Modern Approaches in Fuzzy Sets, Intuitionistic Fuzzy Sets, Generalized Nets and Related Topics

Volume II: Applications

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ISBN 83-894-7554-5

Cognitive mapping approach to forest fires management

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Abstract

Nowadays forest fires management cannot be regarded as isolated set of activities, but rather as integral part of sustainable forest management (SFM). It means that all forest management activities including forest fires management should be designed and implemented to cope with complex real-life situations causing minimal damages to other ecosystems and infrastructure. Especially with respect to forest fires risk management, a scientifically based approach regarding fire prevention activities has to be developed. These activities must be negotiated and planned with the interested parties (stakeholders like individuals, groups, farmers, institutions, etc.) in

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Modern Approaches in Fuzzy Sets, Intuitionistic Fuzzy Sets, Generalized Nets and Related Topics. Volume II: Applications *(K.T. Atanassow, W. Homenda, O. Hryniewicz, J. Kacprzyk, M. Krawczak, Z. Nahorski, E. Szmidt, S. Zadrożny, Eds.), IBS PAN - SRI PAS, Warsaw, 2014*

order to successfully fulfil many ecological, economic and social functions. To achieve good coordination among all parties, participatory approaches to sustainable forest management are widely applied as effective tools for analysis and decision support in ill-structured environments. In this paper, we propose a framework for analysis and development of measures targeted at forest fires prevention. Taking into account the intertwining of public and private interests, as well as local, regional, and global trends, more flexible decision support techniques are needed. In order to meet these requirements we make an attempt to apply an extension of the generic model of cognitive map (CM), intuitionistic fuzzy cognitive map (IFCM). The proposed model can help on structuring of complex problems in the area of sustainable forest management thus providing the necessary basis for prevention policies formulation. It may also facilitate the responsible institutions to take the appropriate measures for forest fires prevention.

Keywords: Cognitive map, Forest fires, Intuitionistic fuzzy cognitive map, Intuitionistic fuzzy index matrix, Prevention, Participatory approach.

1 Introduction

Forests are complex ecosystems coexisting with complex social systems. Numerous stakeholders have legitimate rights and interests in using the forest resources yet the distribution of power relations among the involved parties is usually asymmetric. Furthermore, not only the cultural differences and varying roles of the stakeholders in society but also their individual values, preferences, practical experience and knowledge have to be taken into account. These dissimilarities require a combination of various types of knowledge bases (scientific knowledge, expert knowledge and lay knowledge) for the purposes of decision making. On the other hand it is imperative to all of the interested actors to share the costs and benefits of managing the forest by making reasonable trade-offs.

The complexity of forest management is increasing both due to wide spectrum of criteria involved in the decision making process and the manner in which different social groups, organizations and institutions accept the relative weight of specific criteria, usually tailored to their particular or other corporate interests. Moreover, multiple stakeholders in forestry are constantly competing for increasing economic and ecological efficiency. These circumstances create uncertain business environment and make sustainable forest management more complex task. As a result, the decision-making is influenced by many heterogeneous factors. Besides the influences on the decision process, according to [11] every decision made affects criteria of different nature. These criteria and influence factors include not only environmental issues but also economical and social issues as well. In similar situations the hybrid use of multi-criteria decision analysis (MCDA) methods [5] and participatory approaches prove to be more reliable and flexible way for solving forest management problems.

2 Cognitive mapping approach to decision making in forest fires management

Forest fires are an indispensable part of ecosystems evolution as a whole and of forest health in particular. Although wildfires play an important role in maintaining the health of forest ecosystems, they often expose humans, suburban areas, infrastructure, etc. to high risks. In Europe forests are among the most valuable renewable resources. There are 1.02 billion hectares of forest in Europe, which amount to 25 percent of the world total (Forest Europe, 2011). But over recent decades European forests are threatened with a range of hazards, such as environmental pollution, diseases, biodiversity loss, climate change, desertification, changes in land use, etc. Wildfires occur in most regions of the EU and every year burn down on average 500.000 ha of forests and other wooded lands [12, 34]. Furthermore, the forest fire incidence rate (especially in south Europe) is expected to increase over the next decades mainly as a consequence of the socio-economic development and climate change. In order to respond to these frightening trends the EU had funded numerous research projects in the area of forest fires (SPREAD, WARM, FIRE, TORCH, SALTUS, FIRE STAR, FIRE PARADOX, EUROFIRE, EUFIRELAB etc.). Then in the period 2010-2012 the FIRESMART project has been completed. Its main aim was to contribute to the prevention of unwanted forest fires by identifying hindrances and constraints for effective prevention, and by formulation of recommendations focused on integrating fire prevention in sustainable forest management. In the framework of FIRESMART three major clusters of issues have been identified:

- the scientific basis for prevention measures;
- the integration of prevention measures in forest management;
- the institutional roles and legal framework to be addressed.

