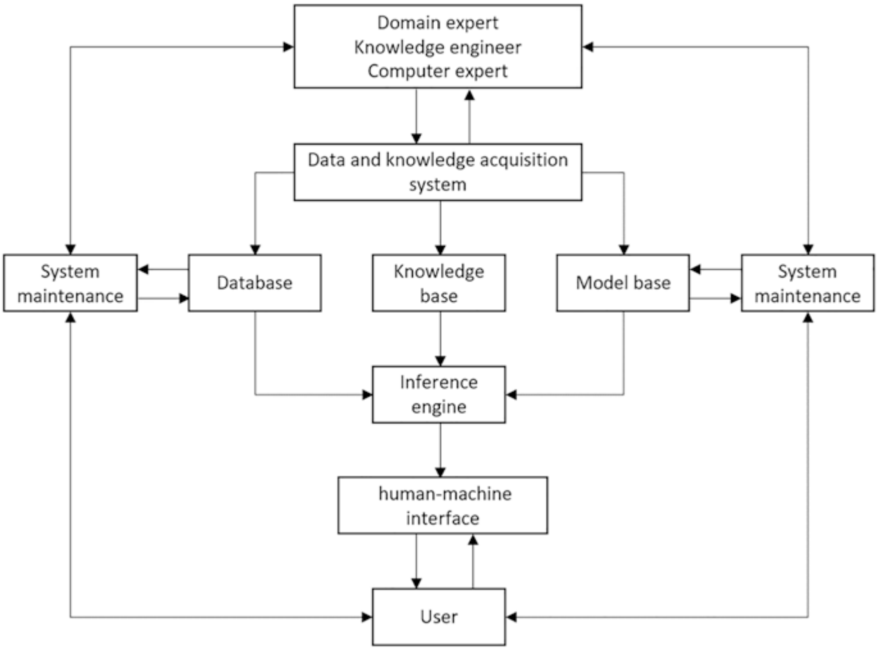

Fig. 9.4 General process of solving the organizational structure problem by ESWCM

that expresses the balance of water and nitrogen in the rhizosphere soil and that of carbon and nitrogen in the crop. During operation, soil physical properties, soil nutrients, and moisture are the initial conditions; meteorological elements such as solar radiation and maximum and minimum temperatures during the day and night are the driving variables; and key agronomic measures and nitrogen, irrigation, and spraying agents are control variables. As a result, the dynamics of cotton growth, photosynthesis, respiration, material production and distribution, root growth, and morphological establishment are simulated. Based on these outputs of the growth model, the expert system COMAX makes a decision plan on whether to implement management measures, including irrigation, fertilization, and use of growth regulators, and provides it to the GOSSYM model, so that it can continue the simulation process. Finally, the expected increase of yield is generated according to the decision plan. Compared with a single growth model or expert system, the system can obtain more accurate, comprehensive, and mechanistic information (Mckinion et al. 1989).

The DSSAT (Decision Support System for Agrotechnology Transfer) system, one of the most widely used crop models in the world, can simulate daily crop growth and development process and respond to many factors, including crop genetic characteristics, management measures, environment, nitrogen and water stress, pests and diseases, etc. It is mainly used for tests and analysis, yield forecast, risk assessment of production, and climate impact in agriculture. It is a comprehensive computer model jointly developed by the Florida State University, Georgia State University, Hawaii State University, Michigan State University, International Fertilizer Development Center, and other international science organizations. The format of the model simulation input and output variables is standardized. The system features simple operation, powerful functions, and wide application range. Its purpose is to accelerate the popularization of agricultural model technology and provide decision-making and countermeasures for the rational and effective use of agricultural and natural resources (Jones et al. 2003).

