Article

Decision Support System Research on Forest Tending Problems Based on Process Management System

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Abstract: In this study, the decision-making process management of forest tending in the forestry business is decentralized, and forest tending decision-making activities at different points in time are integrated by decision makers at different geographical locations. The decision-making process was analyzed and optimized from a system perspective. Based on the optimized decision-making process, a forest tending business group decision support system (FTGDSS) was established. We first reviewed and discussed the characteristics and development of the forest tending business and forestry decision support system. Business Process Modeling Notation was used to draw a current state flow chart of the forest tending business, to identify and discover important decision points in the process of tending decision-making. We also analyzed the content and attributes of each decision point, and described the system structure, functional framework, knowledge base structure, and reasoning algorithm of FTGDSS in detail. Finally, FTGDSS was evaluated from the two dimensions of the technology adoption model. FTGDSS integrates different levels of time-space decision-making activities, historical tending data, business plans, decision-makers' management tendencies into the decision-making process and automatically extracts decision-making data from the forest business process management enterprise resource planning system (*Smartforest*) that improves the ease of use of the decision support system (DSS). It also improves the quality of forest tending decisions, and enables the DSS to better support multi-target management strategies.

Keywords: forest tending; group decision support system; process management; data integration

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1. Introduction

Forestry management has evolved from traditional single-objective forestry management to multi-objective sustainable forestry management that emphasizes on biodiversity conservation [1]. Since the 1980s, decision support systems (DSSs) have become a popular platform for transforming scientific knowledge into practical forest management as an objective forest management solution [2,3]. Wierzbicki defined a DSS as a computer system that supports its users in a rational organization in the decision-making process (or its chosen phase) and, in addition to the database, contains relevant knowledge expressed in the form of a decision model [4]. Alter expressed some doubts about the development of DSSs. Currently, the development of DSSs is limited to the development of new DSS technologies. However, as long as the new technology capabilities are not included in the actual business work system, they have little impact on the application development of DSS. In other words, the goal of decision support is not to focus on the tool itself, but to make better decisions in the business work system [5]. In addition to the problems with the application and development of the DSS itself, for forestry DSSs, the modern forestry management DSS needs to consider multiple constraints besides forestry [6,7] and the multiple objectives of forestry development management [8,9]. To meet the development requirements of multi-objective decision-making, multi-post data information and responsibility sharing are needed, breaking the departmental silos [10]. Therefore, although researchers are aware that the establishment of a multi-objective DSS requires a huge amount of data, there is no clear solution to the problem of data sources and integration. This issue was highlighted in a study of 17 ecosystem service DSSs. It is considered as an obstacle that slows down the development of DSS for multi-objective decision-making [11].

China attaches particular importance to the development of the forestry industry. However, some problems remain to be solved: first, China's forest resources per unit area volume are still low compared to global levels, and the forest management is not effective despite that the central budget for forest tending has been increased from 370 million yuan in 2009 to 10.23 billion yuan in 2014 [12,13]. Secondly, due to the lack of forestry experts and the low enthusiasm of forestry practitioners, other businesses, such as forest tending, are left out of professional technical guidance [14]. Finally, problems exist with business coordination and information transfer, which lead to management's incomplete understanding of the actual work at the grassroots level. Therefore, forest inventory and operation design cannot play the role of management [15].

Considering the status of research on forestry decision support systems and the current development of forestry in China, we chose the forest tending business as the research object, applied process management to forestry decision-making, established a forest tending group decision support system (FTGDSS), which automatically extracts data from the process management enterprise resource planning (ERP) system (*Smartforest*) to solve the automation problem of system data sources. The FTGDSS system provides forestry managers with business guidance plans to make the forest tending budget allocation more scientific, connect decision-making tasks and decision-makers at different time and space, optimize the decision-making support system, break the barriers between departments and achieve information sharing.

2. Materials and Methods

We chose the Linkou Forestry Bureau under the Longjiang Forest Industry Administration as the research case. The Linkou Forestry Bureau is located in the southeast of Heilongjiang province, China. The total working area is 273,000 hectares, including 213,568 hectares of forest land and 14.1 million cubic meters of standing timber. The forest coverage rate is 78.9%, and the Forestry Bureau has 16 forest farms. For the purpose of this research, data were automatically extracted from *Smartforest*. The decision process and design involved in FTGDSS introduce process management ideas. Business process management (BPM) is a discipline that involves, to some extent, a combination of business activity flow modeling, automation, execution, control, measurement, and optimization. It spans organizational boundaries and connects people, information flows, systems, and other assets, creating value for customers and members to support the organization's goals [16–19]. In project management, process management involves the use of a repeatable process to improve the project outcomes [20]. We used the international standard Business Process Modeling Notation 2.0[21] to draw a process flow diagram, organize the basic forest tending business process, identify the repeatable decision-making processes, and then determine the scientific problems in decision-making problems and establish algorithms for different decision-making problems or inference rules. The main purpose of the forest tending decision-making process is to integrate and standardize the decision-making activities at different time and space.

2.1. The Main Decision Model

The key step in developing a decision support system is to define system boundaries, which involves iterative communication and negotiation between users, decision analysts, and software engineers, who together define the decisions' scope and decision-making process [22]. According to the project research, the overall goal was to develop a DSS based on *Smartforest* to support the forest tending decision-making of forestry organizations based on the forest management plan.

In this study, the forest-tending "as-is" process is optimized to determine the "to-be" process, and the "to-be" process is used to determine the stages of the FTGDSS deployment decision-making process (Figure 1), and simultaneously clarify the system's functional objectives. These objectives are (1) assisting the Forest Department of the Forestry Bureau to allocate forest tending funds and tending area and (2) assisting the forestry technicians with selecting the breeding plots and tending methods, and generating pre-plans for forest tending operations.

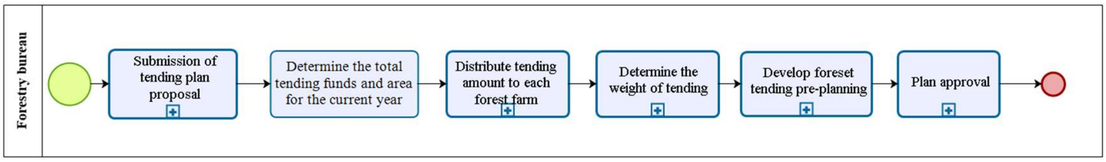

Figure 1. Forest Tending Plan Decision Process-Level 0

After determining the scope of decision-making, it is necessary to clarify the participants involved in the decision-making process, also known as decision-makers, to better organize the decision-making process. Different decision-makers have different roles in the decision-making process, and are therefore concerned about different decision problem domains. Therefore, the role and responsibility of decision makers should be defined according to their power, and decision makers should then be grouped according to the sorted list of power and responsibility, as shown in Table 1. The decision maker model is established by setting multiple user groups and establishing a many-to-one relationship between the user permissions and the users. Each group has multiple users and multiple permissions, including the user identification (ID), the unit type, and the permissions.