All of these problems are related to the necessity of scientifically proven and practically validated preventive measures. Being a key function of complex socio-ecological system, forest fires prevention encompasses wide variety of activities carried out by numerous stakeholders with diverse demands. As the complexity of fire prevention tasks increases, the successful accomplishment of those measures strongly implies better preparedness and coordination among the responsible institution involved in the forest fires management at all levels. The increasing complexity also poses challenges both for the legal framework and the decision-making processes. As mentioned above the involvement of multiple stakeholders in forest fires management requires flexible combination of decision support techniques including participatory modelling approaches. In recent years several exhaustive literature reviews have been made with the aim to shed light on different aspects of forest management and the applicable multi criteria decision analysis (MCDA) methods [1, 11, 29, 30, 35]. From the critical reviews, it becomes clear that in the field of sustainable forest management any single decision making method cannot provide reliable solutions. These can be achieved through hybrid use of qualitative and quantitative methods, because hybridized methods are more flexible in uncertain and conflicting situations [37, 38]. Qualitative methods have the capability to support the participation but most of them are used as problem structuring tools. One of the widely applied soft systems methods for problem structuring in ill-defined situations is cognitive mapping (CM). First introduced by R. Axelrod [4], cognitive mapping approach to decision making and the multiple extensions of fuzzy cognitive maps (FCM) [24], have still limited application in the area of sustainable forest management [22, 23, 27, 28, 29, 36, 33] and forest fire modelling [6, 7].

For the purposes of the generalized framework proposed in this paper we make an attempt to use IFCMs [18], a more sophisticated extension of the FCM, as a tool for problem structuring and expert knowledge elicitation method.

3 Short notes on intuitionistic fuzzy sets and intuitionistic fuzzy cognitive maps (IFCM)

The Intuitionistic Fuzzy Pair (IFP) is an object with the form $\langle a, b\rangle$, where $a, b \in [0, 1]$ and $a + b \leq 1$, that is used as an evaluation of some object or process and which components (a and b) are interpreted as degrees of membership and non-membership, or degrees of validity and non-validity, or degree of correctness and non-correctness, etc. One of the geometrical interpretations of the IFPs is shown on Fig. 1.

Let us have a fixed universe E and its subset A. The set

$$A^* = \{\langle x, \mu_A(x), \nu_A(x)\rangle \mid x \in E\},$$

where

$$0 \leq \mu_A(x) + \nu_A(x) \leq 1$$

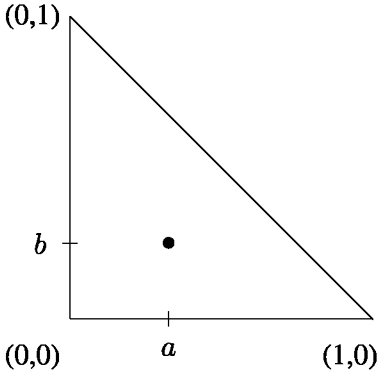

Figure 1: Geometric representation of intuitionistic fuzzy pair

is called an Intuitionistic Fuzzy Set (IFS, see, e.g. [3]) and functions $\mu_A : E \to [0,1]$ and $\nu_A : E \to [0,1]$ represent the *degree of membership (validity, etc.)* and *non-membership (non-validity, etc.)*. Now, we can define also function $\pi_A : E \to [0,1]$ by means of

$$\pi(x) = 1 - \mu(x) - \nu(x)$$

and it corresponds to *degree of indeterminacy (uncertainty, etc.)*.

Below, we write A instead of A^*.

Let $\mathcal{C} = \{C_1, C_2, ..., C_n\}$ be a set of cognitive units and for every i $(i \in \{1, 2, ..., n\})$, $\mu_C(C_i)$ and $\nu_C(C_i)$ are degrees of validity and non-validity of the cognitive unit C_i.

