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Clearcutting as a forest fire prevention measure. A generalized net model

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Abstract: A generalized net model is described that determines the trajectory of a clearcutting in a forest where a wildfire is occurring.
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1 Introduction

The presented Generalized Net (GN, see [4]) model aims to collect and process information about a variety of available characteristics of a burning forest fire, and to offer an advise about the optimal characteristics of forest clearcuttings as a fire prevention measure. Clearcutting is one of the possible approaches in fire fighting, specifically applicable to forest fires, and it represents controlled deforestation preventing further fire spread and keeping it within the boundaries of certain affected territory.

Clearcuttings have different metric characteristics like lenght, width, distance from the fire front, but it should not be neglected that producing a forest clearcutting with certain set of metric characteriistics also takes certain amount of time. In the meanwhile, the fire's characteristics may have substantially changed, possibly diminishing the efficiency of the clearcutting, or making it completely inadequate and useless, or even more hazardous.

For this reason, the constructed GN model can be run in multiple parallel simulations, using different probable sets of parameters of the forest fire and the clearcutting. This can facilitate the decision maker about optimal set of metric characteristics of the clearcutting that is to be produced.

On the inputs of the GN model, there enter tokens charged with initial and interim dynamically changing parameters of the fire and the environment. There are several characteristics that may dynamically change in parallel, mutually affecting each other, which justifies the need to use generalized nets rather than other consecutive approaches. These dynamically changing parameters of the fire and the environment include, but are not restricted to: current location of the fire front, speed and direction of wind. Other parameters of the environment may not change as rapidly as others, for instance density and type of the burning material (timber, bushes, grass, etc.), and characteristics of the terrain.

As an output of the model, the particular characteristics of the clearcutting, made to prevent the further expansion of the wildfire, are determined by some existing functional formulas that include as parameters the time passed, the characteristics of the terrain, the density and type of the burning material, the speed and direction of wind.

There are a lot of normative documents that regulate fire fighting activities (e.g., some of Bulgarian documents [1, 2, 3]).

2 GN model

The GN-model contains 8 transitions, 21 places and 4 types of tokens (see Fig. 1).

Tokens $\alpha_1, \alpha_2, ...$ enter place l_1 with an initial characteristic

$$x_0^{\alpha_i} = \text{"fire coordinates, reported by an observer"}.$$

Tokens $\beta_1, \beta_2, ...$ enter place l_4 with an initial characteristic

$$x_0^{\beta_i} = \text{"current direction of the wind received from the nearest meteorological station"}.$$

Below, for brevity, we omit indices of the α- and β-tokens.

Token γ stays permanently in place l_3 with initial and current characteristic

$$x_0^{\gamma} = \text{"DB with information about the terrain of the fire site"}.$$

Token δ stays permanently in place l_8 with initial and current characteristic

$$x_0^{\delta} = \text{"DB with formulas for the speed of fire spread"}.$$

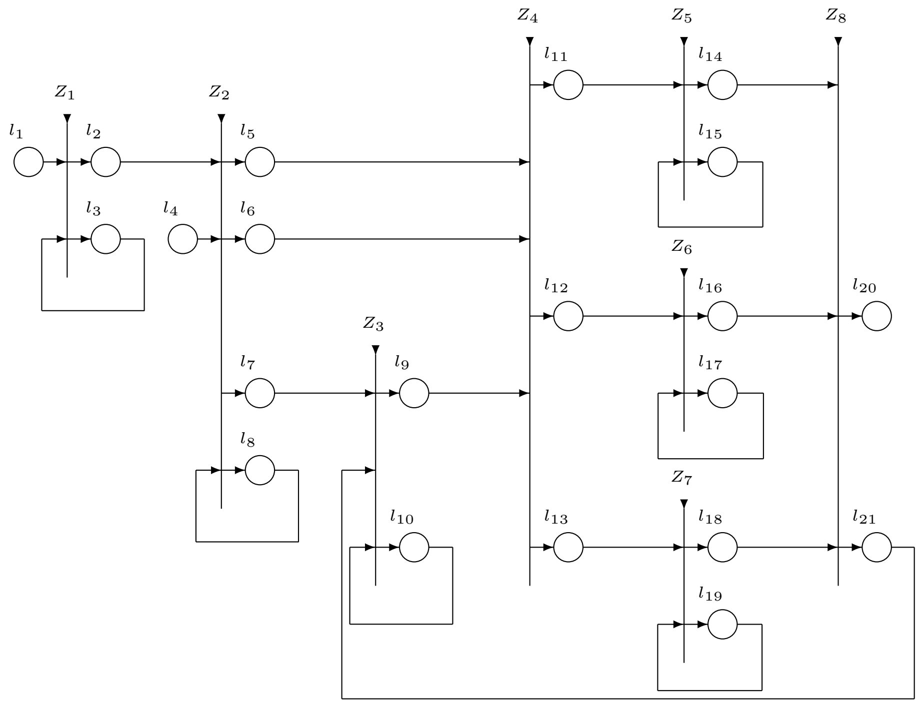

Figure 1.