Table 1. Decision maker list.

Type	Department	Decision tasks
Superior management	Resource Dept.	Make the decision on the actual allocation of tending area and funds based on the proposed tending amount area provided by the Forestry Bureau
	Plan Dept.	To examine, approve, and review the proposal on the tending plan submitted by the forestry administration
Forestry Bureau	Forest Dept.	Formulate a tending pre-plan and report it to the superior management department
		Decompose the general plan issued by the superior management department according to the actual situation of each forest farm
	Resource Dept.	To examine, approve, and review the proposal on the tending plan submitted by the forestry administration
	Forest Survey Dept.	Submit the pre-planned amount of forest tending area to the Forestry Bureau, the Resource Bureau, and the National Development and Reform Commission
		Formulate the plan of each sub-compartment of the forest farm's actual operation and the tending method used by each sub-compartment
Forest Farm	Forest Farm technician	To advise the forest survey department on the planned amount of tending area, the planned sub-compartment of tending, and the proposed mode of operation

2.2. Decision Problem Decomposition

Since the level 0 process contains multiple sub-processes, it was necessary to independently analyze the decision points, decision problem attributes, and decision-making methods contained in each sub-process, and then perform a detailed requirements analysis and function design according to the decision-making process.

2.2.1. "Proposed Tending Area Value" Process Analysis

At the beginning of the forest tending business, each forestry bureau needs to provide suggestions on the tending plan to the superior management department. The specific business performance of the sub-process is as follows. The forest inventory department first calculates the total tending area that the forestry bureau should reach in the current year based on historical tending records and forest tending conditions, and then submits it to the forestry department, resource department, and planning department for approval. After approval, the department hands it to the superior management department as a reference for the current year's tending plan, as shown in Figure 2.

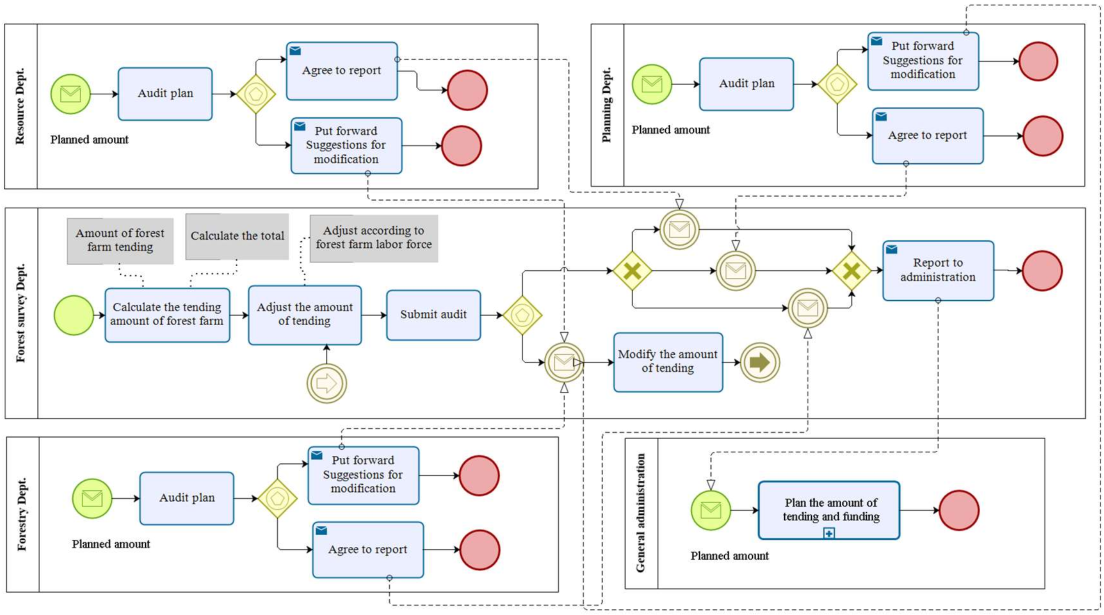

Figure 2. "Proposed tending area value" process

The decision-making problems and decision-making methods considered by combing business activities are shown in Table 2.

Table 2. Decision points when submitting a recommendation for the tending amount process.

No	Decision maker	Decision activities	Decision problems attribute	Decision-making basis	Decision-making data	Decision-making method
1	Forest Inventory Dept.	Calculate the planned area amount of tending	Semi-structured problem	The area amount of the historical tending plan Technical forest standards The completion of the previous year's plan Working area and human resources of the forestry bureau	Knowledge rule data/ Secondary forest data /historical tending data	Expert system/decision support system rule base/unstructured algorithm
2	Forest/Resource/Plan Dept.	Provide modification suggestion	Unstructured problem	The forestry administration's current business plan	/	AHP

2.2.2. "Forest Farm Tending Area Allocation" Process Analysis

After completing the proposed tending area amount process, the Forestry Bureau submits the summary data to the superior management department for reference. Since we only considered the research at the organization level's forestry bureau and subordinate forest farms, the "the high-level management department proposition of the current year's plan" process is not explained in detail. The superior management department allocates the annual major plan to each forestry to implement detailed forest tending operations. After being allocated the total area amount of the tending plan, the forestry department can allocate the tending area amount to each forest farm according to factors such as the number of employees, the area for tending, and other forestry operations. The forest farm then asks the forest survey department to conduct a field survey, as shown in Figure 3.

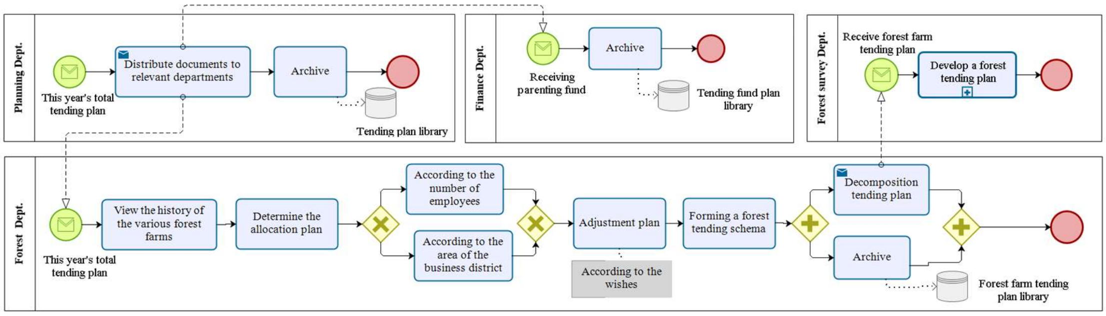

Figure 3. "Forest farm tending area amount allocation" process

A list of decision points and decision methods was obtained by analyzing the process, as shown in Table 3.

Table 3. Decision points of the forest farm tending area amount allocation process.