Extending Chen's formal definitions of Fuzzy Cognitive Map (FCM, see [9]), we introduce the concept of an Intuitionistic FCM (IFCM) as the pair

$$IFCM = \langle C, E \rangle,$$

where

$$C = \{\langle C_i, \mu_C(C_i), \nu_C(C_i)\rangle | C_i \in \mathcal{C}\}$$

is an IFS and

$$E = [\mathcal{C}, \mathcal{C}, \{\langle \mu_E(e_{i,j}), \nu_E(e_{i,j})\rangle\}],$$

is an Intuitionistic Fuzzy Index Matrix (IFIM, see [2]) of incidence and for every $i, j \in \{1, 2, ..., n\}$, $\mu_E(e_{i,j})$ and $\nu_E(e_{i,j})$ are degrees of validity and non-validity of the oriented edge between neighbouring nodes $C_i, C_j \in \mathcal{C}$.

4 IFCM as a decision aid in participatory modeling methodologies

This paper is focused on forest fires management as an intrinsic part of sustainable forest management but special emphasis is placed on forest fires prevention. The main aim of our study is to draft a generalized framework able to trace the entire chain of causes for unwanted wildfire incidents, starting from the immediate trigger events up to the legal requirements and social values. That seems to be the only way to implement coherent and consistent preventive measures. To this end we used the risk analysis framework (with its extensions to management factors) proposed by M. E. Pate-Cornell [31, 32] in the form adapted by Donald G. MacGregor [25] for analysis of the fire incidents. The General model of incidence decomposition as given by MacGregor includes four levels of influence (see Fig. 2). It is based on the principle of decomposition which is appropriate for analysis and better understanding of complex systems. The decisions taken at each higher ranking level exert influences on the preceding levels. Thus, laws, statute and cultural values do not belong to the Organizational Level but *Social Meta Decisions* (S_i) influence strongly the entirety of *Organizational Meta Decisions* (O_i), e.g. policies, plans and procedures. The latter constitute the frames for structuring and evaluation of *Decisions ($A_{i,j}$) specific to concrete fire incidents.* And finally, on Outcomes level *Decision outcomes and effects* (E_i) are proximal consequences of fire incident-specific decisions ($A_{i,j}$) and in the same time indirect results of all superior levels. The extension of Pate-Cornell framework to Social/cultural level and the corresponding risk factors reveals further dimensions of causality not obvious at Outcomes Level. In case of forest fire management activities (prevention, presuppression, suppression, and fire use) the analysis of influences and causal relationships between consequent levels of decision making gives the opportunity to better planning and implementation of risk reduction measures.

On the basis of the model [25] we propose generalized framework for forest fires problems structuring and for analysis of preventive measures thereof. The process can be divided in stages as follows:

4.1 Stage 1.Identification and scaling of decision problems

Always when dealing with natural resources management problems we have to take into account their interconnectedness and inherent hierarchical nature which makes the hierarchical decision analysis a prerequisite condition for further actions. The hierarchical analysis also underpins the integration of the economic, ecological and social aspects of the forest management into a decision making

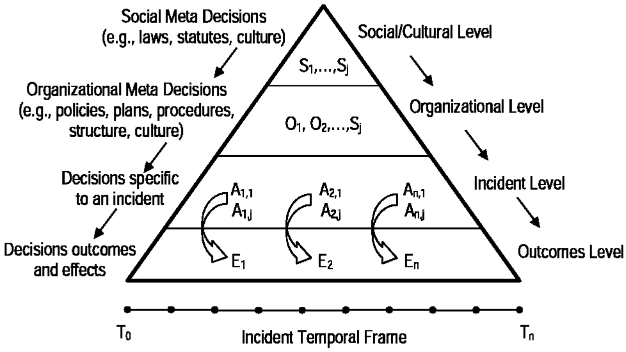

Figure 2: Fire incident decomposition model proposed by MacGregor [25]. Adapted from [32].

process targeted on sustainability. In order to preserve both the consistency between the decision levels and the balanced participation of different stakeholders it is necessary to preliminary determine the scales of the investigated decision problem. This can be supported by the concept of decision problem space (see Fig. 3) introduced in [19].