DSSAT simulates crop growth by days and describes the growth and development process in detail according to the growth period, including the process from germination to flowering, leaf emergence, flowering period, grain filling, physiological maturity, and harvest. Released in 1989, DSSAT v2.1 included only a few crop models. Following DSSAT v2.1, DSSAT v3.0 was released in 1994, DSSAT v3.1 was released in 1996, DSSAT v3.5 was released in 1998, and DSSAT v4.0 was released in 2005, with each version containing more crop models than the previous version. For example, the DSSAT v4.0 application based on Microsoft Windows provides a friendlier user interface and easier analysis. At the moment, DSSAT v4.0 is the most widely used, which includes 17 crop models and modules, covering zone, management, soil, meteorology, soil-plant-atmosphere, CROPGRO plant growth, CERES plant growth, SUBSTOR plant growth, and soil organic carbon modules based on the CENTURY model. The DSSATv4.5 trial version released in 2008 contains more than 25 different crop varieties: CERES series models of cereal crops, including CERES-Maize, CERES-Rice, CERES-Wheat, CERES-Barley, and so on; CROPGRO series models of legume crops, including soybean model

SOYGRO and peanut model PNUTGRO; non-legume crop series models that include tomato, bahia grass, etc.; potato model SUBSTOR-potato; cassava model CROPSIM-cassava; sunflower model OILCROP; and sugarcane model CANEGRO are also included in DSSAT. Knörzer et al. (2011) added a simple shading algorithm to DSSAT v4.5, so that the model can simulate the relay intercropping. Finally, different crop models are connected and classified, and they are named as different cropping systems model.

In recent years, agricultural IoT has been a focus in the field of agricultural science research. Based on the comprehensive acquisition of data relating to production, intelligent technologies are used to combine the relevant data, so that production can be more intelligent. In the new decision-making system for field crop growth, the data acquisition and the automatization of the model are significantly improved. Taking field crops as the target, Zhao (2015) realized the field crop growth perception and established a smart management platform based on the front-end hardware sensors of the IoTs, which took GIS technology, cloud service technology, data mining technology, and web system construction technology as the core. The system could provide a suitable cultivation plan through the distribution of soil nutrients in a region and monitor growth environment and crop growth in real time. It makes up for the shortcomings of traditional agricultural IoT platforms in field crop growth monitoring applications and provides stable IoT management platform software for smart management.

9.5.3 Pest and Disease Decision Support System

Diseases and pests, posing challenges for agricultural production, are one of the major factors restricting increase of yield, income, and efficiency. Pests and diseases are sudden, destructive, and uncertain. At present, chemical control is a critical way to control pests and diseases. However, problems such as excessive use of pesticides and improper spraying often occur when chemical control is adopted, resulting in the loss of medicinal solution, waste of resources, and environmental and food pollution and posing a threat to food safety. To reduce the frequency and intensity of diseases and pests in an economical and effective manner, ensure stable production and improve quality and efficiency and food safety; it is essential to formulate a comprehensive and appropriate prevention and control plan and take the necessary measures to forestall any damages. Furthermore, these measures ought to base on the premise of accurate detection and diagnosis of diseases and pests, complete prevention and control plan, and timely emergency control measures. Research should be conducted on the relevant theories and methods of decision support for pest control, so that an effective decision support system for pest prediction, diagnosis, and control can be established and decision support services for plant protection can then be provided. Doing so bears practical significance for reducing or even avoiding the outbreak of crop diseases and pests and for maintaining the sustainable and stable development of agricultural production.

