Decision Support Systems for Forest Management: a comparative analysis and assessment

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ABSTRACT

Decision Support Systems (DSS) are essential tools for forest management practitioners to help take account of the many environmental, economic, administrative, legal and social aspects in forest management. The most appropriate techniques to solve a particular instance usually depend on the characteristics of the decision problem. Thus, the objective of this article is to evaluate the models and methods that have been used in developing DSS for forest management, taking into account all important features to categorize the forest problems. It is interesting to know the appropriate methods to answer specific problems, as well as the strengths and drawbacks of each method. We have also pointed out new approaches to deal with the newest trends and issues. The problem nature has been related to the temporal scale, spatial context, spatial scale, number of objectives and decision makers or stakeholders and goods and services involved. Some of these problem dimensions are inter-related, and we also found a significant relationship between various methods and problem dimensions, all of which have been analysed using contingency tables.

The results showed that 63% of forest DSS use simulation modelling methods and these are particularly related to the spatial context and spatial scale and the number of people involved in taking a decision. The analysis showed how closely Multiple Criteria Decision Making (MCDM) is linked to problem types involving the consideration of the number of objectives, also with the goods and services. On the other hand, there was no significant relationship between optimization and statistical methods and problem dimensions, although they have been applied to approximately 60% and 16% of problems solved by DSS for forest management, respectively. Metaheuristics and spatial statistical methods are promising new approaches to deal with certain problem formulations and data sources. Nine out of ten DSS used an associated information system (Database and/or Geographic Information System - GIS), but the availability and quality of data continue to be an important constraining issue, and one that could cause considerable difficulty in implementing DSS in practice. Finally, the majority of DSS do not include environmental and social values and focus largely on market economic values. The results suggest a strong need to improve the capabilities of DSS in this regard, developing and applying MCDM models and incorporating them in the design of DSS for forest management in coming years.

Keywords

Decision Support Systems, Forest Management, Multiple Criteria Decision Making, Group Decision Making, Optimization, Simulation

1. Introduction

Forest management planning encompasses environmental, economic, administrative, legal and social aspects. The large number of issues relating to forest management, such as fauna, flora, recreation, water, forest resources, etc. make the development of forest plans a complex process. Consequently, Decision Support Systems (DSS) are essential tools for practitioners involved in complex decision-making problems, such as those which arise in forest management and forest planning. DSS have been defined by Holsapple (2008, p.22) as "computer based systems that represent and process knowledge in ways that allow the user to take decisions that are more productive, agile, innovative and reputable", and Muys et al. (2010, p.87) considered DSS as "tools providing support to solve ill-structured decision problems by integrating a user interface, simulation tools, expert rules, stakeholder preferences, database management and optimization algorithms". This paper aims to assess the use of different models and methods in DSS for decision-making in forestry, to gain some insight into which methods have been used in different applications, and to see where novel methods have emerged. The study supports the work of the European Cooperation in Science and Technology (COST) Action in demonstrating to new DSS developers how solutions have been found to different types of problems. Consequently, the literature review is comprised of two parts. Firstly, we review the recent literature on DSS relating to forest management planning, secondly we undertake and report an analysis of the literature in relation to the problem types addressed by different models and methods.

2. Literature review and objectives

An extensive literature review has uncovered a large number of published articles in recent years which use DSS to inform decision-making in forestry. Table 1 shows how simulation and statistical methods have been applied to evaluate wind damage and pest management. Simulation is commonly used in growth models, and wildfire and landscape management. In focussing on Multiple Criteria Decision Making (MCDM) methods, we found the Analytic Hierarchy Process (AHP), Simple Multi-Attribute Rating Technique (SMART), and ELimination and Choice Expressing REality (ELECTRE) have all been integrated in DSS to solve problems, e.g. to indicate weights and to rank scenarios. The Preference Ranking Organization METhod for Enrichment Evaluations (PROMETHEE) has been integrated in the LANdscape-scale, succession and DISturbance (LANDIS) DSS and applied to manage public forests in the USA with a consideration of forest products and ecosystem services (Shang et al., 2012). Database and/or Geographic

Information System (GIS) also appear in many DSS alone or together with techniques, such as simulation, MCDM, Linear Programming (LP), statistical analysis and Cost-Benefit Analysis (CBA).

Table 1. Literature review of Decision Support Systems for forest management

It is also necessary to understand and evaluate which models and methods are available for solving main forest management problems and therefore provide guidance to developers on promising methods to improve the decision-making by using DSS. Several recent reviews have explored areas such as spatial forest planning (Baskent and Keles, 2005; Weintraub and Murray, 2006), group decision making (Martins and Borges, 2007) and MCDM applications in forestry (Diaz-Balteiro and Romero, 2008; Mendoza and Martins, 2006). D'Amours et al. (2008) described supply chain planning problems related to the forest products industry. Seidl et al. (2011) reviewed statistical models to deal with pest control and forest damage due to wind or wildfire. Hildebrandt and Knoke (2011) addressed techniques for financial decision-making under uncertainty.

A selection of recent articles that focus on forest management planning using optimization methods is presented in Table 2. LP and Integer Programming (IP) have been used to solve strategic and tactical problems, mainly maximizing the Net Present Value (NPV) and carbon sequestration, volume of harvested timber, but also with other objective functions, e.g. minimizing the outer perimeter of old forests in the landscape (Öhman and Wikstrom, 2008). The main set of decision variables are the area of each treatment unit managed by each alternative and the binary variables that indicate if a stand is assigned to a treatment schedule. IP has also been applied to solve forest industry problems, such as truck routing (Rey et al., 2009). Dynamic Programming (DP) was used in decisions related to fire risk and harvest policies with the objective to maximize the timber NPV (Spring et al., 2008).

Due to the difficulty in obtaining the optimal solution in mathematical models with a large number of integer variables, heuristic techniques have been developed as an alternative method to obtain good solutions with lesser computation times, although this approach does not guarantee optimal solutions. Thus, there is an increasing interest in applying metaheuristic methods to solve optimization problems in forestry, e.g. Genetic Algorithms (GA), Tabu Search (TS) and Simulated Annealing (SA). SA has been used to consider the impact of climate change uncertainty in forest management (Eriksson et al., 2012) and multi-objective forest planning that maximizes total utility (Kurttila et al., 2009). These three metaheuristics were also applied with forest growth and wind damage models and GIS (Zeng et al., 2007a). Other metaheuristic algorithms, such as Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) have also been applied to risk management of wind damage and management of uneven-sized stands, respectively.

Table 2. Literature review of optimization methods for forest management

When there are a number of alternatives or courses of action, MCDM can play a very useful role (Belton and Steward, 2003). As can be seen in Table 3 the combination of MCDM with other techniques, e.g. Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis, and GIS has increased the functionality of the approach and its applicability in forest management. The main applications are the selection and agreement of forest plans. AHP is widely used, in particular when stakeholders are involved in the decision-making process and with the aim to evaluate management alternatives. Likewise, Goal Programing (GP) and Voting techniques are also useful in participatory processes to elicit stakeholder preferences in forest planning.

CBA is the traditional technique in investment project decisions, with the goal of obtaining the future flows of benefits and costs adjusted for the time-bound changing value of money: a common approach uses NPV. However, many environmental goods and services are not traded directly in the market and so it is difficult to determine their value. CBA is mainly applied to market forest products and to make decisions on the use of forest land. The concept of willingness-to-pay has spread in the valuation of goods and services untested in the market, e.g. Contingent Valuation (CV).