It is obvious that all three dimensions of the decision-problem space are interdependent. Hence, the basic scales corresponding to each one dimension should be adjusted to every individual problem. If the decision-making process is aimed at achieving sustainability of forest management, Varma et al. [39] have suggested ways to measure sustainability with regard to its spatial (geographical) and temporal dimensions. As already said, to ensure productive participation of various decision makers and stakeholders with mutually contradictory objectives, sometimes can be a hard task. In a similar case the Social Dimension might be enhanced with additional framework, within which would be sought an appropriate grouping of the stakeholders in the decision making process. For instance, such general framework in the field of natural resources management has been proposed in [10], where stakeholders can be grouped into the following categories:

- Consumers: members of the general public;
- Non-governmental organizations (NGOs):
- Management agencies: local, regional and state agencies competent in the area of natural resource management;
- Political stakeholders; appointed or elected representatives of national parliaments, governments, municipalities , local authorities, counties, etc.;

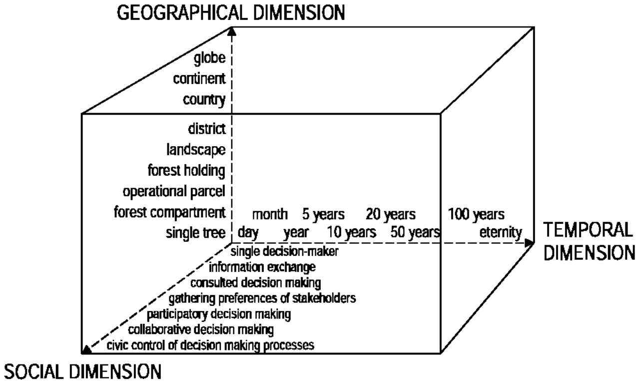

Figure 3: Illustration of three-dimensional decision-problem space (case forestry decisions) according to [19].

- Economic stakeholders: economic entities like farmers, landowners, individual business, business organizations, production plants, chambers of commerce etc.;
- Experts: scientists like agronomists, geologists, biologists, engineers, technical consultants and others who have specialized technical knowledge.

Another division of the interest groups with respect to power given to the participants in the decision-making process [23] subdivides the social dimension into six levels of influence:

- ◦ Informing;
- ◦ Manipulation;
- ◦ Consultation;
- ◦ Collaborative decision making;
- ◦ Delegated power;
- ◦ Total control by participants.

4.2 Stage 2.Construction of IFCM

The construction process of IFCM is similar to those of other extended FCMs [16, 17, 18, 21]. First, after the selection of the stakeholders based on the hierarchical decision analysis they have to build their individual IFCMs, i.e. to determine the conceptual and causal architecture that includes identification of key concepts (factors) and causal relationships among them. The second step, parameterization of individual IFCMs, encompasses construction of linguistic scales, selection of aggregation functions and assignment of intuitionistic fuzzy values to nodes and arcs. Then the aggregated IFCM (group IFCM) should be developed using the operations with IFIM (see, [2]). At each level (See Fig. 2) the risk factors for different forest fire incidents stand for concepts (or factors) in the individual IFCMs. Cultural and behavioural patterns, law provisions, policies, preventive measures and procedures up to fire incident specific decisions must be regarded as risk factors along with the environmental ones. The determination of the concepts and some of the linguistic scales can be supported by the Questionnaire on forest fire prevention in Europe [13] and the Harmonized classification scheme of fire causes in the EU [8].

4.3 Stage 3.Analysis of the aggregated IFCM

At this stage all risk factors are to be ranked according to the criteria for correctness defined in [18].

For every two cognitive units C_i and C_j that are connected with an edge $e_{i,j}$, we can introduce different criteria for correctness, e.g. if C_i is higher than C_j (i.e., $\langle \mu_C(C_i), \nu_C(C_i)\rangle \geq \langle \mu_C(C_j), \nu_C(C_j)\rangle$), then

1 (top-down-max-min)

$$\langle \mu_C(C_i), \nu_C(C_i)\rangle \vee \langle \mu_E(e_{i,j}), \nu_E(e_{i,j})\rangle \geq \langle \mu_C(C_j), \nu_C(C_j)\rangle;$$

2 (top-down-average)

$$\langle \mu_C(C_i), \nu_C(C_i)\rangle @ \langle \mu_E(e_{i,j}), \nu_E(e_{i,j})\rangle \geq \langle \mu_C(C_j), \nu_C(C_j)\rangle;$$