As a research focus, crop disease and pest control decision support system has become one of the main methods of crop disease and pest control. In 1978, PLANT/ds, a soybean disease and pest diagnosis expert system, was developed at the University of Illinois. This is the earliest agricultural expert system. In 1996, the Cereal Forecast System was developed in Switzerland. One of the main functions of the system was to provide recommended spraying doses of fungicides for major wheat diseases. Based on software engineering principles and expert system technology, Shao et al. (2006), using the LUBAN model and JSP programming language, constructed an agricultural disease and pest diagnosis and treatment inference engine and developed a remote diagnosis and treatment expert system for vegetable pests and diseases in Beijing, named VPRDES. This system can be used for remote diagnosis and treatment, information query, and management of more than 140 kinds of common diseases and pests of vegetables in Beijing, thus playing a vital role in promoting the pollution-free control technology of diseases and pests of major vegetables in Beijing, facilitating rational drug use, and improving the safety of vegetable products. As machine learning rapidly matures, it has also been extensively used in the prediction of pests and diseases. Taking apple tree rot as an example, Jiang (2015) studied and analyzed the prediction model of BP neural network and wavelet network. Furthermore, a decision-making system was established for the prediction and control of apple tree diseases, and pests. The system can provide a way for users to understand the information of pests and diseases and offer decision support for the forecasting of pests and diseases, helping fruit farmers make timely preparations for prevention and control. Moreover, prevention and control programs can be formulated earlier based on the severity of the predicted epidemic, so that the economic losses can be reduced.

9.5.4 Fertilizer Decision Support System

Fertilization status is also a major factor affecting crop growth. In the past, farmers can only rely on experience when applying fertilizer. Hence, in the process of fertilization, the amount and proportion of fertilizer applied are not well controlled. People are satisfied with obtaining regional average yield, but they seldom consider the consequences of blind input to farmland, low fertilizer utilization rate, increased production cost, and environmental pollution caused by excessive fertilization. Fertilization decision-making system refers to a computer information system that scientifically assembles modern information technology and soil evaluation and crop fertilization theories. It integrates expert knowledge, sound research results, and quantitative fertilization models to assist soil nutrient evaluation management and recommendation for fertilization. The application of fertilization decision-making system can improve the legitimacy and accuracy of fertilization. To build the precise fertilization decision support system, the quantitative relationship between different growth and development stages of crops and soil, meteorology, and management measures ought to be studied, so that a theoretical basis for generating variable prescriptions at different scales can be provided. The crucial problem is the determination of the amount of fertilization, and the difficulty lies in the formulation of decision models.

During the research and development of fertilization technology, there have been frequent reports on various kinds of computerized fertilization systems, including rice, cotton, vegetables, and fruits. At present, mature fertilization systems include the sand ginger black soil wheat fertilization expert system developed by Anhui Institute of Artificial Intelligence, Chinese Academy of Sciences; the soil fertilizer test and agricultural statistics package developed by Soil and Fertilizer Institute of Chinese Academy of Agricultural Sciences; and the soil fertilizer information management system developed by Yang et al. (1994). Apart from these, a decision support system for soil information management and fertilization in Dafeng City, Jiangsu Province, was developed by the School of Resources and Environment of Nanjing Agricultural University. The Artificial Intelligence Research Center of Hebei Agricultural University has developed the GIS application in precision agriculture – variable fertilization intelligent spatial decision support system (VRF-SIDSS). Fang from Northeast Agricultural University designed an intelligent decision support system for soybeans in Heilongjiang Province. However, these decision-making systems are specifically designed for a certain region or a certain crop; thus, they are not universally applicable. Precision agriculture demands the development of a fertilization decision system that is universally applicable. Auburn University developed a recommended fertilization system with 52 crop fertilization standards, and the International Agrochemical Service Center of the United States has developed a fertilizer application recommendation software that can provide consultation service for n nutrient elements of 140 crops. Zhang et al. (2009), using remote sensing data, farmer survey information, and soil sampling point data, and combining them with expert fertilization knowledge models and Java language, developed and established a farmland management and fertilization decision support system on the WebGIS platform and realized visual management of farmland resources. Decision-makers can learn about farmland management and soil fertility status through the network platform and get expert recommendation fertilization guidance through this system. Ren et al. (2011) proposed a fertilization decision system that was built on knowledge base. Through the design of knowledge base as the interface between data and program, the organic integration between knowledge base and system is realized by relying on reasoning machine, and the localization customization and extension of system are achieved through the change and maintenance of knowledge base. The system features higher scalability and versatility and has been applied in many places in China.