Table 3. Literature review of MCDM techniques and economical models for forest management

Traditional statistical methods, such as ANalysis Of VAriance (ANOVA), Bayesian analysis and Regression Analysis (RA) are the most widely used techniques (Table 4). In response to the increasing use of GIS and due to the characteristics of the data provided in forestry, spatial statistics have emerged for the analysis of this type of data (Newton et al., 2012). Simulation models, such as Monte-Carlo Simulation Method (MCSM), and Growth Models (GM) are useful complementary tools to other statistical techniques (Loudermilk et al., 2011). To a lesser extent, other statistical methods have been applied to forestry problems, such as correlation analysis, Principal Components Analysis (PCA), and a General Linear Model (GLM) among others.

Table 4. Literature review of statistical methods for forest management

Tables 2, 3 and 4 also present information about DSS and commercial software used in cited papers. Examples of DSS are Heureka, MONSU, Monte and GAYA that are included in the assessment presented in this article. Finally, there is a lack of systematic studies that analyse to what extent DSS in forest management are supported by specific models and methods, and the relationship between the different types of problems and the approaches dealing with them. This analysis will guide DSS developments in order to better fit the requirements of practitioners.

The objectives of the study were to analyse and assess the models and methods in DSS for forest management, taking into account the important features used to categorize forestry related problems. It is useful to know the appropriate methods used to answer specific problems, as well as the strengths, weaknesses and drawbacks in each case. We were also interested in new methods used to answer specific problem types. Such applications could show innovation in tackling particular problems and be useful to design and apply DSS for forest management in coming years. The following sections of the paper report an analysis of the link between particular methods and common problem types, and this is laid out in a classical format with a description of the method used to carry out the research, followed by the main results obtained, discussion and conclusions. Acronyms of DSS and methods appear in Appendix 1.

3. Methods

We describe an assessment of methods used in DSS for Sustainable Forest Management (SFM). The framework of the analysis is provided by the COST action FP0804 Forest Management Decision Support Systems (FORSYS) (2012). The main objective of this European project was to develop information standards and guidelines for the development, testing, evaluation and application of DSS for multifunctional and sustainable forest management. In particular, Working Group 2 reviewed, assessed, and recommended models and methods for developing DSS tools. The COST Action developed a typology to enable the classification of the wide range of problems solved by forest management DSS. This typology takes into account various dimensions or features of forest management problems. In particular, the country report protocol for the classification of problems solved by DSS considers the following problem dimensions and categories:

1. *Temporal scale*: long term (strategic), medium term (tactical) and short term (operational).

2. *Spatial context*: non-spatial and spatial context (with and without neighbourhood interrelations).

3. *Spatial scale*: stand level, forest/landscape level and regional/national level.

4. *Number of decision makers*: single decision maker and more than one decision maker/stakeholder.

5. *Number of objectives*: single objective and multiple objectives.

6. *Goods and services*: market non-wood products, market wood products, non-market services and market services.

Each participating country developed a report on the design and use of computer-based tools and forest management DSS. All country reports (26) written by 94 authors, experts on this topic, have been reviewed (Borges et al., 2013). In addition, the media semantic wiki developed by the FORSYS project has also been revised to include additional information to allow detailed analysis of the problems and methods described by the country reports. The COST Action was primarily focused on European countries and consequently there were more reports from Europe (19) however, there were several reports from other continents, including: North America (2), South America (2), Africa (2) and Asia (1). Additionally, a semantic wiki constructed by the COST Action includes DSS developed in Belgium, Latvia and Lithuania, but they do not appear in any of the country reports. All DSS analysed are included in Borges et al. (2013). The validity and wide representativeness of the input data used in our assessment are supported by the number of countries and authors who provided this information and their well-known expertise in forest management.

The methods used by DSS for forest management have been classified in six groups in accordance with the techniques of decision making: Multiple Criteria Decision Making, Optimization, Simulation, Economic models, Statistical methods and Information systems (Table 5). We consider in the MCDM group continuous and discrete multiple criteria techniques. Group Decision Making and Voting Techniques have been included in this group, because they are more frequent in relation to MCDM, although they can be applied to problems with a single objective.

Grouping the different methods was necessary for an appropriate application of the statistical analysis, with the exception of the information system group which is divided in Database (Database Management System –DBM- and Relational Database Management System –RDMS-) and GIS subgroups. Forest management problems were analysed using two categories in the spatial context, number of decision-makers and objectives, while temporal scale, spatial scale and goods and services have three categories. In the latter case, due to the large number of possible combinations of both market and non-market products (wood and non-wood) and services, the problems have been classified into three categories for statistical purposes, referring to ‘only products’, ‘only services’ and ‘goods and services’. Combining all the categories inside each problem dimension, 136 problem types were identified, 24 of which do not have an associated DSS, and were therefore taken out of the analysis.

Firstly, a descriptive analysis of the data has been made to describe the distribution of DSS by problem types and approaches. Secondly, contingency tables have been used to study the relationships among problem dimensions and between the problem dimension and approaches to solve forest problems. Each problem dimension was considered as a categorical variable to classify a forest management problem. Contingency tables were used to contrast the relationships between problem dimensions, using Pearson chi-squared (χ^2) test. This involves a statistical inference procedure that measures the divergence between an observed and a theoretical distribution when the variables are not related, and indicating to what extent there are differences between the two due to chance using a hypotheses test. We tested the null hypothesis -that there is no association between two categorical variables- through the analysis of data in a contingency table (Moore, 1995). For example, it is possible that the temporal scale and the number of objectives of a decision problem are related. This allows us to examine whether an increasing number of objectives are more frequently assessed as a strategic problem than an operational problem. In our study we accept the statistical significance when P value is less than 0.05.

Table 5. Models and Methods in Forest Management DSS classified by approaches

4. Results

4.1. Distribution of forest problems by dimension

From the analysis of DSS in the goods and services dimension, we see that 93% of DSS help solve problems related to market wood products. The percentage of the DSS developed to manage market and non-market services is 24%. Due to a high number of combinations of the four elements of this problem dimension, Figure 1 shows only principal cases found in the country reports. Approximately one third of the total DSS (32%) focus on market wood products, not including other capabilities for different goods and services. The second largest group is DSS that consider all products and services, including market as well as non-market (21%) benefits. Other important DSS are those developed for market wood products and non-market services (18%) and market non-wood products as well as market wood products (10%). All other mixes are grouped in the category "Other" (Figure 1). Finally, it is remarkable that only a small percentage (5%) of DSS have been developed to address 'non-market services'.

Figure 1. Forest management problems identified in country reports classified by goods and services.

The characteristics of forest problems have been classified using the six problem dimensions, defined by the FORSYS project: temporal scale, spatial context, spatial scale, number of decision makers, number of objectives and finally, goods and services. A statistical analysis using contingency tables shows significant differences among the distribution of problems inside each problem dimension, classified by one another, when both are considered as categorical variables.

To summarize the main results, Figure 2 shows links reflecting a significant relation between two problem dimensions. It can be seen that all problem features are related to others, except those problems that are focused only on services (approximately 5%). The spatial context and the scale present a link, meaning that if the problem has a regional, forest or stand level, this situation affects the proportion of spatial or non-spatial problems.

