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THE USE OF MATHEMATICAL MODELING FOR DETERMING THE BUDGET OF A FOREST FIRE PREVENTION CAMPAIGN

INTRODUCTION

Forest fires are very common during summer. Many countries have significant financial losses caused by forest fires every year. During 2007-2016, in Serbia were 992 forest fires. Serbia lost 20 399 ha of forest in those wildfires. In total 119 046 m^3 of wood was burnt. If we consider the finantial loss, then we deal with a price of 35 €/m^3 for firewood (cheapest option) to 50 mm wide oak (1000 €/m^3) or beech (400 €/m^3) boards multiplied by the number of m^3 of burnt wood. Besides, there are additional firefighting costs, ground rehabilitation and afforestation costs, too. It is clear that it is worth for the goverment to undertake forest fire prevention campains to decrease the number of forest fires and environmental and finantial losses. Such a campain could include: informing and education of people about the risk factors for forest fire occurence, eduaction of people about forest fire prevention, increasing the number of voluntary fire department members and their education, and the investment in fire exitinguishing equippment, etc.

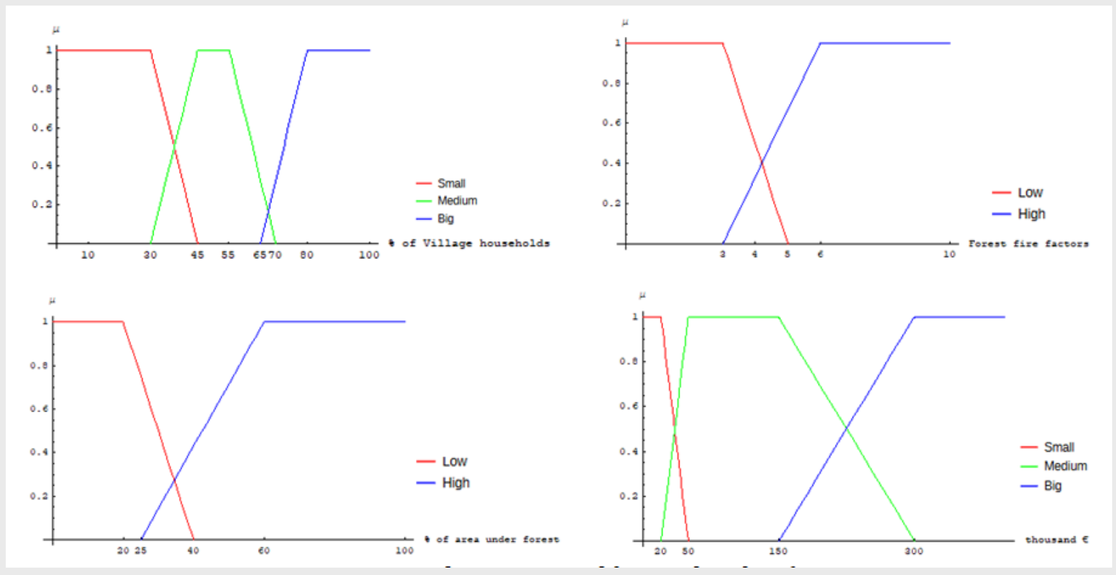
This paper is devoted to the use of Fuzzy Logics in creating a mathematical model for determing the budget of a forest fire prevention campaign which could be undertaken to decrease the financial losses caused by wildfires.

CORE IDEA OF THE RESEARCH

The goal is to determine the campaign budget for the Republic of Serbia using Fuzzy logics if we know the following facts:
% of village households :41
Number of forest fire factors :7
% of area under forest : 27

Fuzzy logics is a generalization of binary logics, which enables that a variable can take a value which is neither true nor false. It is used in analyzing inaccurate systems which use terms like ‘small’ ‘medium’ or a ‘big budget’. Using Fuzzy systems in modeling consists of three phases:

Phase 1 - Fuzzification: Defining Fuzzy sets for linguistic variables and membership functions for Fuzzy stets.



