A Fuzzy Logic Model for Assessment of Socio–Economical Consequences for Household in Case of Power Outage due to Natural Disasters

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Abstract. The paper proposes a fuzzy logic model for level assessment of the negative socio–economical consequences to the household and each of its members in case of power cuts due to natural disasters. The appropriate preventive activities are proposed to help to reduce the vulnerability and to increase the preparedness against the negative impact of power cuts on households. The fuzzy logic model is designed as a three-level hierarchical system with four inputs and one output. The system is designed in Matlab computer environment using Fuzzy Logic Toolbox. The designed fuzzy logic model is part of the Cloud Integrated Information System for risk management of natural disasters, which are developed.

1. Introduction

In recent years, there has been an increase in the number of extreme weather related disasters throughout the world. Natural disasters have become the primary threats for the continuity of electricity service in Europe and in the rest of the world [1]. The electricity has now become a vital part of modern societies. The electrical equipment is involved in every aspect of people’s lives. Therefore, the power outage severely disturbs the normal course of daily activities [2]. It is useful for every household to have more information about level of the potential negative socio–economical consequences in case of power cuts due to natural disasters [3]–[5]. This is especially important in case of natural disasters characterized by extreme temperatures [6], [7]. Therefore, each household should plan and implement appropriate vulnerability reduction activities according to the type of expected extreme temperatures, whether they are extremely high or extremely low [8]–[11]. It should be noted that the level of negative socio–economical consequences for the household depends strongly on the duration of the power cut in extreme temperature conditions. There are various qualitative and quantitative methods for assessment of negative socio–economical consequences in case of power cuts. However, there are not enough methods to take into account the subjective perception of the household and each of its members about the level of negative consequences in case in case of power cuts due to natural disasters [12]. The intelligent methods are an appropriate tool for assessment of these negative consequences. These methods using the fuzzy logic theory provide adequate processing of the expert knowledge and uncertain quantitative data [13]. The concept of the fuzzy logic is proposed by Zadeh in 1965 [14]. It is developed around the basic idea of so-called fuzzy sets or membership function. Fuzzy set theory is regarded as an extension of classical set theory. It enables the processing of imprecise information by means of membership functions, in contrast to Boolean transformations. Usually the membership...
functions is assigned 0 to false values and 1 to true ones, but fuzzy logic also allows in-between values [15].

The aim of this paper is to propose a fuzzy logic model for level assessment of the negative socio-
economical consequences to the household and each of its members in case of power cuts due to
natural disasters. The appropriate preventive activities are proposed to help to reduce the vulnerability
and to increase the preparedness against the negative impact of power cuts on households.

2. A Three-level Hierarchical Fuzzy System for Assessment of Negative Socio–Economical
Consequences for Household in Case of Power Outage

The general idea of this research is to propose on fuzzy logic model for assessment of socio–
economical consequences for the whole household or individual household member, which may occur
during power outage due to natural disasters.

Here, the fuzzy logic model is designed as a three-level hierarchical system with four inputs and one
output. The system inputs correspond to the linguistic variables (indicators), which described four
types negative consequences (negative effects) by reason of household power outage. The system
output represents an assessment of negative socio–economical consequences for household or its
members in case of power outage due to natural disasters.

The each system level of the designed system includes one fuzzy logic subsystem with two inputs and
one output. The output of the third subsystem is output of the designed fuzzy logic system. A scheme
of this three-level hierarchical fuzzy system is presented on Figure 1.

![Figure 1. Three-level hierarchical fuzzy system.](image)

Those four input variables of the designed fuzzy logic system are defined using the expert knowledge
and research studies related to various types of household members, as follow:

- **Input 1** “Negative effects on domestic activities”: Inability to use all electrical appliances to carry out
  household daily activities related to the normal operation and maintenance of the house - cleaning,
  ironing, washing, cooking, etc.; Difficulties caused by lack or reduced lighting; Blocking access to
  private cars that are located in garages with electrical power supply and remote control.
- **Input 2** “Negative effects on ICT activity”: Interruption of all information sources - internet connection,
  radio and television channels; Difficulty in using home phone; Inability to use mobile phones after
  exhausting of batteries if there is no extra charger, etc.
- **Input 3** “Negative physical and psychological consequences”: Difficulties in daily work obligations,
  stress and moral damages of household members, etc.
- **Input 4** “Indirect economic costs”: Spoilage of food products after defrosting refrigerators and freezers
  for prolonged power outage; Wasting the batteries of the alarm system, Unforeseen future payments
  related to the incurred (example, damages in various serving systems), etc.