Figure 2. Significant relations between features of problems solved by DSS, shown by links between items, obtained through contingency tables with 5% statistical significance.

Here we present the relation between temporal scale and number of objectives of forest problems (Table 6). The majority of issues assessed by the DSS described in the country reports are strategic issues (43%), followed by tactical (33%) and operational problems (24%). Some cases consider two types of the three (4%), which are short term and medium term or medium term and long term. In contrast, problems with multiple objectives represent 73% of the total, the remaining problems have a single objective. Nevertheless, Pearson Chi-Square test showed significant differences between proportions inside the categories of temporal scale and number of objectives. Indeed, one third or more of all the operational and tactical problems addressed by DSS involve a single objective, dropping to 15% for strategic problems. In other words, the importance of multiple objectives is higher in long term problems (85%) than in medium term (67%) and short term problems (62%) (Table 6).

The number of objectives is related to the number of people involved in taking a decision. The problems have been divided into two groups in accordance with the number of decision makers. The percentage with more than one decision maker/stakeholder is 44%, whereas this number is 56% for problems with a single decision maker. Nevertheless, these global percentages do not reflect the fact that a single decision maker addresses problems with a single objective more frequently (81%). In contrast, 89% of multiple objectives decisions are taken in problems involving more than one decision maker/stakeholder.

Table 6. Contingency table of problems by temporal scale and objective dimensions

The number of decision makers is also related to the spatial scale, approximately half were forest/landscape problems, one third stand level and the remaining 17% regional/national problems. As the spatial scale of the problem addressed by the DSS increases, then frequently more than one decision maker or group of stakeholders are involved in the decision making process. In contrast, stand level decisions are made by a single decision maker more frequently (69% of problems). This percentage decreases to 56% for forest or landscape problems. Nevertheless, more than one decision maker or group of stakeholders are more frequently involved when regional problems are addressed. In this case, a single decision maker only occurs in 30% of the DSS problems described.

Another expected relation among dimensions of forest problems is the difference between the percentage of cases classified by spatial scale and spatial context. Taking the context into account most of the problems are spatial (72%), 38% with neighbourhood interrelations and 30% without. No information exists for the remaining spatial problems. The percentage of non-spatial problems is 22%, and the percentage of spatial problems varies from 60% in regional problems to 87% in forest/landscape problems. The highest proportion of non-spatial cases appears in regional forest problems (40%).

Problems that can be solved by a DSS only dedicated to products represent on average 43% of cases. Differences are seen when we analyse the performance by the number of decision makers involved. The previous proportion rises up to 57% when there is a single decision maker. In the case of more than one decision maker or stakeholder this value is only 26%. A negative relation appears when the problems involve both products and services. In this case two out of three problems with more than one decision maker have products and services and this proportion is lower with a single decision maker (Table 7).

Table 7. Contingency table of problems by Decision Making Dimension and Products & Services

There is a strong relationship between the percentage of problems involving only products and the number of objectives. When the problem has a single objective a high proportion of these (78%) correspond to DSS with a capability focused only on products. Nevertheless, this percentage is 31% in multiple objective cases. A similar situation links the number of objectives, single or multiple, to products and services, but in the opposite way. A small number of problems with a single objective (16%) are focused on products and services, while this occurs in two out of three cases in multiple objective problems.

4.2. Distribution of forest problems by models and methods

In decision making the most appropriate method to solve a particular problem usually depends on its relevant characteristics. Relations among methods and problems characteristics have also been analyzed using contingency tables. Links shown in Figure 3 represent significant relations between the methods and the problem dimensions (with a P value less than 0.05).

Figure 3. Significant relations between methods (rectangles) and features of problems (ellipses) solved by DSS, shown by links between items, obtained through contingency tables with 5% statistical significance.

The frequency table (Table 8) classifies the number of problems divided into a temporal scale dimension and methods to solve them. For example, 6 of the 29 short term problems (operational), have been solved by a DSS that uses MCDM.

Table 8. Distribution of DSS by temporal scale of problems and methods in cases and percentage

Overall, in long term problems MCDM, economic models and information systems are the methods more commonly used than any other temporal scale. In the medium term, DSS use more optimization and simulation methods, and in short term more problems are associated with statistical methods.

Information systems are more frequently used in DSS problems with a longer planning horizon. Globally, they appear in 90% of the DSS described in the country reports, but there are significant differences when taking the temporal scale into account. They are used more frequently in medium and long term problems than in short term problems (82%).

As can be expected, economic models are most commonly used in DSS involving long term decisions. The percentage of DSS using economic models is 10% for operational problems, increasing to 26%, and 38% in tactical and strategic problems respectively.

Multiple Criteria Decision Making techniques are related to the number of objectives of forest problems and to those involving only products. Firstly, as can be expected almost all problems solved by MCDM are in the group of multiple objectives problem types. However, the percentage of problems with multiple objectives solved by MCDM is only 40%. The percentage of problems solved by MCDM reduces to 19% when the problem type relates only to forest products. In all other different cases this percentage rises to 41%.

Simulation models are more commonly used to solve problems on a smaller spatial scale, mostly at the forest level, which represents 58% of the total and 33% at stand level. From the spatial scale perspective, the percentage of the regional/national problems using simulation models is 35%, and this value increases to 64% at the stand level and to 72% at the forest level.

Simulation models are also related to the number of decision makers or stakeholders involved in the forest problem. Problems in which a single decision maker uses simulation models make up 72% of cases and this percentage decreases (53%) in problems with more than one decision maker. We can say that two out of three problems solved by simulation models have a single decision maker and the remaining third has more than one decision maker or stakeholder.

Economic models are more frequently used in long term problems (61%) than in the medium term (30%) and short term (9%) timescale (Table 9). On the other hand, 38% of all long-term problems use economic models, and this percentage decreases in shorter term planning horizons to 26% in the medium-term and 10% in the short-term. The global percentage of problems solved by a DSS which include economic models is 27%. However, some significant differences occur if taking into account whether the problem considers only products, where the proportion using economic models is higher for problems focused on products (Table 9).

Table 9. Contingency table of problems by Temporal Scale Dimension and Economic Models

Almost 80% of the total problems solved by a DSS have a database. Considering the planning horizon the results are the following: 86% of long-term problems have a database, 82% addressing medium-term and 62% in addressing short-term problems. 47% of the problems that have a database are long-term problems, decreasing to 34% for medium-term and the remaining 19% for short term problems.

Unsurprisingly, a DSS linked to a GIS addresses mainly spatial problems (86%). Even so, 37% of non-spatial problems use GIS in their associated DSS. The problems are divided into spatial with neighbourhood interrelations and spatial with no neighbourhood interrelations, 69% of the first category have GIS tools and 65% for the second. There are four countries, Austria, Canada, Hungary and the USA, which do not differentiate spatial problems into two categories and 50% of them use GIS.

Problems with multiple objectives use GIS in 65% of DSS cases, whereas this percentage drops to 41% in problems with one objective. GIS are also related to the goods and services; in particular 42% of problems which involve only products use a GIS as part of the DSS, and in problems which involve both goods and services the percentage increases up to 70%.

Many problems that involve only products have an information system (83%) and almost all of them in other cases (96%) (Table 10). Almost all problems that involve products and services have some information system (95%). The remaining problems which focus on only products or only services also have an information system but the ratio is slightly reduced up to 84%.

