Catalogue Describing the Fire Vulnerability of Landscape Structures in the Slovak Paradise National Park

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Abstract

The submitted paper presents the proposal of the specific spatial decision support system (SDSS) for the data management, prediction and fire suppression in the wildland-urban interface (W-UI) area of the Slovak Paradise National Park (the experimental site of the WARM project in Slovakia). Except a proposal the presented contribution introduces basic knowledge on SDSS concept, its relation to the Geographic Information System (GIS), describes the process of SDSS building and the basic possibilities of its application.
There are following essential components of the SDSS:

1. The data for the SDSS (the raster digital terrain model with resolution of 25 m, content of specific layers of the basic map of the Slovakia in scale 1:50.000, forest stands description). There are included here also the data about all fire occurrence events during the period of years 1976 – 2000 and climatic and meteorological data. The last group of data contains collected data on the fire defense structures that are localized and described. Here, in this group are also fire risky objects and structures, access communications, obstacles and extremely valuable and vulnerable objects.
2. Information obtained and gathered from the database as the result of the geographical, forestry, transportation and meteorological analyses. The important is especially information concerning geographical, forestry and meteorological conditions under which fire has occurred.
3. Based on mentioned analyses catalogue of the typical fire occurrence situations was designed. The catalogue assumes the following categories of situations: continuous forest cover, transport corridors, agricultural land, agricultural and industrial structures, scattered settlements and continuous urbanized areas of villages. The each particular category was thoroughly documented (by a verbal description and photo documentation), distinguished by the fire relevant parameters and geographically identified and localized.

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The next synthetic results are maps of a fire probability of fire occurrence, flammability of particular structures and maps of distances and accessibility of terrain by road network for purposes of fire suppression. This information serves as the support system of rules for fire occurrence risk and vulnerability description of all assumed structures in the experimental site.

Introduction

Forest fire is not of so strong importance in the temperate zone from the point of view of frequency, extent and losses amount as they are in Mediterranean countries. Nevertheless, it is permanent negative phenomenon also under conditions of Slovakia and it causes big losses particularly considering higher price of forest production. The estimated annual loss approaches the amount of EU 8 000 000. The fire occurrence is frequent especially in the intermediary zone between urban areas and interrelated agricultural and forest land and also in the corridors of transportation routes (mainly railways). Also losses concerning property of any kind are considerably higher under these conditions. There are large areas with the frequent land-use changes here in Slovak Paradise wildland – urban interface (W-UI).

We have choose territory of the Slovak Paradise National Park including northern part of its protecting corridor as the experimental study area (ESA) for W-UI fire research after preliminary analysis of the fire occurrence in Slovakia. This area is situated in the north-eastern part of the Slovak Ore Mountains (Slovenske Rudohorie) and its northern part is created by the Hornad Basin (Hornádska kotlina). The area of ESA is 270 km^2, from which forest is 200 km^2, agricultural land 58 km^2, urbanized areas 7 and other landuse 5 km^2. There is quite lafge forest cover here also with the different types of agricultural crops growing areas, continuous urbanized areas of villages changed by scattered buildings of lodges and other recreational facilities and transportation corridors.

The objective of this paper is to introduce the proposal, process of building and the basic possibilities of application concerning the specific spatial decision support system (SDSS) for the data management, prediction and the fire suppression in the WU-I area of the Slovak Paradise National Park. But, the concept of SDSS is not a simple one. There are different approaches in the definition and possibilities of its building introduced. Typicaly, the SDSS is based on the geographical information system (GIS) and uses its data sources.

GIS provide a powerful and unifying framework for managing many different spatial data sets required in the most planning, design and development activities, too. Further, the GIS allow analysts to conduct simple and complex spatial analyses that transform data into visual information in a map form. Despite these benefits, GIS have not proven to be as useful for supporting the resolution of ill-defined decision problems, characterized by the presence of multiple interest groups and multiple, but sometimes contradictory objectives. To date, commercial GIS software is primarily able to facilitate without substantial macro programming effort less complex decision support tasks, involving only a single decision objective and a single participant.

In recent years, a variety of spatial information systems have been developed. These provide numerous resources upon which an integrated system infrastructure can be developed for more specific orientations including support of complex spatial decision-making.