No.	Decision maker	Decision activities	Decision problems attribute	Decision-making basis	Decision-making data	Decision-making method
1	Forest Dept.	Allocate the planned amount to each forest farm	Structured problem	According to the level of productivity According to the area for tending Comprehensive consideration of factors such as productivity level, the area for tending, etc.	The list of employees, and the planned area for tending issued by the superior management department (including other business operations)	Expert system model reasoning/allocation strategy
2	Forest Dept.	Adjustment plan	Unstructured problem	Forestry Department's business plan for the year	/	Artificial adjustment

2.2.3. "Forest Tending Pre-Plan" Process Analysis

After allocating the tending area amount, the forest farm technicians propose ideas to the forest survey department to provide sub-compartments and tending methods according to the forest conditions and business plan of the forest farms. The forest survey department verifies and confirms the field survey, as shown in Figure 4.

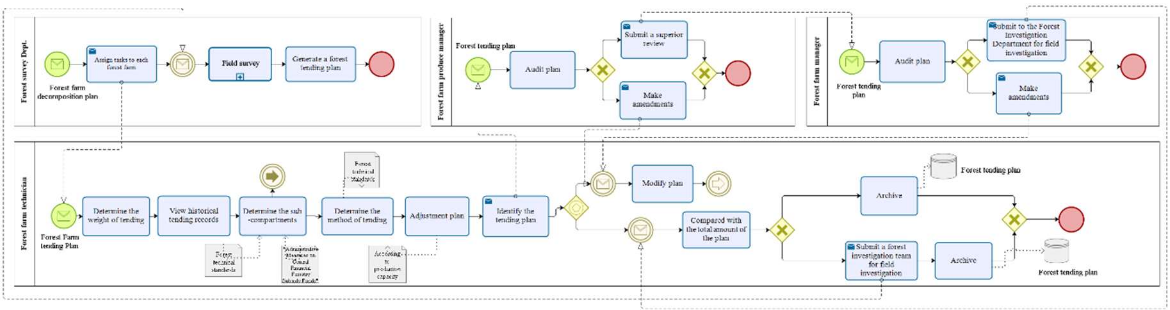

Figure 4. "Forest tending pre-plan" process analysis

The process is sorted to obtain a list of decision points, as shown in Table 4.

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Table 4. Decision points of creating a pre-plan of the forest tending process. Note: DSS denotes decision support system.

No.	Decision maker	Decision activities	Decision problem attribute	Decision-making basis	Decision-making data	Decision-making method
1	Forest farm technician	Determine the tending importance	Unstructured problem	Forestry Bureau and forest farm current year's business plan	/	Artificial adjustment
2	Forest farm technician	Determine the sub-compartment	Semi-Structured problem	Forest technical standards Historical tending/forestation record	Forest inventory secondary data / historical tending data / tending importance (weight)	DSS inference engine reasoning/scheme scoring algorithm
3	Forest farm technician	Determine the tending methods	Semi-Structured problem	Forest technical standards		
4	Forest farm technician	Adjustment plan	Unstructured problem	The tending plan issued by the forest inventory department Forestry Bureau and forest farm business plan for the year	/	Artificial adjustment

2.3. The Decision Algorithm

2.3.1. The Fund Allocation Algorithm

The tending plan determines the tending funds allocation. The fund allocation decisions involved should consider factors such as the actual number of forest-tending employees, site conditions, and historical tending conditions on the forest farm. FTGDSS provides three options for decision makers in combination with the above factors.

2.3.1.1. Option 1: According to the Number of Employees

Since the tending area amount and production capacity are affected by other business activities, it is necessary to consider the proportion of forest tending operations workers in comparison to the total number of employees to calculate the production capacity level of forestry tending operations on forest farms. Therefore, we have the following formula:

$$i = \frac{S_T}{S}, \quad (1)$$

Where i is the proportion of the total number of people on the forest farm, S_T is the number of employees participating in the tending work on the forest farm, and S is the total number of forest farms. Due to the randomness of the work arrangements of the forest farm staff, to eliminate the contingency of a certain year, the average of the ratio of the number of employees for three consecutive years is considered, and represented by Equation (2). The forest tending productivity of the forest farm is shown in Equation (3), where i_s is the 3-year average of the proportion of the total number of workers on a forest farm, p is the forest farm tending productivity, and T_i is the area amount of forest tending work for a forest farm in a year.

$$i_s = \frac{i_1+i_2+i_3}{3}, \quad (2)$$

$$p = \frac{T_i}{i_s \times S}, \tag{3}$$

To exclude the contingency of a certain year, the average of the data is taken for three consecutive years in Equation (4), and the amount of forest tillage based on the forest production capacity is allocated per Equation (5).

$$p_i = \frac{p_1 + p_2 + p_3}{3}, \tag{4}$$

$$T_i = \frac{p_i}{\sum_{n=16}^{i} p_i} \times T, \tag{5}$$

where p_i is the average forest tending productivity of the ith forest farm and T is the total amount of the current year's tending plan issued by the superior management department.

2.3.1.2. Option 2: According to Tending Area

The main data applied are the number of application areas of each forest farm provided by the resource department and the planned quantity data (including the number of tending plans and other business operations) issued by the superior management department. The specific calculation formula is:

$$T_i = \frac{A_i}{\sum_{n=16}^{i} A_i} \times T, \tag{6}$$

Among them, T_i is the area for tending that should be assigned to the ith forest farm; A_i is the area of the ith forest farm; and T is the total area of the current year's tending plan issued by the superior management department.

2.3.1.3. Option 3: Comprehensive consideration of Production Capacity, and Other Forestry Operation Volume and Working Area Factors

Since the productivity level of forest farms is limited, even if a forest farm should complete more forest tending according to the area of the working area or historical tending, it should be limited by productivity and cannot exceed the productivity level. Although this is generally not the case in actual production, the following should be considered:

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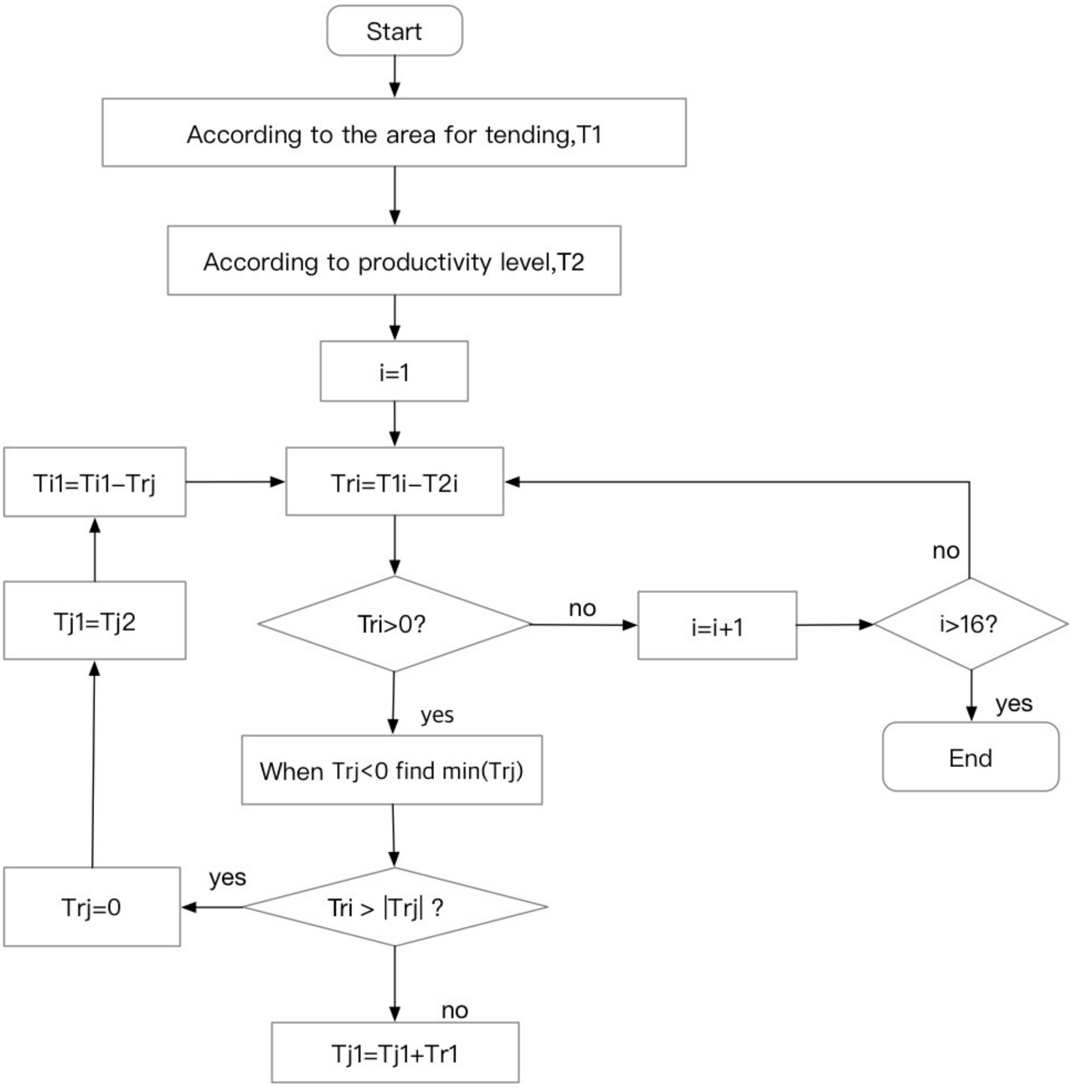

Figure 5. Comprehensive consideration of multiple factor scheme algorithm

1. According to option 2, the forest tending area is allocated based on the ratio of the working area (the area for forest tending) and is adjusted to T_1;
2. According to option 1, the forest tending area amount T_2 is allocated based on the production capacity level;
3. The difference between the allocation of 16 forest farms according to the planned area of tending and the production capacity plan can be calculated.

$$\Delta T_{ri} = T_{1i} - T_{2i}, \qquad (7)$$

where ΔT_{ri} is the difference between option 1 and option 2 of the ith forest farm, T_{1i} is the measure of the forest tending area of the ith forest farm distributed according to the proportion of the working (tending) area to obtain the tending area value, and T_{2i} is the forest tending amount of the ith forest farm distributed according to the production capacity;

4. According to the constraints, the amount of allocated tending area should not exceed the level of production capacity, so, if $\Delta T_{ri} < 0$, the tending area exceeds the level of production capacity and if $\Delta T_{ri} > 0$, the condition is met, but the maximum production capacity is not reached;
5. Compare ΔT_{ri} with $|\Delta T_{ri}|$. If $\Delta T_{ri} > |\Delta T_{ri}|$, the tending area amount of the jth forest farm is converted to $T_{1j} = T_{2j}$. The tending amount of the ith forest farm needs to be adjusted to $T_{1i} = T_{1i} - \Delta T_{rj}$, that is, $\Delta T_{ri} = \Delta T_{ri} - \Delta T_{rj}$. If $\Delta T_{ri} < |\Delta T_{rj}|$, then the tending amount of the jth forest farm is converted to $T_{1j} = T_{1j} + \Delta T_{ri}$. The tending amount of the ith forest farm needs to be adjusted to $T_{1i} = T_{2i}$, that is, $\Delta T_{ri} = 0$;

6. Keep looping through 16 forest farms until all $\Delta T_r < 0$.

2.3.2. Sub-Compartment Selection Scoring Plan Algorithm

Because the decision-making process involves three different rules: young forest tending, normal tending, and temporary key tending, according to the principle of uniform scoring and following the priority of tending order, which is young forest tending and then normal tending, meeting the condition of young forest tending is set to the highest score of 10, without considering the weight. The specific steps are as follows:

1. Update the secondary survey data using the stand growth model [23] as the data set to be processed;
2. Record the management weight preferences provided by the user, and calculate the relationship between the weights x_1, x_2, x_3, ... respectively, which can be processed by the addition rule;
3. In the dataset to be processed, according to the knowledge rules in the knowledge base, the set of sub-compartments that require young tree tending is found and recorded as S_1, with a score of 10 points. In the set of the young forest, a loop query is made to determine whether the management preferences set by the managers are satisfied. For example, the managers set the tending of conifers for the current year, and the dominant species in the sub-compartment of young forest are conifers.

$$P_{1i} = \begin{cases} 10, & n = 0 \\ 10 \times \sum_{j=1}^{n} x_j, & n > 0 \end{cases} \tag{8}$$

where P_{1i} represents the score of the ith sub-compartment that satisfies the condition of young forest tending, x_j represents the jth management weight score, and n represents the number of management preferences;

4. If the area of young forest for tending is less than the planned value, then the young set S_1 is removed from the data set to be selected, and the normal set of sub-compartments is searched according to the knowledge base inclusion rule, and is recorded as S_2. The score is satisfied according to the number of rules. If the user provides the management preference weight value, the weight value should be multiplied by the original score and the formula is:

$$P_{2i} = \begin{cases} \frac{R_i}{R}, & n = 0 \\ \frac{R_i}{R} \times \sum_{j=1}^{n} x_j, & n > 0 \end{cases} \tag{9}$$

where P_{2i} is the ith sub-compartment score satisfying the tending condition, R_i is the number of rules in the rule base satisfied by the ith sub-compartment, R is the total number of rules in the rule base, and x_j is the jth management weight score that indicates that the number of management preferences is met;

5. Convert the normal tending sub-compartment score into a 10-point score and sort from high to low;
6. Combine the S_1 and S_2 collections, and then select sub-compartments according to the level of the score and according to the value of the planned tending area until the planned value is achieved.