Table 10. Contingency table of problems Only Products Dimension and Information Systems

5. Discussion

This work provides an assessment of methods used in DSS for SFM, which have been described in the country reports and wiki of the FORSYS project. The results apply largely to European countries, with a smaller sample of countries from other continents. The in-depth analysis takes into account the main features of the problems, as well as the models and methods to analyse and solve them.

One of the most influential problem dimensions is the number of people involved in decision making. Whether the problem involves a single decision maker or more than one decision maker /stakeholder, is related to the number of objectives, single or multiple, the spatial scale of the decision and the types of goods and services considered. For example, several decision makers or stakeholders were involved more frequently in regional or national planning issues than in forest or stand level planning, and this is also the case for forest problems with multiple objectives. At the same time, a single decision maker is associated more frequently with problems focused on 'only products'. In the cases of the DSS described in the country reports that involve goods and services, the highest percentage appears in multiple objectives problems and with more than one decision maker. This seems intuitive as the expert is the forester/planner using a DSS for solving problems of a technical nature and this professional role usually does not need to be shared with non-expert stakeholders, and as Reynolds (2005) has pointed out "the institutional perspective is at least as important as the technical one". Our results can be interpreted in the following way: problems that focus on “only product” are mainly managed from a technical point of view, while those involving goods and services are less related with expert knowledge and more with stakeholder preferences.

The number of objectives has a significant influence on the distribution of forest problems by other characteristics, in addition to the number of decision makers involved in the process. In particular, multiple objectives are more frequently analysed in DSS involving strategic problems than in tactical and operational problems. Moreover, the percentage of problems with multiple objectives is much bigger in problems focused on products and services than single objective cases (Shang et al., 2012), although problems with a single objective are mainly focused on products (Binoti et al., 2012).

We found that there is no significant relation between optimization methods and problem dimensions, although this approach has been used in approximately 60% of DSS developed for forest management. This suggests that optimization models could be seen as general tools to deal with forest management problems, not related to their specific characteristics. In fact optimization models have been used in the majority of published papers describing forest management DSS in the last decade, sometimes being solved by the commercial software CPLEX, or by means of metaheuristics algorithms, such as SA, TS, GA. In general, evolutionary algorithms are now becoming more popular as a tool to solve complex combinatorial optimization problems, although their use has not been widespread in DSS until now. Metaheuristic methods require detailed studies to obtain the values of the parameters, which make them competitive in obtaining good solutions with less computing time. In addition, tuning parameters are linked to specific instances and many papers use artificial forests (Pukkala and Heinonen, 2006; Bettinger and Zhu 2006; Boston and Bettinger, 2006; Hennigar et al., 2008). Thus there is an additional difficulty in applying these methods due to the gap between hypothetical and real forests and landscapes. Dynamic programming is a conceptually smart idea to optimize a sequence of interrelated decisions in forest management. The main drawback for practitioners and DSS developers is that there is not a standard mathematical formulation for problems of dynamic programming, as there is for linear, integer and non-linear programming models. It is necessary to develop the particular equations for each problem when using dynamic programming. An interesting line of future research would be to develop DSS that are able to generate the required equations for common problems.

Our analysis showed that statistical methods are not strongly related to problem features, and are applied to only 16% of problems solved by DSS for forest management. Statistical techniques can be seen as complementary tools to other approaches to inform decision making (Leskinen et al., 2006). In general, traditional approaches such as regression analysis and multivariate models are used more frequently (Ren et al., 2011), although data mining and ANN techniques are becoming more popular in recent DSS (Ficko et al., 2011). Recently, many authors have developed statistical spatial models as a more appropriate methods to capture data from new sources (Newton et al., 2012), such as GIS.

In contrast to statistical methods, 63% of forest DSS have used simulation modelling methods and these are particularly related to the spatial scale and the number of people involved in making a decision. Simulation has been applied more successfully to problems involving a single decision maker working at a forest or landscape level. Muys et al. (2010) highlight a trend to integrate forest simulators with optimization tools and also to involve stakeholders through participatory models, as can be we found in the literature review.

Our results show how closely MCDM are linked to problem types involving a number of objectives and the goods and services dimension. MCDM has the highest percentage use in the DSS concerned with multiple objective problems (73%) and the least percentage in problems focused on only products (26%). It highlights the percentage of problems with multiple objectives solved by MCDM, which is only 40%. In addition, our data show no statistical evidence of the dependence or use of MCDM approaches on the temporal scale of problems, in contrast to what can be expected and had been said in other works (Muys et al. 2010). Thus, there seems to be a demonstrated interested to develop DSS with capabilities in MCDM, not just for long term problems, but for problem types with medium and short term temporal domains. MCDM tools are used to involve stakeholders in forest management and group decision making. Our results suggest that there is a great opportunity to improve the capabilities of DSS in this regard, but with difficulties to overcome often related to new types of data need by MCDM. DSS should be able to capture the preferences and judgements of decision makers/stakeholders periodically, providing quality data with low cost by using the latest technologies, and Menzel et al. (2012) provided a thorough review of DSS from this participatory perspective.

Economic models have been found in approximately one out of four of the DSS described in the country reports, and these are related largely to temporal scale and goods and services. Economic models frequently address long term problems. Their use is also linked to problems focused on the forest products domain in which market values are more readily available. Their future use in the valuation of ecosystem services that benefit people (Millennium Ecosystem Assessment, 2003) is likely to expand as contingent valuation, voting and other approaches to valuation become better developed (Bateman et al., 2011).

Nine out of ten DSS described for forest management have an associated information system, a database and/or a GIS. The dependency analysis of the problem dimension shows some important results. GIS are integrated into more than half of the DSS described. The percentage of problems using GIS is naturally higher in the DSS described in solving spatial problems, but also where multiple objectives and where products and services problem types are concerned. Brown and Reed (2009) evaluate a public participation GIS, as an example to collect non-traditional forest data. Eight out of ten DSS involved a database and this proportion increases when temporal scale is stretched, being used more commonly in long term problem types. If we consider DSS with whatever information system, the analysis shows dependence between this variable and the number of decision makers, having the highest value in cases where several decision makers/stakeholders are involved in the decision making process. Information systems show a high percentage of use and applicability in problems involving products and services. That is, in situations where more tools are needed to present complex information in a visual and intuitive way to support public involvement (Reynolds, 2005).

Almost all DSS for SFM have information systems; nevertheless information has not been properly exploited by classical or novel decision making methods. One reason may be the quantity and quality of data needed and the high cost to obtain and maintain these (Kaloudis et al., 2008). In addition, most of the DSS developed are used only in one country as it is often difficult to apply systems elsewhere (Cucchi et al., 2005; Muys et al., 2010). This fact may constitute a major constraint in the current application of DSS, accounting for inefficiency and overlap in development effort. It is hoped that one of the outcomes of the FORSYS COST Action will be to broaden the available DSS resources across the forest industry and policy makers.

5. Conclusions

The analysis of DSS for forest management has shown the preferred approaches, models and methods, to deal with a particular problem, taking into account the nature of the decision problem. This can be characterized by the following six problem dimensions: temporal scale (strategic, tactical, operational), spatial context, spatial scale (stand, forest /landscape, regional/national), number of decision makers or stakeholders, objectives (single, multiple) and finally goods and services involved.