The GN-transitions have the following forms.

$$Z_1 = \langle \{l_1, l_3\}, \{l_2, l_3\}, \begin{array}{c|cc} & l_2 & l_3 \\ \hline l_1 & true & false \\ l_3 & false & true \end{array} \rangle.$$

Token α enters place l_2 with a new characteristic "information about the fire-site".

$$Z_2 = \langle \{l_2, l_4, l_8\}, \{l_5, l_6, l_7, l_8\}, \begin{array}{c|cccc} & l_5 & l_6 & l_7 & l_8 \\ \hline l_2 & true & true & false & false \\ l_4 & false & false & true & false \\ l_8 & false & false & false & true \end{array} \rangle.$$

Token α splits to two tokens α' and α'' that enter places l_5 and l_6 with a characteristics "estimation of the forest territory" and "optimistic, average and pessimistic estimations of the distance of the clearcutting and its direction", respectively.

Here, we can use the formulas for figure surfaces, discussed in [7]. In the present case, they can give Intuitionistic Fuzzy (IF, see, e.g., [6]) estimations as for the forest territory, as well as the degrees of validity, non-validity and uncertainty of these IF estimations.

Token β enters place l_7 without a new characteristic.

$$Z_3 = \langle \{l_7, l_{10}, l_{21}\}, \{l_9, l_{10}\}, \begin{array}{c|cc} & l_9 & l_{10} \\ \hline l_7 & false & true \\ l_{10} & true & false \\ l_{21} & false & true \end{array} \rangle.$$

Token β from place l_4 or token β from place l_{21}, enters place l_{10} with a characteristic "map of the fire territory for the current time-moment".

Each token β from place l_{10} enters place l_9 with a characteristic "estimation of the territory affected by the fire for the current time-moment".

The above mentioned formulas are also applicable for obtaining the IF estimations of the territory affected by the fire.

Each of the tokens α', α'' and β splits to three copies that enter places l_{11}, l_{12} and l_{13}, where they unite with tokens ω_1, ω_2 and ω_3 that stay in the three places (one token in one place), keeping all previous characteristics of the tokens that have generated them and getting the new characteristic "estimation of the speed of burning of the separate parts of the forest territory".

We must mention that in a series of papers the Game Method for Modelling (GMM, see [5]) is used for modelling of fire development of a forest (see [8, 9, 10, 11, 12, 13]). The GMM gives the possibility to easily simulate different situations and in the present case, to search suitable places, where the clearcutting to be constructed with the aim to prevent fire spread. There are formulas determining the distance between the affected region and the place, where a clearcutting can be constructed. We will discuss these formulas in a next research in details, giving IF-estimations for them. Here, in transitions Z_5, Z_6 and Z_7, we only use the fact that these formulas can give the minimal, average and maximal distances between the fire and clearcutting. Its trajectory is suitable, if the fire reaches the clearcutting after its accomplishment, i.e., the fire cannot continue its spread behand the clearcutting. If the fire goes behind the clearcutting, then its location has not been suitable selected. The aim of parallel simulation of the GMM-problems, solved in separate parts of the GN-model is to determine which of the three distances (minimal, average or maximal) is simultaneously the nearest to the fire and the most efficient one.

For $i = 1, 2, 3$, the transitions Z_5, Z_6, Z_7 have the forms:

$$Z_{4+i} = \langle \{l_{10+i}, l_{13+2i}\}, \{l_{12+2i}, l_{13+2i}\}, \begin{array}{c|cc} & l_{12+2i} & l_{13+2i} \\ \hline l_{10+i} & false & true \\ l_{13+2i} & W_{13+2i,12+2i} & W_{13+2i,13+2i} \end{array} \rangle,$$

where

- $W_{13+2i,12+2i} =$ "the GMM-procedure is finished",
- $W_{13+2i,13+2i} = \neg W_{13+2i,12+2i}$,

where $\neg P$ is the negation of predicate P.

Token ω_i enters place l_{13+2i} with a characteristic "the current step of the GMM-procedure, working on the data from the current token characteristic, obtained in place l_{10+i}" and place l_{12+2i} with a characteristic

$$\begin{cases} \text{"the clearcutting is suitable"}, & \text{if in the GMM-configuration the fire cannot reach} \\ & \text{behind the current clearcutting and it is the one} \\ & \text{nearest to the fire site} \\ \text{"the clearcutting is not suitable"}, & \text{if in the GMM-configuration the fire reaches} \\ & \text{behind the current clearcutting} \end{cases}.$$

$$Z_8 = \langle \{l_{14}, l_{16}, l_{18}\}, \{l_{20}, l_{21}\}, \begin{array}{c|cc} & l_{20} & l_{21} \\ \hline l_{14} & W_{14,20} & W_{14,21} \\ l_{16} & W_{16,20} & W_{16,21} \\ l_{18} & W_{18,20} & W_{18,21} \end{array}, \rangle.$$

where

- $W_{14,20} = W_{16,20} = W_{18,20} =$"the three GMM-processes finish and the suitable trajectory of the clearcutting is determined",
- $W_{14,21} = W_{16,21} = W_{18,21} = \neg W_{14,20}$.

When predicate $W_{14,20} = true$, the three ω-tokens enter place L_{20} where they unite in one ω-token with the characteristic "the trajectory of the clearcutting".

When predicate $W_{14,21} = true$, the three ω-tokens enter place L_{21} where they unite in one β-token without any new characteristic.

3 Conclusion

In addition, for each simulated set of fire's and clearcutting's parameters, the generalized net model can be further extended with a new contour of GN tokens, to produce a rough economic analysis of the adequacy of this kind of fire prevention measure. Since clearcutting basically represents controlled deforestation, the economic analysis would help the decision maker estimate the profits and losses of applying that measure or avoiding it in preference of other fire prevention measures.

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