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Spatial Decision Support Systems

In any problem situation, the decision-making process in rational mode pases through stages of the problem definition, identification of alternatives, their analyses, and evaluations, followed by the prescription of the best alternative as indicated by gathered information. This process is typically characterized by recursive feedback loops in the decision process, where the evaluation and selection criteria are refined and steps repeated as a result of refinement. However, these loops are generally non-systematic and informal.

Theoretical background for decision-making with focus to spatial application could be found in many papers. Very clear and simple are definitions of the basic terms used in this field (decision, criterion, factor, constraint, decision rule, choice function, choice heuristic, objective, evaluation) by EASTMAN et al. (1993). Some authors (FEICK and HALL, 1999) point out the complexity of decision-making process that arises from three sources: multi objective and multi participant context of decisions and their tendency to be poorly defined. The decision-making is then a nonlinear and recursive process that is initiated by a negotiated agreement on the nature of the ill-defined problem under study, the assumption underlying the collection of data, and generation of choice alternatives.

The decision support systems (DSS) are software products that help users apply analytical and scientific methods to a decision-making. They work by using models and algorithms from disciplines such as decision analysis, mathematical programming and optimization, stochastic modeling, simulation and logic modeling (BHAGRAVA, SRIDHAR, HERRICK, 1999). The DSS has six characteristics (DENSHAM, 1991): 1) explicit design to solve ill-structured problems; 2) powerful and easy-to-use user interface; 3) ability to flexibly combine analytical models with data; 4) ability to explore the solution space by building alternatives; 5) capability of supporting a variety of decision-making styles; and 6) allowing interactive and recursive problem-solving.

As an extension of the DSS, the Spatial Decision Support System (SDSS) is a computer-based information system used to support spatial decision-making where it is not possible for an automated system to perform the entire decision process. The intangible factors in the decision making process may be accounted for through information supplied and the choices made by a decision maker who operates the SDSS interactively or operates it through an analyst. In comparison with the DSS, the SDSS needs to: 1) provide mechanisms for the input of spatial data; 2) allow representation of the spatial relations and structures; 3) include the analytical techniques of spatial and geographical analysis, and 4) provide output in a variety of spatial forms, including maps.

Just like the DSS, the SDSS contains four main modules: a data management system, analytical modeling capabilities and analysis procedures, display and report generators, and a user interface. DENSHAM (1991) separates the display generator and the report generator in to two modules and describes the user interface as a module encompassing the other four modules. He also highlights the generating and evaluating alternatives procedure in this interactive, iterative, and participatory process.

By Enache (1994) like DSS, SDSS have three levels of technology: 1) an SDSS toolbox, i.e. a set of hardware and software components that can be assembled to build a variety of system modules; 2) an SDSS generator, i.e. hardware and software modules that can be assembled to build a specific SDSS, and 3) specific SDSS. Densham (1991) also distinguishes five functional roles: 1) the SDSS toolsmith develops new tools for the SDSS toolbox; 2) the technical supporter adds components to the SDSS generator; 3) the SDSS builder assembles modules into specific SDSS; 4) the intermediary sits at a console that interacts physically with the system, while 5) the decision maker is responsible for developing, implementing and managing the adopted solution.

Certain authors look at the expert analyst required to operate the system as posing a barrier to decision-makers who must translate the problem into a form that can be understood by experts who, in turn must translate their understanding of the problem into a form that can be modeled by software. This prevents decision-makers from the direct interacting with a problem and may prevent them from discovering how intermediate decisions affect final outcomes.

Conceptually, a spatial decision support system involves linking the GIS and analytical/decision models to produce systems especially able to cope with spatial problems. It is designed to aid in the exploration, structuring, and solution of complex spatial problems. The aim is to support decision making by employing quantitative approaches with the use of geographic information that is stored in a manipulable form within the GIS. Many authors discussed possibilities of GIS using in spatial decision making, constraints and lacks of the GIS in this field and also role of the GIS as the part of SDSS.