The fundamental goal of fertilization is to make the crops grow better, the focus of farmers. Agricultural decision-making systems based on the growth model predict the growth and development of crops in advance and guide people in decision-making. Such systems have been widely studied and developed.

9.5.5 Aquaculture Decision Support System

Gao (2016) designed and implemented a set of aquaculture monitoring and management system based on IoT technology. Within this system, the bottom terminal device reports the status information to the supervision system through the Internet of Things. Producers can view the real-time status of the fish pond on the platform through the internet supervision system. Moreover, they are able to control the device switch according to the pond status and send instructions to the terminal through the supervision system. At the same time, the system also provides practical functions that include food feeding decision-making, remote disease diagnosis, and quality tracing, effectively improving the efficiency of aquaculture.

Qiao et al. (2015) summarized the feeding rules of fish and constructed an intelligent feeding system based on real-time machine vision decision-making in order to determine the feeding status of fish in real time and to control feeding relying on the system. The system collects and processes fish feeding images through real-time image processing technology. Plus, it extracts the position and quantity characteristic values of fish groups, obtains the feeding rules of fish groups, and establishes kinematics and dynamics models of actuators, including feeding and throwing of bait machines, hence achieving the intelligent control of bait throwing.

Chen et al. (2018) using the culture process of South American shrimp as an example, integrated the Activiti workflow engine and Drools rule engine into the Eclipse development environment and built an automatic aquaculture decision-making process management system based on workflow and rule engine. This system allows for all-round monitoring and management of the entire process of aquaculture operations, automatic decision-making, aquaculture environment, water quality, scientific feeding, disease control, and aquatic animal growth status, providing aquaculture experience and improving aquaculture benefits. The system reached the goal of processed, automated, and refined management of the whole aquaculture process.

The WIN-WEB mode cow SDSS designed by Lan (2008) combines a human-computer interface that comes with a web browsing function and a local decision-making function with a system interaction interface. Such design allows intelligent online analysis of historical data and data mining, so that the best problem solutions can be available. In addition, it can provide assistance for individual cattle farmers in breeding, feeding management, feed formulation, and disease treatment.

Chen and Jiang (2016), aiming at making production management of large-scale breeder farms more information-based, and improving the support for leadership production decision-making, built a system that supports fine farming of chickens. It also supports the intelligent production management system for farms with rational leadership decision-making. This system, based on the idea of "object-oriented," designed a flock production management module. Based on this, the data warehouse and data mining technology are used to design the production management and group production management modules. Additionally, SQL Server is used to analyze the decision data. The application of the system will standardize the breeding and management behavior of breeder farms and significantly improve the breeding benefits of breeder farms.

Liu et al. (2018b) constructed a new comprehensive decision support system, using data warehouse technology, to easily determine the specific form of the objective function according to the number of livestock, poultry, price, feed, and so on and to visualize it, thus providing reliable support for decision-making. At the same time, it also provides new ideas for solving the problems that traditional database systems cannot solve, such as the accuracy of original data extraction, regional differences, and variability of impact levels.

In the field of automatic feeding of cows, the Netherlands has developed a computer breeding management information system based on automatic identification of individual animal numbers. It features simulation and prediction of growth process, measurement of individual milk quantity, quantitative ingredients, monitoring of weight, health and physiological indicators, benefit evaluation, and growth rate control.

In Germany, electronic devices such as sensors are used to monitor the physiological parameters of dairy cows, and VB language is used to establish a data analysis system to analyze the changes in physiological parameters of dairy cows during lactation and estrus. A mathematical model was established using fuzzy logic mathematical methods as the mathematical theoretical basis for a computer monitoring system for estrus in dairy cows. The dairy estrus computer monitoring system, installed in the process computer that is connected to the data equipment, engages in the real-time monitoring of dairy estrus and makes timely and accurate dairy estrus forecasts (Xiong et al. 2004).