Two intermediate linguistic variables are defined in the design of the model as follows:

- **Intermediate variable 1** “Negative effects on daily activity”;
- **Intermediate variable 2** “Negative social consequences”.

These two intermediate variables are the outputs of the first and second subsystems respectively.
In proposed model, the inputs of the first fuzzy logic subsystem are Input 1 “Negative effects on domestic activities” and Input 2 “Negative effects on ICT activity”, and the output variable is the Intermediate variable 1 “Negative effects on daily activity”. The inputs of the second fuzzy logic subsystem are Intermediate variable 1 “Negative effects on daily activity” and Input 3 “Negative physical and psychological consequences”, and the output variable is the Intermediate variable 2 “Negative social consequences”. The inputs of the third fuzzy logic subsystem are Intermediate variable 2 “Negative social consequences” and Input 4 “Indirect economic costs”. The output of this fuzzy subsystem is output of the whole fuzzy logic system. The linguistic output variable is defined as “Negative socio-economical consequences”.

Here, the value of this output variable gives an assessment for the level of the “Negative socio-economical consequences” for household or its members in case of power outage due to natural disasters. The higher value of the level corresponds to greater severity of the negative socio-economical consequences.

It has to be emphasized that each estimated level of consequences refers to a certain time interval of power outage. It is logical to have different levels for the negative socio-economical consequences for periods of 3, 9, 12, 24 hours. Nevertheless, there is a direct positive correlation between the level of the consequences and the duration of the time-free interval. This dependence is not necessarily linear. Direct economic costs in cases of a sudden power outage of the household normally associated destruction or damage to the various electrical devices (some of which are very expensive). These direct costs can be very high compared to other costs of the household or some individual members. Generally, the direct costs can be objectively calculated without taking into account the subjectivity and personal attitude of the individual members of the household to the electrical devices compared to other costs as Indirect economic costs and Social cost. For this reason, the proposed fuzzy logic model does not include the Direct economic costs.

3. Design of Fuzzy Logic Model for Assessment of Socio–Economical Consequences for Household in Case of Power Outage

In proposed fuzzy logic model the input linguistic variables (four indicators and two intermediate) are represented by three fuzzy membership functions: “Low”, “Middle”, and “High”. The all input variables are assessed in the interval [0, 10] using trapezoid membership functions. The fuzzy logic system output (Negative socio-economical consequences) is described by five fuzzy membership functions: “Very low”, “Low”, “Middle”, “High”, and “Very high”. The level of negative socio-economical consequences is assessed in the interval [0, 100] using triangular membership functions. The input and output membership functions are shown on Figures 2-3.

![Figure 2. Membership functions of the input variables.](image)

![Figure 3. Membership functions of the fuzzy system output.](image)

The inference rules in the fuzzy logic system and subsystem are defined through “IF - THEN”-clause. Rule numbers of the knowledge base per each of the fuzzy logic subsystems are 9. Some of the inference rules are defined as follow:

IF “Negative effects on domestic activities” are “Low” and “Negative effects on ICT activity” are “High” THEN “Negative effects on daily activity” are “Middle”;
IF “Negative effects on domestic activities” are “High” and “Negative effects on ICT activity” are “Middle” THEN “Negative effects on daily activity” are “Middle”;
IF “Negative effects on daily activity” are “Low” and “Radius of turn” are “Middle” THEN “Intermediate variable 2” are “Low”;
IF “Negative effects on daily activity” are “Middle” and “Negative physical and psychological consequences” are “High” THEN “Negative social consequences” are “Middle”;
IF “Negative effects on daily activity” are “High” and “Negative physical and psychological consequences” are “Middle” THEN “Negative social consequences” are “High”;

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IF “Negative social consequences” are “Low” and “Indirect economic costs” are “Low” THEN “Negative socio-economic consequences” are “Very low”;
IF “Negative social consequences” are “Low” and “Indirect economic costs” are “High” THEN “Negative socio-economic consequences” are “Middle”;
IF “Negative social consequences” are “High” and “Indirect economic costs” are “High” THEN “Negative socio-economic consequences” are “Very high”.