Enache (1994) presents that in a wide sense every GIS application helps a user to make better reasonable decisions. The only problem lies in a missing connection between the GIS as the mean for geographic information management, tools for patterns and context recognition and tools for decision making in a specific sense. According to Keenan (1997), three levels of the GIS usage in a decision-making exist:

1. Traditional GIS application in geology, soil science, natural resources management, urban planning, etc. In this sense GIS are the means that supports better decision because it helps collection, management, analysis, visualization of data and information that are used by a user. It increases the productivity of data processing and thus it enables and provokes the alternative analyses, models, scenarios, etc. The comparison and assessment of their crucial parameters may be directly or indirectly used for decision making. Common transition of the GIS software environments to the Windows platform, development of the database management systems, data and tools portability between applications and multitasking support this trend, too. This approach is still the most common.

2. Utilization of GIS for the solution of specific tasks, e.g. location and allocation problems or network analyses. It is important to point generic spatial nature of such tasks and ability of GIS environment to structure data for them. Especially in case of network analyses the techniques of the operational analyses were very well adapted to the GIS and this positive development is still ongoing.

3. Application of the GIS in the SDSS in a special sense. Apart from the requirement and advantage to use convenient data structure (compare with the second group) there is also a need to use specific methods of decision-making.

This debate is very intensive technologically dependent. Keenan (1997) introduced GIS as a SDSS generator. It would play the same key role in SDSS building as it is known from the DSS building using generator – a mean for model development and data definition (Bhagrava, Sridhar, Herrick 1999) in form of user friendly visual interface. Feick and Hall (1999) introduced two known approaches to the integration of multi criteria analyses tools and GIS – adding these tools into the general purpose GIS

(Idrisi, SPANS) or implementation of these tools and GIS functionality within user friendly, domain specific SDSS environment. Yeh and Qiao (1999) indicate this problem as “modeling inside and outside GIS”. Considering last development (in science and technology too) these authors introduce probably the best look to the discussed problems.

In recent years, a variety of spatial information systems have been developed. These provide numerous resources upon which an integrated system infastructure can be developed. With the support of object-oriented programming (mainly COM programming) and system integration techniques, is possible to propose an integrated SDSS which incorporates the essential functions of GIS, database systems, knowledge based and model management techniques to support overall modeling and decision-making processes. One of the most important techniques proposed in this system is to handle models and associated model knowledge to develop a functional model manager component. It is possible to organize models into a hierarchical structure according to commonality or semantic relatedness on the level of general and the domain model.

SDSS are frequently used in many fields. There were more bibliographies and technological reviews published (Mowrer, 1997). We try to point at least the most interesting articles in forestry an fire suppression, for example of Varma, V., et al. (2000) that describes the methodological components of the SDSS (GIS, techniques of the multicriterial evaluation, linear programming methods) for decision support in sustainable development in forest management. Strange et al. (1999) suggests four levels approach to the evaluation of management alternatives in multi use forest management using GIS, cost surface analyses and linear programming. In Slovak conditions, Fabrika (2000 and 2002) introduced the connection of the growth simulator with forest space information system and Tucek, Suchomel and Pacola (2002) introduced concept of the SDSS for laying out forest road under economic and technological criteria. As an typical example of the using of SDSS for fire suppression purposes we can introduce FireSmart (Sanchez-Guisandez, Cui and Martell, 2002).

Methods

In the preparation phase of SDSS building we carried out analysis of the potential data sources for the ESA territory. On the base of it, we decided to use data in two levels of precision – coarse data with details satisfying to the Basic map of Slovak republic in scale 1:50.000 and raster resolution 25 m and precise data with details satisfying to the Basic map in scale 1:10.000 and raster resolution 10 m or better. In this paper we present analyses based on first set of data.

We have established also database of data about all fire occurrence events during the period of years 1976 – 2000 in the ESA territory. We used records of fire brigades headquarters in Poprad, Spisska Nova Ves and Roznava districts to which this area belongs. Unfortunately, due to the inaccuracy and inconsistency of records we had to reduce number of data used in next analyses.

From the technological point of view, we use the Arc View (ESRI) environment as GIS base for SDSS building. Arc View shape files and dbf tables are used for location and attribute data structuring and saving. Arc View is very common GIS environment used for spatial data management, analysis and visualization with a strong support of its analytical components – Spatial analyst, 3D analyst and Network analyst.

For knowledge base building, decision models preparing and modeling results assessment, we propose to use an EMDS system (Environmental Management Decision Support, USDA Forest Service). EMDS is an application framework for knowledge based decision support of ecological assessment at any geographical scale. The system integrates state-of-art GIS as well as knowledge based reasoning and decision technologies to provide a decision support for substantial portion of the adaptive management process.