3 (top-down-min-max)

$$\langle \mu_C(C_i), \nu_C(C_i)\rangle \wedge \langle \mu_E(e_{i,j}), \nu_E(e_{i,j})\rangle \geq \langle \mu_C(C_j), \nu_C(C_j)\rangle;$$

4 (down-top-max-min)

$$\langle \mu_C(C_i), \nu_C(C_i)\rangle \wedge \langle \mu_E(e_{i,j}), \nu_E(e_{i,j})\rangle \leq \langle \mu_C(C_j), \nu_C(C_j)\rangle;$$

5 (down-top-average)

$$\langle \mu_C(C_i), \nu_C(C_i)\rangle @ \langle \mu_E(e_{i,j}), \nu_E(e_{i,j})\rangle \leq \langle \mu_C(C_j), \nu_C(C_j)\rangle;$$

6 (down-top-min-max)

$$\langle \mu_C(C_i), \nu_C(C_i) \rangle \vee \langle \mu_E(e_{i,j}), \nu_E(e_{i,j}) \rangle \leq \langle \mu_C(C_j), \nu_C(C_j) \rangle.$$

Other criteria also are possible.

If Cr is some one of the above six, or another criterion for correctness, and if all vertices and arcs of a given IFCM satisfy criterion Cr, then this IFSC is called Cr-correct IFCM.

The validity of the following assertion is checked easily on the basis of the above definitions of correctness.

Theorem. *If the IFCM is:*

a)(top-down-min-max)-correct, then it is (top-down-average)-correct and (top-down-max-min)-correct;

b)(top-down-average)-correct, then it is (top-down-max-min)-correct;

c)(down-top-max-min)-correct, then it is (down-top-average)-correct and (down-top-min-max)-correct;

d)(down-top-average)-correct, then it is (down-top-min-max)-correct.

When the risks of catastrophic fires are to be estimated, Risk Assessment and Management Systems like RAMS model of Humboldt County Fire Safe Council [20] may support the ranking of environmental, socioeconomic and technical risk factors.

On the basis of risk ranking, experts can support the responsible institutions to set priorities and to develop preventive measures for each level of the model. Proposal of amendments to the legislation in force are also possible.

5 Conclusion and future works

Taking into consideration the pivotal role of prevention in risk management we proposed a framework for problem structuring and risk prioritization in forest fire risk management that can be adapted to socio-ecological and socio-technical systems of quite a different nature. The implementation of cognitive mapping approach may be effective on knowledge elicitation and structuring of ill-defined problems in the area of sustainable forest management. In the future after indispensable validation, IFCMs can be integrated in methodologies for analysis and planning of forest management activities.

6 Acknowledgements

The authors are grateful for the support provided by the projects DFNI-I-01/0006 funded by the National Science Fund, Bulgarian Ministry of Education and Science.

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The papers presented in this Volume 2 constitute a collection of contributions, both of a foundational and applied type, by both well-known experts and young researchers in various fields of broadly perceived intelligent systems.

It may be viewed as a result of fruitful discussions held during the Twelfth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2013) organized in Warsaw on October 11, 2013 by the Systems Research Institute, Polish Academy of Sciences, in Warsaw, Poland, Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences in Sofia, Bulgaria, and WIT - Warsaw School of Information Technology in Warsaw, Poland, and co-organized by: the Matej Bel University, Banska Bystrica, Slovakia, Universidad Publica de Navarra, Pamplona, Spain, Universidade de Tras-Os-Montes e Alto Douro, Vila Real, Portugal, Prof. Asen Zlatarov University, Burgas, Bulgaria, and the University of Westminster, Harrow, UK:

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The consecutive International Workshops on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGNs) have been meant to provide a forum for the presentation of new results and for scientific discussion on new developments in foundations and applications of intuitionistic fuzzy sets and generalized nets pioneered by Professor Krassimir T. Atanassov. Other topics related to broadly perceived representation and processing of uncertain and imprecise information and intelligent systems have also been included. The Twelfth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2013) is a continuation of this undertaking, and provides many new ideas and results in the areas concerned.

We hope that a collection of main contributions presented at the Workshop, completed with many papers by leading experts who have not been able to participate, will provide a source of much needed information on recent trends in the topics considered.

ISBN 838947554-5
9 788389 475541