We found some general tools such as optimization and statistical models and also some challenges to be solved in relation to these approaches. New trends include methods to provide advice to adapt traditional optimization models, for example considering uneven-aged forests within different ecosystems. In addition, a new generation of evolutionary algorithms is gaining importance to help integer programming solvers, but they require tuning parameters to be competitive and their value is dependent on instance data. Regarding statistical methods there is a need to develop and integrate spatial models in GIS tools, which will be a requirement to tackle spatial problems and also to involve stakeholders in participatory processes, among other applications.

There is also a strong need to consider multiple objectives and to involve stakeholders in relevant phases of decision making in forestry. MCDM and group decision making should be developed further in DSS to provide a stronger stakeholder contribution to decision making. In this case, one of the challenges is non-traditional forest data, as lack of availability as input to models can limit their use in real problems. Additionally, the majority of DSS are focused on market products, alone or together with services. There are few DSS dealing only with services, and especially with non-market services. In this latter case, but also in general, we can say that quantity and quality of data required are a major issue to implement DSS in practice. New technologies to capture data will provide an opportunity to overcome this weakness, as well as a challenge to develop new models and methods that are really effective for practitioners.

Finally, DSS are mainly focused on technical and market economic objectives rather than social and environmental ones. We suggest that the future development of DSS for forest management should place stronger emphasis on economic models integrating the value of environmental services and collaborative decision making of multiple decision makers and stakeholders.

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Table 1. Literature review of Decision Support Systems for forest management

DSS	Problems/Uses	Methods	Reference
4S Tool[a]	Internet-based DSS to inform forest management for private forest owners.	Database and GIS[q]	Kirilenko et al., 2007
EMDS[b]	Environmental analysis and planning at user-defined spatial scale from landscapes to continents. Evaluation of management priorities.	GIS[q], AHP[r] and SMART[s]	Reynolds, 2005; Gärtner et al., 2008
ESC[c]	Informs decision on tree species choice for given site conditions.	Delphi and RA[t]	Pyatt, et al., 2001
ESDSS[d]	Supports estimation of regional eco-security and decisions about environmental protection and land use.	AHP[r], Delphi and GIS[q]	Xiaodan et al., 2010
FORESTAR[e]	Selects harvesting targets (landscape level) and determines cutting intensity and cycle (stand level).	Simulation and GIS[q]	Shao et al., 2005; Dai et al., 2006
ForestGALES[f]	Informs decisions on management to reduce wind damage.	Risk model, RA[t] and windflow model	Gardiner and Quine, 2000; Cucchi et al, 2005
FTM[g]	Models and analyses tree growth, forest operations, economy, biodiversity and nutrient balances.	Simulation and GIS[q]	Andersson et al., 2005
GeoeSIMAeHWIND[h]	Assessing the short- and long-term risk of wind damage in boreal forests (stand and regional level).	Simulation	Zeng et al., 2007a
IA-SDSS[i]	Supports land-use planning and local forestry development with consideration of carbon sequestration.	Integrate EMDS[b], CBA[u] and AHP[r]	Wang et al., 2010
LANDIS[j]	Simulates forest landscape (fire, wind, harvesting and insects).	Simulation	Shang et al., 2012
LMS[k]	Landscape changes integrating landscape-level spatial information, stand-level inventory data, growth models. SFM[o] evaluation in private land-management.	Simulation and GIS[q]	Reynolds, 2005
NED	Project level planning and decision-making processes. From small private holdings to cooperative management across multiple ownerships.	Simulation (growth, yield and wildlife), Database and GIS[q]	Reynolds, 2005
SDSS[l]	Elaborates silvicultural scenarios, assessment of indicators and comparison of the scenarios (MCDM[p])	Simulation, and ELECTRE[v] III	Pauwels et al, 2007
SprayAdvisor	Decisions for herbicide spray programs.	Experiment design and statistical analysis	Thompson et al., 2010
Woodstock[m]	Pest management decisions on use biological insecticides, rescheduling of harvest and forest restructuring.	Simulation and LP[x]	Iqbal et al., 2012
WRR-DSS[n]	Decisions for effective fire management planning.	MCDM[p] and Fuzzy set theory	Kaloudis et al., 2008

Acronyms of DSS: a- 4S Tool: Forest Stand Software Support System, b- EMDS: Ecosystem Management Decision Support System, c- ESC: Ecological Site Classification, d- ESDSS: Eco-Security assessment Decision Support System, e- FORESTAR: Forest Operation and Restoration for Enhancing Services in a Temperate Asian Region, f- ForestGALES: Geographic Analysis of the Losses and Effects of Storms in Forestry, g- FTM: The Forest Time Machine, h- Geo-SIMA-HWIND: Forest growth SIMA and wind damage HWIND models integrated into GIS, i- IA-SDSS: Integrated Assessment framework and a Spatial Decision Support System, j- LANDIS: LANdscape-scale, succession and DISturbance model, k- LMS: Landscape Management System, l- SDSS: Silvicultural Decision Support System, m- WRR-DSS: Wildfire Risk Reduction DSS, n- Woodstock: Remsoft Spatial Planning System.
Acronyms of Models and Methods: o- SFM: Sustainable Forest Management, p- MCDM: Multiple Criteria Decision Making, q- GIS: Geographic Information System, r- AHP: Analytic Hierarchy Process, s- SMART: Simple Multi-Attribute Rating Technique, t- RA: Regression Analysis, u- CBA: Cost-Benefit Analysis, v- ELECTRE: ELimination and Choice Expressing Reality, x- LP: Linear Programming,