On the whole, the development of the farming decision support system is inseparable from the support of advanced information technology. Information acquisition technology has evolved from manual acquisition to automated acquisition. At the same time, the scope, accuracy, and quality of information acquisition have continued to improve, ensuring the accuracy and credibility of data obtained during the breeding process. Furthermore, the information processing methods in the breeding process are also moving toward modeling and intelligence. The application of computer technologies, ranging from data warehouse technology and online analysis processing to data mining and information processing, is more efficient, timely, and accurate than traditional decision support system processing methods.

9.5.6 Transportation Link Decision Support System

At present, living standards gradually improved as a result of rapid socioeconomic development, driving up the demand for agricultural products and the promotion of circulation scale. Agricultural products logistics, the service, and guarantee system for agricultural development, once encounter security problems, the whole system of agriculture would be inevitably affected, resulting in a huge impact on national economic stability and security. Therefore, the development and improvement of the decision-making system for the transportation of agricultural products is an important step to ensure the reasonable circulation of agricultural products.

The optimization of transport route is the most direct means to improve efficiency and ensure safety. At present, extensive research are conducted based on the optimal decision scheme of route. They take into consideration multiple factors in the actual situation to develop the decision-making system of agricultural products transportation. Gao (2011) developed a kind of agricultural product transportation system based on genetic algorithm. The system is designed as a B/S model based on the SOA architecture to adapt to the agricultural information system that changes with the needs and improve the availability and scalability of the system. The system features the integrated application of information acquisition and editing and intelligent information matching technology to achieve the entire-process operation of the source, processing, publishing, and application of information, thus ensuring the source of information and the availability of information. Aiming at addressing the shortcomings of simple genetic algorithm, such as insufficient convergence and weak local search ability, a new improved genetic algorithm (RGA) was proposed. Zhang et al. (2017) proposed a decision-making method for regional agricultural product distribution route that combines PM2.5 emissions and transportation distances. First, a routing decision-making model with the least PM2.5 emissions and the shortest transportation distance in the agricultural product distribution system is established. Then, an evolutionary algorithm based on similarity selection is proposed to facilitate decision-making in the regional agricultural product distribution route that combines PM2.5 emissions and transportation distances. This algorithm avoids the precocity of evolutionary algorithms and improves the diversity of the population. In light of the fact that some customers are in urgent need of supply during the distribution process, a virtual decision-making point is established to build a path decision-making model that meets the needs of these users. Finally, the validity of the proposed algorithm is verified using test cases, and a satisfaction index is given to measure the superiority of the algorithm. Xiao et al. (2008) studied the supply chain optimization and coordination of long-distance fresh products and designed a simple cost sharing mechanism. Kong and Li (2012) integrated GIS, wireless data transmission, wireless communication, and other information technology based on the characteristics of agricultural product logistics security and built a distributed emergency decision support system (DDSS) to reduce or even prevent such emergencies as agricultural product decay. Finally, based on GPS/GIS/SM (3G) technology, vehicle dispatching is taken as an example to illustrate the remote data collection and decision management implementation of typical functional areas.

In addition to optimizing the distribution route in the transportation of agricultural products, the appropriate location of logistics centers is also an important research direction. The appropriate location of agricultural product logistics centers can improve the efficiency of distribution and transportation, which, in turn, reduces the transportation time of agricultural products, improves the timeliness of transportation, provides better guarantee of product quality, and enables consumers to be assured of agricultural products, thus improving the safety of product consumption

(Fan 2010). The research of logistics center location theory can be divided into the following two categories:

- Quantitative analysis of site selection without subjective weight. Zhai et al. (2008) believed that the solution accuracy of the center of gravity method was poor and the distribution cost of the point was not the lowest. By comparing with the differential method, the optimal solution is obtained using the conjugate gradient method with fast convergence speed on the basis of using the centroid method to obtain the initial point. This method is mainly applicable to the study of the location of single distribution center. In the establishment of the model, only the relationship between transportation rates, transportation distance, and transportation volume was taken into account, and a certain fixed cost was not taken into account. Finally, the optimal solution was the coordinate value, and the coordinate point might be located in the middle of a lake or a street, so that practical significance might be possible. Wan et al. (2007), taking into consideration the actual planning problem of location, proposed the Dijkstra algorithm, the shortest path algorithm in graph theory, to build a logistics center location model. The algorithm can calculate the shortest distance between a specified node and other nodes in a logistics network. The main idea is to first find a path with the shortest distance from the source point and then obtain the shortest path from the source point to other target nodes by iterating the path distance. The disadvantage of this method is that only the shortest distance between nodes is considered, and the cost and time required by transportation between nodes are not considered.
- Consider the selection method of qualitative factors and quantify qualitative factors. Analytic hierarchy process can quantify qualitative factors. Some scholars have combined the methods of gravity center, goal planning, data envelopment, and other methods that involve the geographic location, cost, and supply capacity of logistics centers with analytic hierarchy processes, which have gradually improved the site selection method. Chen et al. (2005) first analyzed relevant data and information, including market demand, product characteristics, distribution status, geographical characteristics, and so on, then developed several alternative addresses using the center of gravity method, and finally determined the optimal solution using asymmetric analytic hierarchy process. This method combines the center of gravity method with the asymmetric analytic hierarchy process to select the location, so that the time required for decision-making is shorter. Zhang and He (2007) used the weights of fixed-cost investment, land area, throughput, number of logistics centers, and analytic hierarchy process as the constraints for goal planning. This method combines the objective planning method with the analytic hierarchy process and appropriately improves the analytic hierarchy process through matrix transformation, thereby omitting the process of consistency check. What is noteworthy is that this method is only applicable to the case where multiple logistics centers are selected when there are fewer resource constraints. When considering the service level of the logistics center, Nozick and Turnquist (2001) introduced a logistics location modeling

method in consideration of facility cost, inventory cost, transportation cost, and customer response speed and analyzed its operation mode. The inventory cost function is first embedded into a fixed facility location model, so that the optimal number and location of locations are directly related to inventory costs, and then the fixed facility location model is extended to multiple objectives, including cost minimization and coverage maximize, and finally this comprehensive model is applied to the logistics center location for a satisfactory location plan.

9.6 Development Trend of Agricultural Decision-Making Systems

9.6.1 Modeling and Precision

A high-quality expert decision-making system requires not only the accumulation of empirical knowledge but also the support of high-quality crop growth and development simulation models. From the simulation of physiological and ecological processes to information agriculture, the bridge in the middle is the crop model. The function of the model is mainly to understand, predict, and regulate the growth system of crops. The key to building such a model is basic research and field trials, the combination of which would lead to an effective crop model. Real-time control expert systems are widely used in Dutch vegetable and flower facility cultivation. The prerequisite for this is a systematic study of the relevant growth mechanisms of plants. Based on this, an agricultural expert decision-making system capable of simulating the expert level has been established (Liu et al. 2018a).

9.6.2 Comprehensiveness and Extensiveness

Natural conditions vary significantly between regions, therefore agricultural decision-making systems must be highly integrated and adaptable. A highly integrated agricultural decision-making system needs to make account of the influence of multiple factors and related knowledge bases and model bases. An agricultural decision-making system based on a particular topic will become a subsystem. Individual decision functions such as irrigation, fertilization, variety selection, pest and disease control, soil conservation, and environmental control will be incorporated into the crop production management decision-making system. Combining crop simulation models with agricultural expert knowledge to develop a comprehensive and functional agricultural expert system will be an important direction for the development of agricultural expert decision-making systems.