EMDS is described as an application framework because it does not come ready to run. Instead, it provides a set of general solution methods for conducting ecological assessment and developing priorities for management activities. User could construct data in form of Arc View themes that enter into an assessment, design the knowledge base that describes how to interpret information of interest in the Assessment environment and he designs a decision model for planning management activities based on results of an assessment. The EMDS integrates the logic engine of Net Weaver to perform landscape evaluations and decision modeling engine of CriterionPlus for evaluating management priorities.

In analyses we used geographical analyses – database queries, overlay, extraction, map algebra tools, surface analyses, distance analyses commonly included to GIS environment complemented by statistical analyses.

Results

There are three essential components of SDSS built up by now – data sources, results of forest fire database analyses – input rules for knowledge base content and catalogue describing the fire vulnerability of landscape structures – typical fire occurrence situations.

Data sources

Data sources consist of basic data, forest and other fire data and fire defense structures and defense related data. Group of basic data is supported by raster digital elevation model, aspect and slope layers with resolution of 25 m. On this base level we use layers of the basic map of Slovak republic (scale 1:50.000) containing administrative boundaries, roads, railways, water bodies and streams, urban areas and scattered settlements. The next very important group of data source is forestry maps and the detailed forest stands descriptions. There are really precise information included to the stand description in Slovakia – tree species composition, age, average height, diameter, volume of trees, crown closure, stand density, growing stock, ground cover and many others.

Forest and other fire data describe all fire occurrence events during the period of years 1976 – 2000 including location, climatic and meteorological data and specific fire defense data. The last group of data contains collected data on the fire defense structures (brigades and equipment, water resources) that are localized and described. Here, in this group are also fire risky objects and structures, access communications, obstacles and extremely valuable and vulnerable objects.

Results of forest fire database analysis – input to knowledge base content

Using different types of geographical and statistical analyses, we tried to found relationships between geographical, forestry and meteorological conditions and probability of fire occurrence which would be possible to use for subsequent knowledge base rules formulation. It is need to note that we have not finished all possible analyses yet. In this paper we could present analyses of forest fire occurrence in relation to the two groups of parameters. First group includes the geographical conditions – altitude, slope and aspect of the terrain, distance from the nearest settlement and nearest road and second one includes forest conditions – tree species composition and age of the stand.

Table 1. Relationship between fire occurrence frequency and altitude

Average altitude of individual fire area, m	Share of fire number in class, %
below 600	23
601 – 700	13
701 – 800	10
801 – 900	10
901 – 1000	25
1001 – 1100	6
1100 – 1200	12
over 1200	1

Table 1 and Table 2 introduces results of the analysis of the forest fire occurrence frequency and altitude and slope respectively. Even though there is an increasing tendency of number of fire occurrence in lowest and also higher parts of territory and on the higher slopes, we do not propose to build any rule from this analysis.

Table 2. Relationship between fire occurrence frequency and slope

Average altitude of individual fire area , o	Share of fire number in class, %
below 5	6
5.1 – 10	19
10.1 – 15	15
15.1 – 20	25
20.1 – 25	25
25.1 – 30	6
over 30	4

Table 3 presents results of the analysis of the forest fire occurrence related to the aspect. There can be seen the clear concentration of the fire occurrence on south-east, south and south-west aspects. 76 percent of fire events occurred on these aspects.

Table 3. Relationship between fire occurrence frequency and aspect (as an azimuth angle from the north)

Average aspect of individual fire area , o	Share of fire number in class, %
below 45	0
45. 1 – 90	12
90. 1 – 135	31
135. 1 – 180	23
180. 1 – 225	10
225. 1 – 270	15
270. 1 – 315	3
over 315	6

Table 4. Relationship between fire occurrence frequency and distance from the nearest urban area including scattered settlements

Average distance of individual fire area , m	Share of fire number in class, %
below 250	17
251 – 500	19
501 – 750	17
751 – 1000	15
1001 – 1250	10
1251 – 1500	8
1501 – 1750	6
1751 - 2000	2
over 2000	6

Table 4 and Table 5 point out results of the analyses of the forest fire occurrence frequency and distance from the nearest settlement or road respectively. The 68 percent of fire has occurred within the distance buffer wide 1000 m around the closest settlement. Similarly, the 68 percent of fire has occurred in the distance buffer wide 200 m around the closest road.