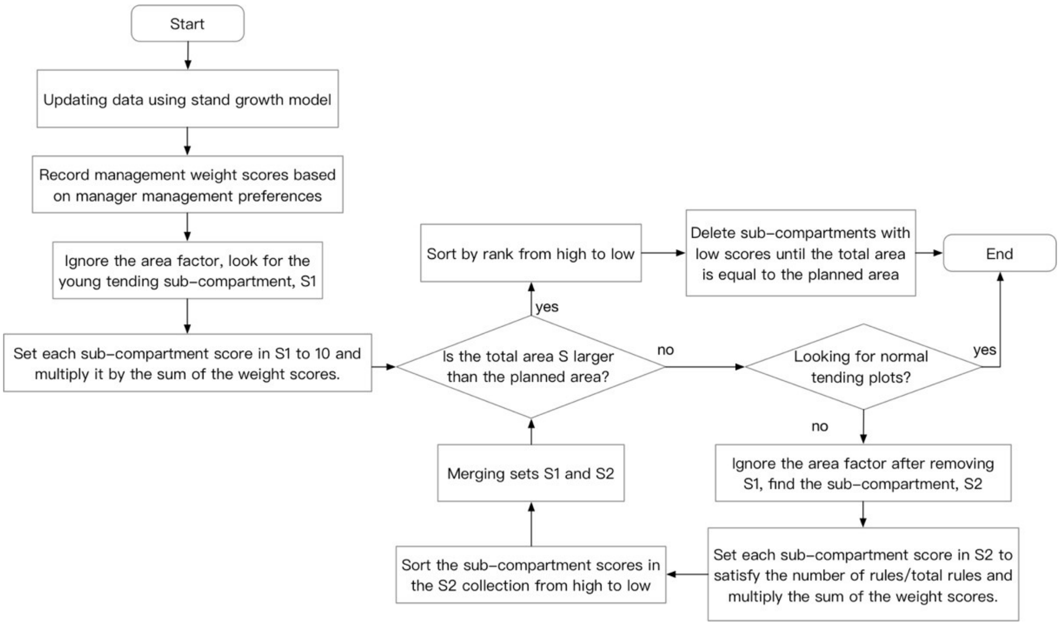

Figure.6 Scheme scoring algorithm

2.3.3. Algorithm for Selecting the Operation's Sub-Compartment

The sub-compartment is the actual operation area selected by the forest survey department when conducting the field survey. The specific location of the sub-compartment of the forest operation is conditional, and it is necessary to refer to historical tending operations. During the field survey, we found that there were repeated tending situations in the same area for consecutive years, as shown in Figure 7. For the decision-making problem of sub-compartment selection, implementing automated management is difficult because of the field survey. Therefore, visual display and geographic location screening algorithms are used to help improve the scientific selection of land in forest survey departments. The specific algorithm is as follows:

1. After the technician finishes the decision-making of the forest manager's sub-compartment and tending operation scheme, the selected sub-compartment is overlapped with the previous year's historical tending operation area for inspection;
2. In the case of overlapping parts, it is necessary to check the operation mode used in the overlapping areas of the previous year. If continuous annual tending operations are needed, the overlapping parts will be retained. If continuous tending is not necessary according to the technical standards of tending, the overlapping areas are removed;
3. Produce the sub-compartment map and the corresponding longitude and latitude coordinates.

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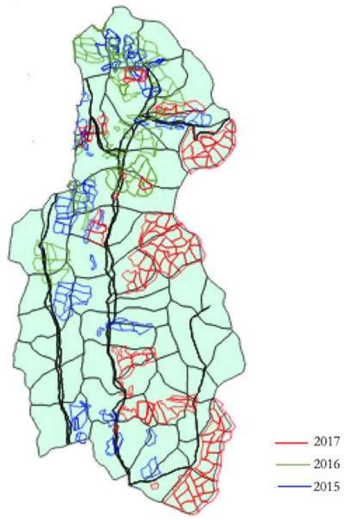

Figure.7 2015-2017 map of historical tending areas for Chaoyang sub-unit

2.3.4. The Knowledge Base and Inference Engine

For semi-structured decision problems, according to the characteristics of the DSS, it was necessary to refer to the relevant text rules to establish a knowledge base and an inference engine for rule matching assistance.

2.3.4.1. Knowledge Base Design

Knowledge representation is a method and process of inputting knowledge into a computer in a way that the machine can recognize [24]. Currently, knowledge representation mainly consists of two aspects: declarative representation and procedural representation. Declarative representations mainly describe the state, attributes, and logical relationships of things, whereas procedural representations focus on the methods and steps employed to solve problems, behaviors, and operations of things. Currently, there are four basic representations of knowledge representation: (1) first-order predicate logic representation, (2) production representation, (3) semantic network representation, and (4) framework representation [25,26]. In this article, tending experts typically use Table 5 to determine the type of tending. In the specific decision-making, the rule number in the table should be matched according to the characteristics of the land parcel, and the tending technology method is then determined by the rule number and the tending type correspondence table.

Table 5. Identified rule of the forest tending method based on forest type. Note: DBH denotes diameter at breast height.

ID	Forest type	Tending object	density	Damag ed tree	DBH	Species	Crown height ratio	Upper forest stand density	Method
9101	Public welfare forest	Protective forest	>0.8	≥10%	Null	Null	Null	Null	2
9501	Public welfare forest	Special purpose forest	>0.8	≥5%	Null	Null	Null	Null	2
6201	Commercial forest	Plantation	>0.8	Null	<6 cm	Coniferou s	≤30%	≥0.6	2

6202	Commercial forest	Plantation	>0.8	Null	<6 cm	Broadleaf	≤25%	≥0.6	2,4
6101	Commercial forest	Natural forest	>0.8	Null	<6 cm	Coniferous	≤30%	≥0.6	2
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Production representation is used to express the procedural nature of knowledge, but it performs poorly in terms of the structural aspects of knowledge, and framework representation is only complementary. Because forest tending decisions have multiple attributes and step-by-step reasoning, for this study, we used framework-based knowledge representation to design a knowledge base for FTGDSS. As the framework is the main body, the production rules are embedded within. In the actual implementation, the production rules and the framework can invoke each other. Accurate knowledge about site conditions, tree species, and technical models is represented by the framework. The following are examples of framework representations:

Frame name: <forest feature>

Parent frame name: <density>

Attribute slot:

<Sparse forest>: <The density degree is equal or greater than 0.1 and less than 0.20>

<Moderate canopy>: <0.20–0.69>

<Densest>: <density greater than or equal to 0.70>

...

The representation of the rule uses the production representation to indicate the causal relationship [26], and each category attribute in the rule is replaced by the frame number in the frame representation. Production rule representation consists of a condition and conclusion, which express the causal relationship. The production representation of the forest tending decision-making knowledge is as follows:

IF the ecological public welfare forest (forest type) and general timber forest category (forest type) and Ⅲ class (grade) and canopy density is less than 0.6 (site conditions) and thick layer of soil (soil thickness) THEN rule number is 6.

IF the appropriate tending and rule number is 6 THEN the forest tending technical rule can be 1 or 2 or 3.