Table 2. Literature review of optimization methods for forest management

Problems/Uses	Methods	Performance Measures	Decision Variables	DSS/Software	References
Forest harvest planning	BIP[a], SA[b], TS[c] and GA[d]	Harvest costs	Binary variables indicate if the forest stand must be harvested or not.		Quintero et al., 2011
Forest harvest planning	Bin-packing, LP[e] and SA[b]	Mean annual increment of the stands	Binary variables indicate whether or not a stand would be harvested.	Optimal Software and Spectrum	Strimbu et al., 2010
Forest inventory	LP[e]	NPV[m]	Area of forest in each site class harvested in each period.		Gilabert and McDill, 2010
Forest management (climate change)	SA[b]	NPV[m]	Treatment alternatives for each stands in each period.	GAYA	Eriksson et al., 2012
Forest management planning	LP[e] and GIS[f]	NPV[m]	Strategy assigned for each management unit (stand).		Costa et al., 2010
Forest planning	SA[b]	Total utility (timber/ landscape fire resistance)	Selection of the management schedules for the stands.	Monte	González-Olabarria and Pukkala, 2011
Forest regulation	MIP[g] and GA[d]	NPV[m]	Management alternative adopted in each management unit.	SifPlan	Binoti et al., 2012
Habitat in strategic forest planning	BIP[a]	NPV[m]	Binary variables indicate if a stand is assigned to a treatment schedule.	Heureka and CPLEX	Öhman et al., 2011
Harvesting decisions under fire risk	DP[h]	Timber and carbon sequestration	If the forest stand must be harvested or not and if the revenue flow must be used for consumption or saving.		Couture and Reynaud, 2011
Multi-objective forest planning	SA[b]	Total utility (NPV[m], total volume, …)	Treatment alternatives for stands.		Kurttila et al., 2009
Optimization of heuristic algorithms parameters	SA[b], TS[c] and TA[i]	Growing stock volume and total clear-felling area	Binary decision variables that indicate whether each stand is treated according to an alternative treatment.	MONSU	Pukkala and Heinonen, 2006
Planning. Simulation of harvesting/burning	LP[e] and Simulation	Harvest volume	Not specified.	CPLEX	Savage et al., 2011
Profitability of forestry projects	GA[d]	Annual Equivalent Value	Rotation length (years), Frequency of thinnings, Time of thinning (years), Intensity of thinnings (%)	Carbomax	Gutiérrez et al., 2006
Risk management of wind damage in forest planning	SA[b], TS[c], GA[d] and GIS[f] ACO[j]	Total utility (wind damage risk, even-flow target of harvested timber)	Alternative schedules for each stand in each period.	SIMA-HWIND and ArcGIS	Zeng et al., 2007a Zeng et al., 2007b
Spatial optimization using raster cells	TA[i]	Total utility (Proportion of the boundary between adjacent units…)	Binary decision variables that indicate whether each stand is treated according to an alternative treatment.	MONSU	Heinonen et al., 2007
Stand growth and harvest policies	DP[h]	NPV[m]	Total discounted time of being in state i and making decision k.		Zhou and Buongiorno, 2011
Stand-level forest planning	LP[e] and TS[c]	NPV[m] and carbon sequestration	Area of each treatment unit managed by each alternative, area of each treatment unit that is clear-cut in each period.		Backeus et al., 2005
Strategic and tactical forest planning	LP[e] and MIP[g]	NPV[m], harvest volume and penalty of road usage	Area of each stand allocated to a treatment schedule. Binary variables representing usage of road segment.	CPLEX	Andersson and Eriksson, 2007
Strategic forest planning	MIP[g]	NPV[m] and Outer perimeter of old forests	Stand assigned to a treatment schedule. Two stands are assigned to treatment schedules that result in old forest.		Öhman and Wikstrom, 2008
Strategic forest planning (landscape)	TS[c]	Even-flow of timber harvest volume	The management prescription assigned to each stand.		Bettinger et al., 2007
Strategic timber supply	LP[e]	Harvested timber volume	Not specified	Woodstock[n]	Hennigar and MacLean, 2010
Strategy for protecting against wildfire	DP[h]	Timber NPV[m]	Age at which to cut trees on multiple stands, fire protection, and whether to salvage-harvest burnt old-growth trees.	GPDP software	Spring et al., 2008
Structure and management of uneven-sized stands	PSO[k]	NPV[m]	Frequencies of diameter classes. Total number of trees and parameters of distribution function.		Pukkala et al., 2010
Truck routing for forest products	IP[l]	Transport costs	Binary variables indicate if truck type executes a trip schedule or not.	CPLEX	Rey et al., 2009

Acronyms of Models and Methods: a- BIP: Binary Integer Programming, b- SA: Simulated Annealing algorithms, c- TS: Tabu Search, d- GA: Genetic Algorithms, e- LP: Linear Programming, f- GIS: Geographic Information System, g- MIP: Mix Integer Programming, h- DP: Dynamic Programming, i- TA: Threshold Accepting, j- ACO: Ant Colony Optimization, k- PSO: Particle Swarm Optimization, l-IP: Integer Programming, m- NPV: Net Present Value
Acronyms of DSS: n- Woodstock: Remsoft Spatial Planning System

Table 3. Literature review of MCDM techniques and economical models for forest management

Problems/Uses	Methods	Notes	DSS/Software	References
	MCDM			
Evaluation of risks of rare plants	AHP[b] and GIS[c]	*Criteria*: Accessibility, travel difficulty and habitat search Alternatives: Elevated, moderate and low risk.		Young et al., 2011
Forest management planning	AHP[b]	*Criteria*: NPV[k] and old forest area.		Nordström et al., 2010
Forest products and timber management	AHP[b] and SWOT[d]	*SWOT[d] factors:* Strengths (e.g. Additional income), Weaknesses (e.g. Policy barriers and lack of enforcement), Opportunities (e.g. Inclusion of diverse values and actors) and Threats (e.g. Logging damage to Brazil nut stands).		Duchelle et al., 2012
Identifying SFM[a] indicators	ANP[e] and CM[f]	Set of Pan-European SFM[a] indicators.	Decision Explorer and Super Decisions	Wolfslehner and Vacik, 2011
Identifying SFM[a] indicators	AHP[b] and SWOT[d]	Workshop with stakeholders to select indicators.		Jalilova et al., 2012
Participatory forest planning	GP[g]	*Criteria*: Net income, regeneration cutting area, total wood volume, mature forest area, volume of broadleaved trees and value of growing stock. *Alternatives*: Seven harvesting plans.		Eyvindson et al., 2010
Participatory forest planning	Voting techniques and SMAA[h]	*Criteria*: Scenic beauty, Hiking, Tourism, Reindeer husbandry, Watershed protection, Nature conservation, Game management, Timber management and Natural product.		Vainikainen et al., 2008
Participatory forest policy-making processes	AHP[b]	*Criteria*: Conservation, timber industry, tourism, agriculture and recreation. *Forest management options*: conservative, pro–industry and limited industry activities	Expert Choice	Ananda, 2007
Regional forest management	AHP[b]	*Criteria*: Social, economic and environmental *criteria* (nine objectives). *Alternatives*: Forest action lines.	Super Decision	Maroto et al. 2012
Risk evaluation (fire and phytosanitary)	AHP[b] and GIS[c]	*Criteria*: Land cover type, biodiversity legislative tools, tourist sites, access routes, timber yield, fire and phytosanitary risks.	ArcGis	Pasqualini et al., 2011
Strategic forest planning	SMAA[h]	*Criteria*: Income, biodiversity, beauty and bilberry.		Kangas et al., 2006
Strategic processes in natural resources management	AHP[b], SMAA[h], SMART[i] and SWOT[d]	Four different case studies to analyze the combination of MCDM[l] technique with SWOT[d].		Kajanus et al., 2012
Uncertainty in forest planning	AHP[b], RA[j] and statistical inference	Forest plans (natural growth, scenic beauty index, game values, income).		Leskinen et al., 2006
	Economic Models			
Decisions of land use	CBA[m]	*Criteria:* Timber, fuel wood, maize, wild animals, carbon storage, watershed services, strict conservation, biodiversity and non-uses values. *Three forest systems:* Maize production, strict forest conservation and SFM[a].		Reichhuber and Requate, 2012
Estimation of private net benefits	CBA[m] and CV[n]	*Criteria:* Market private capital incomes, non-market private capital incomes (private amenities), government grants, silvicultural treatments cost and stripping costs.		Ovando et al., 2010
Forest pest management	CBA[m] and simulation	Cost-benefit analysis of sequestering carbon in forest through pest management *Criteria:* carbon sequestration revenues protection cost (pest management options)	SBW[s] DSS, CASPER and Distance Tool V	Slaney et al., 2012
Forest pest management	CBA[m], CV[n], LP[o], GM[p], yield models and simulation	Cost-benefit analysis to estimate market and non-market benefits and costs of controlling future pest *Criteria:* Market benefits and costs (timber and the aerial spraying costs and non-market benefits of pest control programs (recreational, wildfire habitat and other environmental services)	SBW[s] DSS	Chang et al., 2012
Transformation of even-aged stands	CBA[m] and MC[q]	*Criteria:* Regeneration cost, tending cost, time consumption for an even-aged rotation, timber prices and wind risk Three Strategies depending on when harvesting is initiated.	Mattlab	Schou et al., 2012
Uncertainty in forest NPV[k] computations	CBA[m], MCSM[r] and GM[p]	*Criteria:* Timber price, timber costs, errors in the prices, the simulations, the estimation of growth and data treatment.	ALS[t] software and SIMO software	Holopainen et al., 2010