9.6.3 Openness and Extensibility

The agricultural decision-making system must be open and extensible. The system should be easy to upgrade, expand, and integrate, and the system should develop new technologies in synchronization with other technologies. The development of agricultural decision-making systems will unfold in the direction of dynamic data, high timeliness, and practicality, and it will become more intelligent as well. In addition, diversification of knowledge acquisition methods should be achieved, allowing authorized users to expand the knowledge base, so that the system can be equipped with self-learning and adaptive functions, and play the role of expert systems. At the same time, in such development, we must pay attention to the secondary and multiple development of the expert system, so that users can create their own knowledge base and model library according to local and individual conditions and expand the scope of application.

9.6.4 Interactivity and Usability

With the popularization of intelligent mobile terminals, in addition to emphasizing the combination with agricultural field models, deep knowledge, and common sense, agricultural decision-making systems integrate new technologies into expert systems and form a comprehensive system integrating multiple technologies, which is an important development direction. More mature technologies such as object-oriented technology and database technology can be considered and applied to expert decision-making systems. Such incorporation would allow the mutual penetration and integration between various disciplines. From physiological models to growth models, and to decision-making systems, work at different levels needs to be integrated. This process requires the cooperation of experts in different fields and the combination of different advantages to achieve breakthroughs. Global positioning system (GPS), geographic information system (GIS), and remote sensing (RS) technology are three major modern information technologies. They can quickly and accurately obtain multidimensional information in agricultural production systems and manage and analyze spatial data. The introduction of "3S" technology can provide a large amount of basic data and dynamic data for agricultural systems and provide data support for the establishment of system databases and model libraries. At the same time, multimedia technology, computer vision technology, virtual reality technology, and neural networks are becoming more mature. Applying these technologies to agricultural decision-making systems can make the system more human-oriented and easier to operate.

9.6.5 Networking and Human-Oriented Development

With the rapid development of computer networks and artificial intelligence, network information transmission has become fast and convenient. In the future, agricultural decision-making systems should consider networking the system. The data warehouse, model resources, and knowledge resources in the network environment all provide concurrent and shared model services and knowledge services on the network in the form of servers. Relying on big data technology, multiple data, such as soil, environment, water conservancy, and meteorology, can be clearly grasped, and the cultivation and sales of similar agricultural products can be better understood, thereby improving the accuracy and timeliness of decision-making, production efficiency, and resource utilization. On the basis of this, the model server can integrate a large number of mathematical models, data processing models, and human-computer interaction multimedia models to provide users with different types of model services, and it can also provide users with comprehensive services that combine multiple types of models. The knowledge server can centralize a knowledge base of multiple intelligent problems or knowledge of different knowledge representations (rule knowledge, predicate knowledge, framework knowledge, semantic network knowledge, etc.) and a variety of different inference engines, such as forward reasoning machine, reverse reasoning machine, hybrid reasoning machine, etc. Only agricultural decision-making systems that can successfully run on the network can be more practical and universal. Moreover, such systems can facilitate communication between farmers and experts and solve practical problems encountered by farmers in production.

The design and application of the system should also be human-centered. Most of the users of the system are farmers with limited professional knowledge. Complicated and visually unfavorable interactive interfaces are often unfriendly to farmers. If the decision-making system comes with a high threshold, it will not be universally applicable. Using graphical interface technology, integrated text, graphics, sound, and other multimedia technologies to visualize agricultural information allows users to understand agricultural information and decision-making technology information more clearly, hence making human-computer interaction more convenient and allowing users to accept and promote it.

9.7 Summary

This chapter first analyzes the typical decision-making problems in different fields of agriculture. Based on the introduction of typical decision-making methods, and taking typical agricultural problems in different fields as examples, the decision-making methods and key technologies are analyzed. Moreover, several typical decision support systems have been elucidated. Finally, the development of agricultural decision support system is illustrated.

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