2.3.4.2. Inference Rule Design

The FTGDSS inference is based on the knowledge in the knowledge base. Once the knowledge representation in the knowledge base is completed, the reasoning can be applied by using a computer program. This section mainly describes the reasoning mechanism of matching the factual data with the rules in the knowledge base. Data cleaning and preparation are required before reasoning. FTGDSS uses a stand growth model, a unit volume growth model, and a density growth model [23] to update the existing secondary survey data in real time. According to the national technical regulations on forest tending in China [27], the sub-compartments that do not satisfy the tending condition are removed. According to Table 5, the relationship structure of the reasoning rule base for forest tending decision-making is designed as follows: Rule table (rule number, forest type, origin, stand structure, stand type, forest classification, diameter at breast height (DBH), slope, density, ... , number of seedlings).

Simultaneously, a many-to-many relationship is established between the tending method database and the tending rules database. If a rule matches multiple tending methods, only one set of data can be stored in the rules database. This storage method reduces the number of rules and is convenient for the updating of rules.

The FTGDSS reasoning search method adopts a forward reasoning strategy: it matches the rule attributes in the rule base according to the stand characteristics and site conditions in the fact information table, and then provides multiple tending methods from which users can choose. According to the reasoning process, each rule in the knowledge base is interpreted as the concept of the principal component in multivariate statistics. If the number of rules satisfied by the same plot is large, it means that the plot is more likely to be suitable for tending. Based on this, the inference process was established as follows:

1. Initialize the data and knowledge base, including a data update and data cleaning, and set the number of successful matching rules as *i*, the initial value as 0, the number of rules in the rule base as n, *j* as the total number of matching rules, and the initial value as 0;
2. Add the fact data to be processed into the system loop and match it according to the rule attribute factors in the rule table. If all matches are successful, $i = i + 1$ and $j = j + 1$ match the next rule at the same time; if the match is not successful, the matching of the next rule is conducted, and $j = j + 1$ is recorded simultaneously;
3. Judge whether j > n is true. If it is true, finish the loop; otherwise, continue the loop;
4. After the end of the loop, a set of matching rule numbers is obtained and the tending methods table is matched according to the set. Finally, the forest tending methods are output to the user.

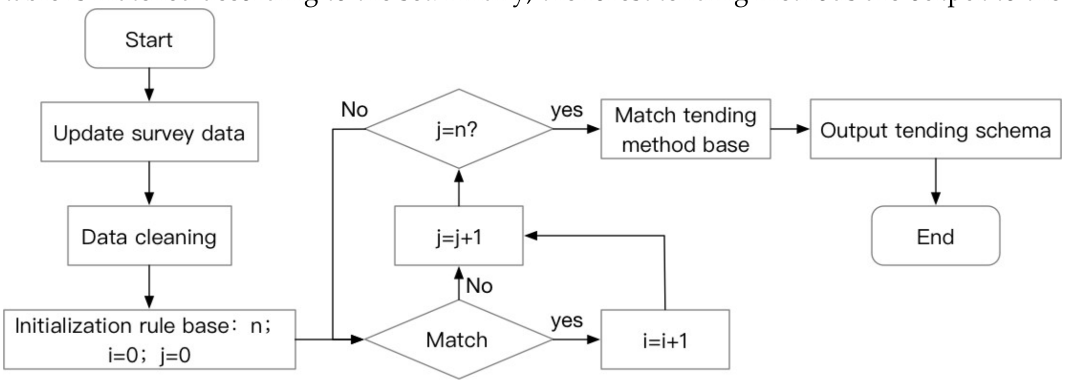

Figure.8 Forest tending decision support system reasoning process

3. System Statement

3.1. System Structure Framework

FTGDSS takes the data generated by *Smartforest* as the data source, and the decision result generated by FTGDSS supports the business development in *Smartforest*. The overall framework of the system environment is shown in Figure 9. *Smartforest* is a B/S structure system built on a cloud server and developed with the Spring MVC framework and Activiti process engine. FTGDSS is a DSS based on the three-library framework proposed by Bonczak [28] in the technical background of *Smartforest* (Figure 10).