Table 5. Relationship between fire occurrence frequency and distance from nearest road (all types of roads)

Average distance of individual fire area , m	Share of fire number in class, %
below 100	33
101 – 200	35
201 – 300	13
301 – 400	12
401 – 500	4
501 – 600	2
over 600	1

The vulnerability of forest by fire is described by the probabilities p(t) informing about the expected destruction of particular tree species according to their age (t) during a common year. These probabilities were derived from the empirical distribution functions obtained by using data about the burned out areas divided according to the age of destroyed forest stands during the period of years 1991 – 2000. The results of the statistical analysis pointed out very significant ($\alpha = 0.05$) goodness of fit between the empirical distribution functions and corresponding assumed Weibull probability distribution functions F(t):

$$F(t) = 1 - e^{-ct^{\gamma}}$$

Then probabilities p(t) for tree species groups of pine, spruce, larch and broadleaved species were estimated. Tables of probabilities for tree species and age classes were used in GIS environment for calculation of vulnerability of each forest stand in the ESA territory. Vulnerability as a new attribute was included to the database table describing the stand. As a result we produce map – a geographical distribution of fire vulnerability of forest.

The application of Weibull distribution for the purposes of decription concerning the forest land management risk recommended also KOUBA (2002) and KOUBA and KASPAROVA (1989). The importance of description concerning the risk accompaining the forest management is also presented by SISAK and PULKRAB (2001).

It is possible also build up knowledge base network within the Net Weaver environment (part of the EMDS system) for purposes of direct calculation of interactively pointed locations, areas or features – typically forest stands using information layers or/and database tables in Arc View GIS environment. This assessment should be part of the real management situation evaluation or/and proposed composite development (planning) scenarios or alternatives assessment as well. Similarly, knowledge about higher risk of the fire occurrence on south (south-east, south-west) aspects and places close to settlements and roads (200 m and 1000 m buffer zones respectively) allow to use overlay operation for identification of zones with cumulated – very high risk of forest fire occurrence. Both applications are typical examples of specific SDSS using employing also tools of the GIS.

The next synthetic results are maps of the distances from the nearest road, water source and fire brigade location, maps of the terrain accessibility by road network calculated for whole ESA territory for purposes of fire suppression. This information serves as the support system of rules for fire occurrence risk description and vulnerability of all assumed structures in the experimental site.

Catalogue of typical fire occurrence situations

Based on the mentioned analyses the catalogue of typical fire occurrence situations for the ESA territory was designed. The catalogue assumes the following categories of situations: continuous forest cover, transport corridors, agricultural land, agricultural and industrial structures, scattered settlements and continuous urbanized areas of villages.

The each particular category was thoroughly documented (by a verbal description and photo documentation), distinguished by the fire relevant parameters and then geographically identified and localized. In the case of transportation corridors we will use 100 and 200 m wide buffers around railways and roads and in the case of scattered settlements we prepared buffers with radius 500 and 1000 m.

Conclusions

In the presented paper we documented possibility of the specific SDSS building for the data management, prediction and fire suppression in the WU-I area of the Slovak Paradise National Park. As the technological base, we used Arc View GIS, EMDS and related software products. There were prepared sufficient data sources for needs of modeling and new data, information and knowledge derivation. Especially, analysis of forest fire occurrence data offers useful information concerning vulnerability of forest stands calculation. Using of the derived probabilities of fire occurrence according to the stands tree species composition and their age in the GIS environment facilitate to prepare map of forest stands vulnerability for the whole ESA territory. Next important result of the solution is the catalogue describing vulnerability of landscape structures in the ESA territory.

In future, we plan to process most of data layers in more precise level (satisfying to the Basic map in scale 1 : 10 000 and raster resolution 10 m or better) and use the Remote Sensing techniques for information refinement and fulfilling. Implementing of network analyses and surface modeling tools will allow to reach more realistic results in distances and access modeling. Knowledge base building will continue by urban and agriculture fire data analysis and climatic and meteorological data implementing for forest and other kinds of fire. We propose also user interface customization and specific tools for the fire suppression implementing. After this we will start with scenarios building for specific parts of the ESA territory and/or for different management and fire occurrence situations.

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