Acronyms of Models and Methods: a- SFM: Sustainable Forest Management, b- AHP: Analytic Hierarchy Process, c- GIS: Geographic Information System, d- SWOT: Strengths, Weaknesses, Opportunities and Threats, e- ANP: Analytic Network Process, f- CM: Cognitive Mapping, g- GP: Goal Programing, h- SMAA: Stochastic Multicriteria Acceptability Analysis, i- SMART: Simple Multi-Attribute Rating Technique, j- RA: Regression Analysis, k- NPV: Net Present Value, l-MCDM: Multiple Criteria Decision Making m- CBA: Cost-Benefit Analysis, n- CV: Contingent Valuation, o- LP: Linear Programming, p- GM: Growth Model, q- MC: Markov Chain, r-MCSM: Monte Carlo Simulation Method,
Acronyms of DSS: s- SBW: Spruce Budworm, t- ALS: Airborne Laser Scanning

Table 4. Literature review of statistical methods for forest management

Problems/Uses	Methods	Notes	DSS/Software	References
Analysis of patterns of tree mortality	LR[a]	*Variables:* Explanatory variables and competition indices (spatial point process analyses).		Hurst et al., 2012
Analysis of spatial distribution	Spatial statistics	*Variables*: Population distribution, density and size structure at the genus and species level, relating these to two environmental variables (forest type and elevation). Three nested spatial scales: regional, landscape and local		Newton et al., 2012
Butterfly conservation	GLM[b] and PCA[c]	Vegetation and climate data.		Streitberger et al., 2012
Changes in distribution and abundance of fir tree	ANN[d], GLM[b] and GIS[e]	19 *variables* to analyze changes in spatial distribution, tree abundance in forest stands, age structure and abundance of tree regeneration.	MapInfo and Statistica	Ficko et al., 2011
Ecological and climatic factors influencing tree sensitivities and responses in climate	Correlation analysis and RA[f]	Chronology analysis and climate data defined in other studies.	ARSTAN, COFECHA and WinDendro	Griesbauer et al., 2011
Effects of harvesting and fire in insects	ANOVA[g]	*Variables:* Harvesting and burning effects.	SPSS	Toivanen et al., 2009
Effects of urbanization on vegetation carbon storage	ANOVA[g] and GIS[e]	*Variables:* Carbon storage, carbon density and maturity of forests.	SPSS and ArcGIS	Ren et al., 2011
Fire effects on forest floor	PCA[c] and ANOVA[g]	Biodiversity *indexes* (Shannon index and Pielou's index) and 11 forest *characteristics.* Three treatments (single-burned, multiple-burned, and unburned controls) and six sampling times.	SAS	Coleman and Rieske, 2006
Fire management	Simulation	Develop a stochastic simulation model (LLM). *Criteria:* Fire, fuel, Longleaf Pine and Hardwoods.	LIDAR, Python and ArcGIS	Loudermilk et al., 2011
Fire risk indices	Correlation analysis and GIS[e]	Meteorological *variables.* Five meteorological forest fire indices.	ArcGIS	Holsten et al., 2013
Influence of forest management on stand structure and genetic diversity	Bayesian Statistics, MCSM[h] and MC[i]	*Variables:* Tree measurement, molecular data, and structure data (dendrometric parameters).	R, Gene Mapper and Programita	Paffetti et al., 2012
Reforestation, prediction of dominant tree volume	ANN[d]	Variables: Dominant tree bole volume, density, altitude, exposure and slope.	SPSS	Diamantopoulou et al., 2009
Spatial aspects of forest structure in fire Review study	Spatial statistics			Larson and Churchill, 2012

Acronyms of Models and Methods: a- LR: Logistic Regression, b- GLM: Generalized linear model, c- PCA: Principal Components Analysis, d- ANN: Artificial Neural Network, e- GIS: Geographic Information System, f- RA: Regression Analysis, g- ANOVA: ANalysis Of Variance, h- MCSM: Monte Carlo Simulation Method, i- MC: Markov Chain

Table 5. Models and Methods in Forest Management DSS classified by approaches

Models and Methods	
Multiple Criteria Decision Making	Analytic Hierarchy Process (AHP), Goal Programming, Multi-Attribute Value (MAV), Multi-Attribute Utility Theory (MAUT), Multi-Attribute Function, Multi-Criteria Analysis (MCA), Preference Ranking Organisation Methods for Enrichment Evaluations (PROMETHEE), Simple Multi-Attribute Rating Technique (SMART), Stochastic Multicriteria Acceptability Analysis (SMAA), Group Decision Making and Voting Techniques
Optimization models	Dynamic Programming (DP), Graph Theory, Heuristics, Linear Programming (LP), Mathematical Programming (MP), Mix Integer Programming (MIP), Non-Linear Programming (NLP) and Optimization (without specific methods)
Simulation models	Dynamic Modeling, Growth Models (GM), Monte Carlo Simulation Method (MCSM), Simulation Models (without specific methods), Risk Model and Yield Models
Statistical methods	Bayesian Method, Data Mining, Fuzzy/Neural System, Least Squared Method, Logistic Regression (LR), Multivariate Model, Regression Analysis (RA), Statistical Models (without specific techniques), Stochastic Models and ANalysis Of VAriance (ANOVA)
Economic models	Cost-Benefit Analysis (CBA), Gap Model, Economic Accounting, Economic Models and Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis
Information Systems	Database Management System (DBMS), Relational Database Management System (RDBMS) and Geographic Information System (GIS)

Table 6. Contingency table of problems by temporal scale and objective dimensions

Temporal Scale		Objective Dimension		Total
		Multiple objectives	Single objective	
Long term (strategic)	*Count/(% Temporal Scale)*	44/(84.6%)	8/(15.4%)	52/(100.0%)
	% Objective Dimension	50.0%	25.0%	43.3%
Medium term (tactical)	*Count/(% Temporal Scale)*	26/(66.7%)	13/(33.3%)	39/(100.0%)
	% Objective Dimension	29.5%	40.6%	32.5%
Short term (operational)	*Count/(% Temporal Scale)*	18/(62.1%)	11/(37.9%)	29/(100.0%)
	% Objective Dimension	20.5%	34.4%	24.2%
Total	*Count/(% Temporal Scale)*	88/(73.3%)	32(26.7%)	120/(100.0%)

Table 7. Contingency table of problems by Decision Making Dimension and Products & Services

Decision Making Dimension		Products & Services		Total
		No	Yes	
More than one decision maker/ stakeholder	*Count/(% Decision Making Dimension)*	17/(32.1%)	36/(67.9%)	53/(100.0%)
	% Products & Services	29.8%	57.1%	44.2%
Single decision maker	*Count/(% Decision Making Dimension)*	40/(59.7%)	27/(40.3%)	67/(100.0%)
	% Products & Services	70.2%	42.9%	55.8%
Total	*Count/(% Decision Making Dimension)*	57/(47.5%)	63/(47.5%)	120/(100.0%)

Table 8. Distribution of DSS by temporal scale of problems and methods in cases and percentage

Problems	Multiple Criteria Decision Making	Optimization	Simulation	Economic Models	Statistics Methods	Information Systems	Total problems
Operational	6	14	14	3	8	24	29
Tactical	13	25	27	10	5	35	39
Strategic	19	32	35	20	6	49	52
Total	38	71	76	33	19	108	120
Percentage%[a]	31.7	59.2	63.2	27.5	15.8	90.0	

a- The percentage is obtained using the total of each column divided by the total problems. As a problem can be solved by more than one method or model the sum of all percentages is not 100.