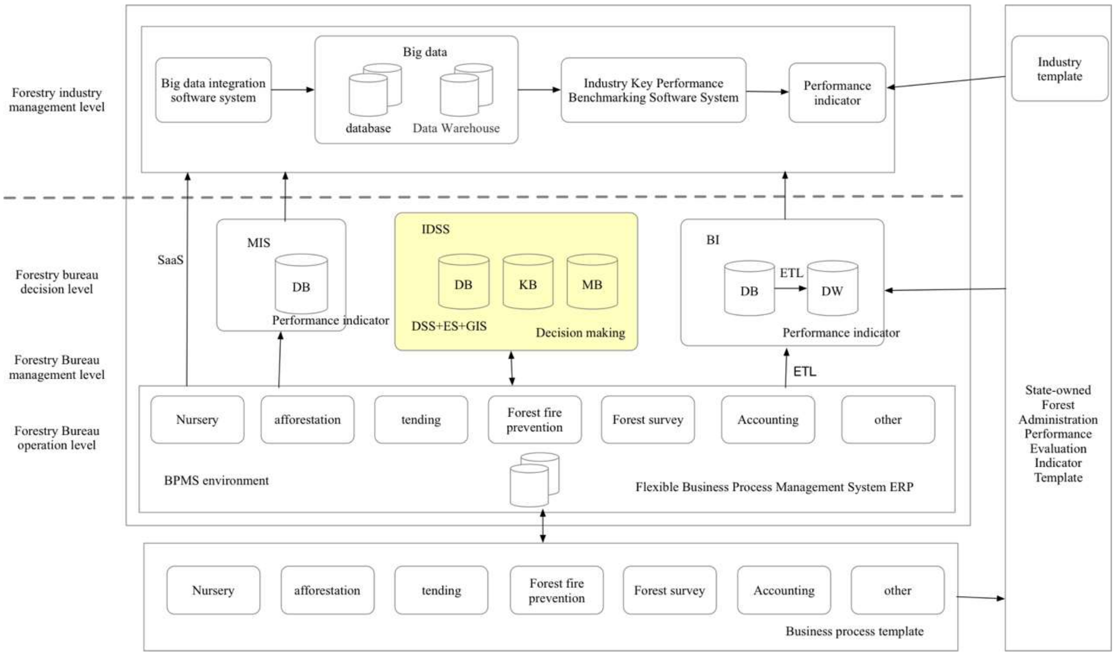

Figure.9 Forest Tending Decision Support System Environment

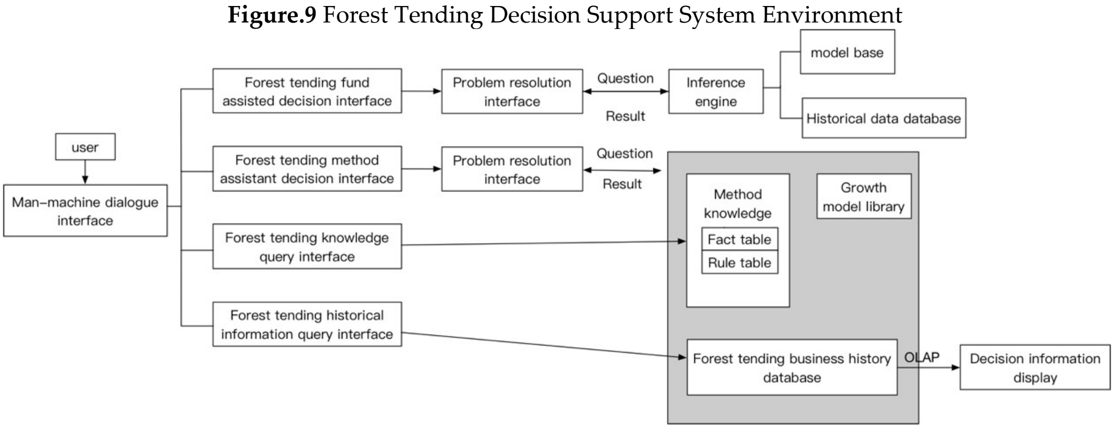

Figure.10 FTGDSS system structure

3.2. System Functional Framework

According to forest industry management needs, the functional requirements of FTGDSS were designed, and the system was divided into four modules: (1) forest tending fund allocation assistant decision system, (2) forest tending method assistant decision system (3) forest tending history information inquiry system, and (4) forest tending knowledge inquiry system. The system function module diagram is shown in Figure 11.

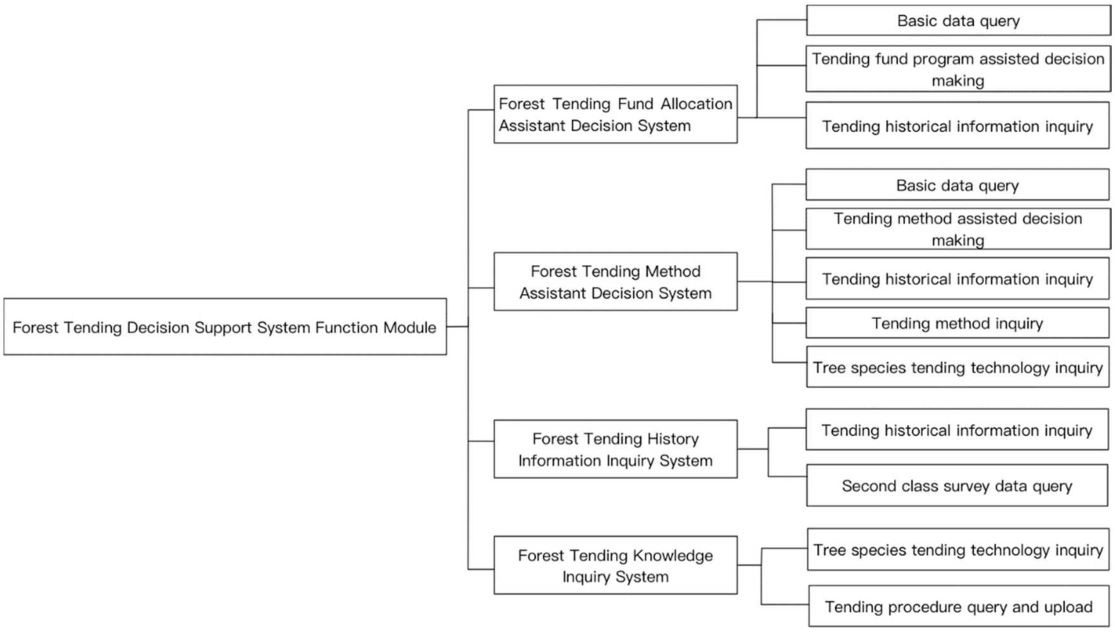

Figure.11 FTPDSS function module diagram

3.3. System Implementation

The system provides decision-making and computing services in the SaaS form of cloud computing. Currently deployed on the Alibaba Cloud platform, client users can access the system through a web browser from the user's machine. The management, storage, and maintenance of the knowledge base of the system is implemented using MySQL and PostgreSQL databases. The relevant system running screenshots are shown below.

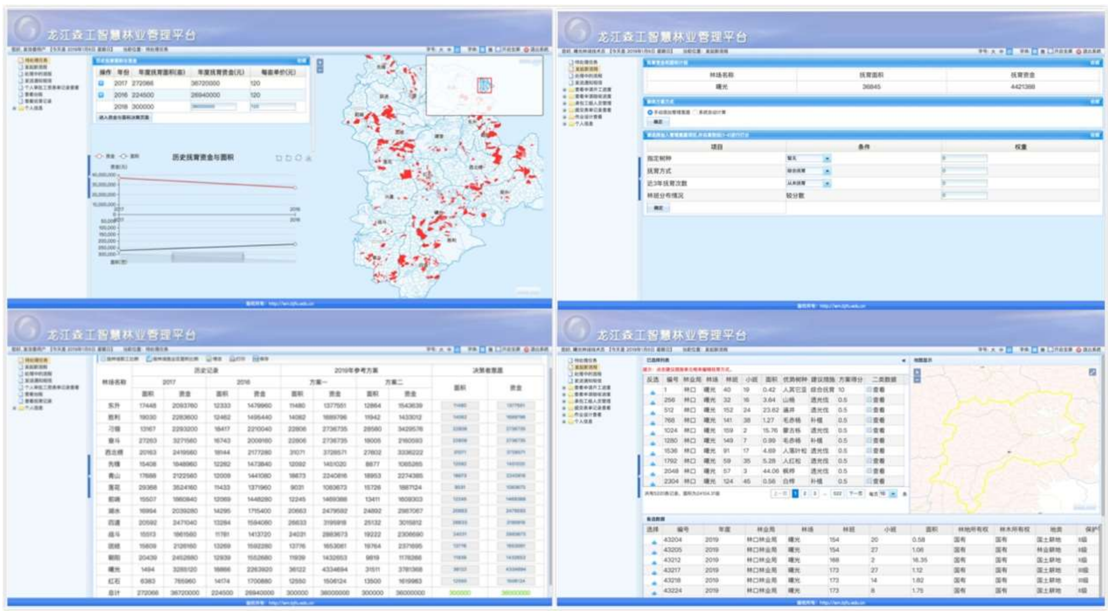

Figure.12 System running screenshot

4. Results and Discussion

The system was tested in the user unit several times, and many end users directly participated in the testing process. The users responded well and the test results reflect the robustness and functional rationality of the system to some extent. However, we are considering using some additional tools or theories to evaluate the system. In total, 32 forestry decision support systems were collected with detailed system descriptions from FORSYS, with an emphasis on the scope of the