Input and output variable membership functions

The mathematical model is obtained by using the *Wolfram Mathematica* software.

```
In[24]:= fun = y0 + ((y1 - y0) / (x1 - x0)) * (x - x0)

In[25]:= f = fun /. {x0 → 30, y0 → 1, x1 → 45, y1 → 0}

In[26]:= small = Plot[Which[x ≤ 30, 1, x ≥ 30, f], {x, 0, 45}, AxesLabel -> {"% of Village households", "μ"}, PlotStyle → RGBColor[1, 0, 0],
          Ticks → {{10, 20, 30, 45}, Automatic}];

In[27]:= g = fun /. {x0 → 30, y0 → 0, x1 → 45, y1 → 1}

In[28]:= h = fun /. {x0 → 55, y0 → 1, x1 → 70, y1 → 0}

In[29]:= medium = Plot[Which[x < 45, g, (x ≥ 45) && (x ≤ 55), 1, x > 55, h], {x, 30, 70}, AxesLabel -> {"% of Village households", "μ"},
          PlotStyle → RGBColor[0, 1, 0], Ticks → {{20, 30, 40, 50, 60}, Automatic}];

In[30]:= l = fun /. {x0 → 65, y0 → 0, x1 → 80, y1 → 1}

In[31]:= big = Plot[Which[x ≤ 80, 1, x > 80, 1], {x, 65, 100}, AxesLabel -> {"% of village households", "μ"}, PlotStyle → RGBColor[0, 0, 1],
          Ticks → {{55, 100}, Automatic}];

In[32]:= Show[small, medium, big, Ticks → {{10, 30, 45, 55, 65, 70, 80, 100}, Automatic}]
```

A peace of code used for obtaining the membership function graphics

```
membership_small = f /. x → 41 // N

0.266667

membership_medium = g /. x → 41 // N

0.733333
```

A peace of code used for obtaining the membership function values for the given input data

This gives the following membership function values:
% of village households : [0.26(small) ; 0.73(medium) ; 0 (big)]
Number of forest fire factors :7 [0 (low); 1 (high)]
% of area under forest : [0.65 (low) ; 0.057 (high)]

Phase 2 - Fuzzy inference: consists in defining Fuzzy rules according to the knowledge in the observed area. Such rules are in the *If-Then* form. Based on this rules, we define Fuzzy output values of variables.

No.	% of village households	Number of forest fire factors	% of area under forest	Budget
1.	Small	low	low	small
2.	small	low	high	small
3.	small	high	low	small
4.	small	high	high	medium
5.	medium	low	low	small
6.	medium	low	high	medium
7.	medium	high	low	medium
8.	medium	high	high	big
9.	big	low	low	medium
10.	big	low	high	big
11.	big	high	low	big
12.	big	high	high	big

Fuzzy Rules of the model

There are four Fuzzy rules that devote to our case: 3,4, 7 and 8. The given rules consist of a conjunction of three conditions, so we take the minimum of the three membership function values of the variables.

Rule 3: small budget 0.26 ∧ 1 ∧ 0.65 = 0.26
Rule 4: medium budget 0.26 ∧ 1 ∧0.057 = 0.057
Rule 7: medium budget 0.73 ∧ 1 ∧ 0.65 = 0.65
Rule 8: big budget 0.73 ∧ 1 ∧ 0.057 = 0.057

Since we have two rules which give a medium budget, we have to determine the disjunction of the two values: Medium budget: 0.057 ∨ 0.65 = 0.65.

Now we have the following values of all three variables:
Small budget: 0.26
Medium budget: 0.65
Big budget: 0.057

Phase 3 - deffuzification : consists in obtaining numerical output data from the system by using following formulae

$$Budget = \frac{\sum[MV_i \cdot FMV_i]}{\sum[MV_i]},$$

```
In[21]:= budget = (20 * 0.26 + 100 * 0.65 + 300 * 0.057) / (0.26 + 0.65 + 0.057) // N
Out[21]= 90.2792

In[22]:= Round[%]
Out[22]= 90
```

The code for calculating the ouput value - deffuzification step

where:
MV_i- the membership coefficient of the i-th conclusion, (i=1,…,N, N is the number of conclusions)
FMV_i- the representative value of the i-th conclusion. For Z, S and TR shapes of the membership functions, the value at the boundary with the complete membership of the set is taken, while in the case of the T shape of the membership function, we take the average value of all values with the full membership of the set. For example, the membership function of ‘small budget’ is Z shaped, ‘medium budget’ is T shaped, whereas ‘big budget’ is S shaped.

Conclusion: The desired budget is approximately 90 000€.

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