Table 9. Contingency table of problems by Temporal Scale Dimension and Economic Models

Temporal Scale		Economic models		Total
		No	Yes	
Long term (strategic)	*Count/(% Temporal Scale)*	32/(61.5%)	20/(38.5%)	52/(100.0%)
	% Economic models	36.8%	60.6%	43.3%
Medium term (tactical)	*Count/(% Temporal Scale)*	29/(74.4%)	10/(25.6%)	39/(100.0%)
	% Economic models	33.3%	30.3%	32.5%
Short term (operational)	*Count/(% Temporal Scale)*	26/(89.7%)	3/(10.3%)	29/(100.0%)
	% Economic models	29.9%	9.1%	24.2%
Total	*Count/(% Temporal Scale)*	87/(72.5%)	33(27.5%)	120/(100.0%)

Table 10. Contingency table of problems Only Products Dimension and Information Systems

Only Products		Information Systems		Total
		No	Yes	
No	*Count/(% Products)*	3/(4,4%)	65/(95,6%)	68/(100.0%)
	% Information Systems	25,0%	60,2%	56,7%
Yes	*Count/(% Products)*	9/(17,3%)	43/(82,7%)	52/(100.0%)
	% Information Systems	75,0%	39,8%	43,3%
Total	*Count/(% Products)*	12/(10,0%)	108/(90,0%)	120/(100.0%)

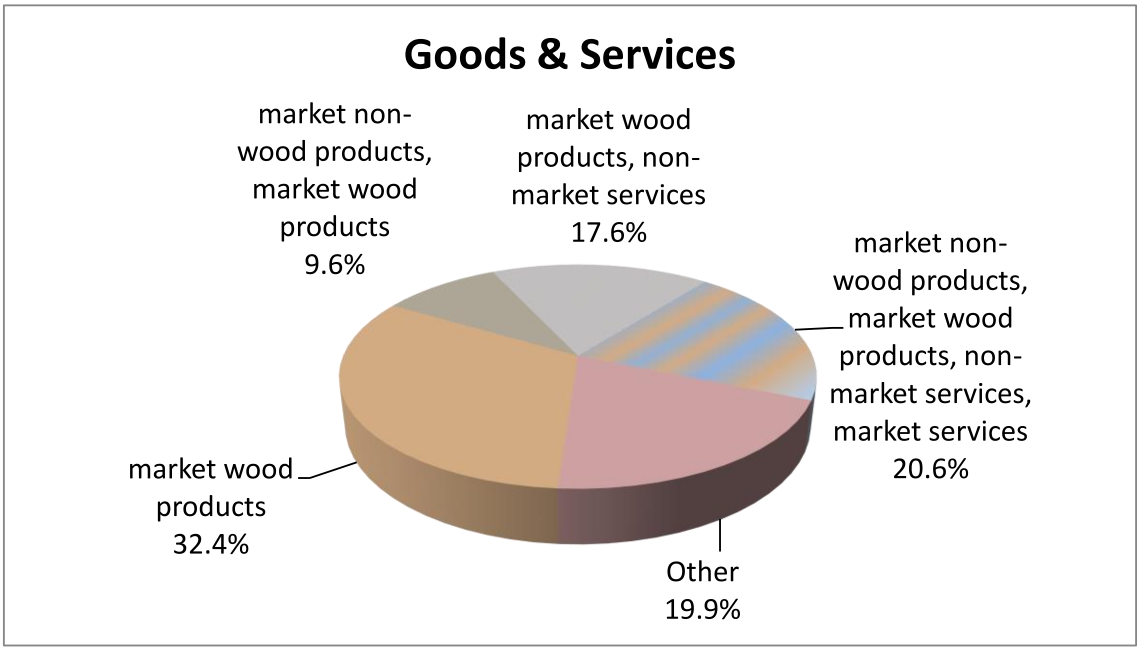

Figure 1. Forest management problems identified in country reports (Borges et al., 2013) classified by goods and services.

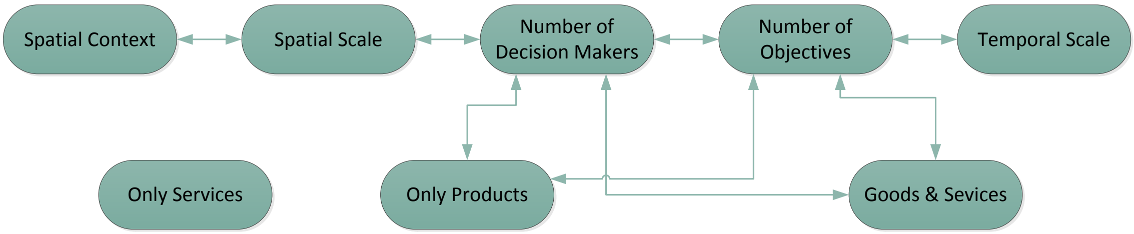

Figure 2. Significant relations between features of problems solved by DSS, shown by links between items, obtained through contingency tables with 5% statistical significance.

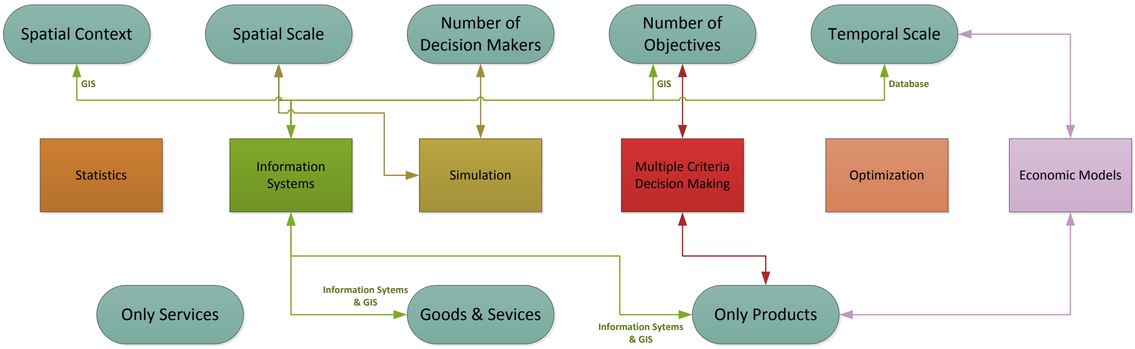

Figure 3. Significant relations between methods (rectangles) and features of problems (ellipses) solved by DSS shown by links between items, obtained through contingency tables with 5% statistical significance.