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system use [29], data acquisition methods, relationship between users and the DSS [30], and modes of assistance [31]. The scope of the system can be divided into enterprise-level support for large data volume and the simultaneous use of multiple users, and a personal level that only supports single users by installing client software [29]. The relationship between users and DSS can be divided into negative (only decision-making, no definitive decision-making advice, and solutions), positive (providing decision-making advice and solutions), and continuous modification of the system and users through a process decision-making plan. The modes of assistance are divided into those that are communication-driven (supporting different decision makers to make decisions for the same decision task) and non-communication-driven [31]. From the two evaluation dimensions provided by the technology adoption model (TAM) [32] for comparative analysis (Table 6), compared with the desktop version of the decision support system (65.6%), FTGDSS is based on the B/S architecture, and whereas most scholars have discussed the use of cloud computing to solve multi-target forestry business decision-making problems [33], FTGDSS is rarely represented in enterprise-level systems (34.4%) and provides cloud computing in the form of SaaS to support multiple user usage and large-scale data operations. FTGDSS automatically extracts the required decision data from *Smartforest*, and 78.1% of the decision support systems need to manually input decision data. Generally, users want to control the process of obtaining the solution, and also want to obtain the most scientific results [22]. Through human-computer interaction, the complexity of work can be reduced, and decision makers can choose and assign according to their own needs and management willingness, so that users can have a type of management role when participating in decision-making. Therefore, the system's perceived ease of use is high.

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Table 6. System structure of forestry decision support system

		scope		Data Input		relationship			modes of assistance	
software	**country of region**	**Enterprise-wide**	**Desktop**	**Auto-acquisition**	**manual-acquisition**	**passive**	**active**	**cooperative**	**communication-driven**	**none-communication-driven**
AFFOREST-sDSS	Belgium		x	x				x	x	
Agflor	Portugal		x		x	x				x
AVVIRK	Norway		x		x	x				x
Capsis	France	x			x			x		x
Conifer Timber Quality	Great Britain	x			x	x				x
DSS for managing forest fire casualities	Greece		x		x	x				x
DTRAN	USA		x		x		x			x
EFIMOD	Russia		x		x	x				x
EMIS	Great Britain	x			x	x				x
EnerTREE	Finland		x		x	x				x
ESC	Great Britain	x			x	x				x
FFIREDESSYS	Greece		x	x		x				x
FMPP	Sweden		x		x		x			x
FORESTAR	China		x		x	x				x
ForestGALES	Great Britain	x			x	x				x
GAYA	Sweden		x		x	x				x
Habplan	USA	x			x		x			x
Hugin	Sweden		x	x		x				x

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LEaRNForME	Italy	x			x	x				x
LMS	USA		x		x			x		x
MAPSS	USA		x		x	x				x
MELA	Finland		x	x			x			x
Mesta	Finland		x		x			x		x
MfLOR	Portugal		x	x			x			x
Monsu	Finland		x		x			x		x
MONTE	Catalonia		x	x				x		x
NED	North America	x			x		x			x
ProgettoBosco	Italy		x		x	x				x
SADfLOR	Portugal	x		x			x			x
SIMPPLLE	USA	x			x	x				x
TEAMS	Arizona		x		x		x			x
WoodStock	Canada	x			x		x			x
		34.4%	65.6%	21.9%	78.1%	53.1%	28.1%	18.8%	3.1%	96.9%

FTGDSS continuously negotiates with users and makes the users participate in the decision-making process to produce a specific decision-making plan. Only 18.8% of the 32 DSSs analyzed make decisions through cooperation with the system, and for more than half of these cases, the DSS only plays a supporting role, such as conducting auxiliary calculations, and cannot directly elaborate a decision plan. Only 3.1% of DSSs are group decision support systems, whereas FTGDSS takes the process as the decision-making driving object, unifies the decision problems of decision makers in different geographical locations and different time points, improves the scientific decision-making for decision makers, and has a certain degree of perceived usability.

One of the principles of the establishment of information systems is that the strategic direction of the information systems and the business strategy should be consistent; that is, the establishment of information systems must support strategic objectives [34,35]. The goal of forestry development is sustainable forest management. We considered the problem of multi-objective forestry management from the perspective of the forest stand. The system provides decision makers with real data for the past five years and assists decision makers in strategic planning, including forest sowing and tending. When allocating funds, it is important to comprehensively consider the economic benefits and forest status of each forest farm; when allocating the tending plan area for each forest farm, the number of forest workers should be considered to make a decision from a social point of view. The ultimate goal of tending is to increase the unit volume, and the system is used to consider the balance between ecology, the economy, and social culture, and thus achieves sustainable forestry management.

Because the forestry tending business needs to operate in different time and space distributions, and has a high degree of spatial-temporal complexity, a forest tending business decision is a semi-structured decision-making process. By referring to the business process management idea, forest tending can be automated to a certain extent, while simultaneously incorporating the manager’s ideas into the decision-making process to improve the relevance of decision-making outcomes and practical scenarios.

For the system itself, forestry business decision management needs to comprehensively consider the data and actual management at each level, and DSS needs a huge amount of data volume support. There is no continuous supply of business data. For DSSs, it cannot be practically implemented. To solve the problem of data acquisition for DSSs, FTGDSS automatically extracts data from the business system *Smartfores*t. Various management departments of China’s forestry management organizations have their own software systems that are not related to each other, which causes data and information silos and leads to the lack of timely acquisition of data, so managers cannot refer to different opinions from various departments. FTPDSS draws on process management ideas, shares and automates the acquisition of data from the *Smartforest* system, and creates a consistent platform for department managers located in different geographical locations to achieve group decision-making, breaking barriers between departments and solving silo applications between departments.

5. Conclusions

We developed a forestry decision support system (FTGDSS) based on the idea of process management, solving the decision-making problem faced by the forest tending business involving many people within different times and spaces. Most data of the system are automatically extracted from the ERP system of forest business process management, which improves the usability of the system. The system supports the achievement of forest management objectives in the decision-making process, and the decision-making results fully reflect the decision maker's management intention. Each decision-making activity is represented by a Business Process Modeling Notation (BPMN) diagram and is executed by the process engine (Activiti) deployed in FTGDSS. When a decision process change occurs, such as adding a decision activity or changing the order of the decision activities, the system change can be implemented by simply modifying the BPMN diagram. The system also provides a weight customization function. Therefore, FTGDSS is flexible and agile, and can quickly respond to changes in the decision process.

However, for the problem of the automatic selection of sub-compartments suitable for tending, the system only provides visual decision reference information to assist decision makers in manually selecting sub-compartments for tending, and cannot directly select sub-compartments for operation. In the future, remote sensing technology will be considered to assist decision-making. The normalized difference vegetation index (NDVI) value of each grid is calculated from remote sensing raster data. The vegetation coverage change is judged according to the NDVI value and the sub-compartment suitable for operation is automatically queried according to the area and the maximum NDVI value. Currently, this algorithm is not included as a function in the system design phase. The system currently uses two types of database management software, which will be merged into a unified platform in the future. These are a few issues that will be the focus of future study.

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