The hierarchical fuzzy logic system is designed in Matlab computer environment using Fuzzy Logic Toolbox [16]. The output of the fuzzy logic model is calculated as a weighted average of all the inference rules, which are defined in the fuzzy logic matrix. The fuzzy logic system is based on Mamdani’s inference machines, max/min operations and center of gravity defuzzification. The inference surfaces in 3D for the three fuzzy logic subsystem with two input variable and one output fuzzy model are shown on Figures 4-6. The logic inference matrix of each fuzzy logic subsystem are given in Tables 1-3, respectively.

![Figure 4. Surfaces of the Fuzzy logic subsystem 1.](image1.png)

![Figure 5. Surfaces of the Fuzzy logic subsystem 2.](image2.png)
Figure 6. Surfaces of the Fuzzy logic subsystem 3.

**Table 1.** The logic inference matrix for “Negative effects on daily activity”.

| Input 1 | Input 2 | Low | Middle | High |
|---------|---------|-----|--------|------|
| Low     | Low     | Low | Middle |      |
| Middle  | Middle  | Middle | Middle |      |
| High    | Middle  | High | High   |      |

**Table 2.** The logic inference matrix for “Negative social consequences”.

| Intermediate variable 1 | Input 3 | Low | Middle | High |
|-------------------------|---------|-----|--------|------|
| Low                     | Low     | Middle | Middle |      |
| Middle                  | Low     | Middle | High |      |
| High                    | Middle  | Middle | High |      |

**Table 3.** The logic inference matrix for “Negative socio-economic consequences”.

| Intermediate variable 2 | Input 4 | Low | Middle | High |
|-------------------------|---------|-----|--------|------|
| Low                     | Very low | Low | Middle |      |
| Middle                  | Low     | Middle | High |      |
| High                    | Middle  | High | Very high |      |

The interval [0, 100] of the system output variable “Negative socio-economic consequences” is divided into five parts to assessment the level of the negative social-economic consequences for household or its members because of power outage due to natural disasters:

IF the estimated output value $\in [0, 20]$ THEN Negative socio-economic consequences are Very low.
IF the estimated output value $\in [20, 40)$ THEN Negative socio-economic consequences are Low.
IF the estimated output value $\in [40, 60)$ THEN Negative socio-economic consequences are Middle.
IF the estimated output value $\in [60, 80)$ THEN Negative socio-economic consequences are High.
IF the estimated output value $\in [80, 100]$ THEN Negative socio-economic consequences are Very high.

4. Activities to Reduce the Vulnerability of Households to Power Outage in Case of Power Outage due to Natural Disasters
4.1. Availability of a Generator
Owning a generator (a portable generator) is a key element in reducing the vulnerability of the household to power outage due to natural disasters (for example, extreme high and low temperatures). The generator enables basic electrical appliances to remain switched on. It can keep works of the lights, heating system, refrigerators, TV, modem, mobile devices, and other electrical appliances. It keeps also the sump pump running to reduce basement flooding during strong precipitation and storms [17].

The generator is necessary to testing and preparing for emergencies time to time. Safety should always come first and for this reason, the household needs to follow a few safety measures when operating a portable generator. Always it is necessary a carbon monoxide (CO) alarm to been turned on. The generator has to use only outside, never uses it indoors or in any enclosed area. The generator’s exhaust has to keep away from windows, doors, or any air leaks i order to avoid the risk of carbon monoxide gas entering in house.

4.2. Availability of Emergency Heating Equipment and Fuel
In seasons with low temperatures under conditions of prolonged power failure, the household is advised to have additional heating equipment and fuel (a gas fireplace, a cooker or a fireplace) in order to maintain at least one heated room. In such cases, it is important this room will be well ventilated. During natural disaster as storms or windy weather, the household needs to check for hot air leaks from windows and doors. Then, if necessary, it does a special isolation, which gives extra heat protection.

It is very useful for the household to have alternative sources of energy as solar, wind or water energy

4.3. Availability of Flashlights and Extra Batteries
Every household should have flashlights on batteries and extra batteries in case of power outage. It is also advisable to have a portable radio in the house. The radio is an important source of weather and emergency information during natural disasters.

4.4. Additional Useful Activities, if for Long Period the Power Outage is Expected
The cell phones and any battery powered devices must been charged. It is useful the household to own a cell phone with an emergency charging option (car, solar, hand crank, etc.) in case of a power failure. If a power outage is 3 hours or less, you need not be concerned about losing your perishable foods. For prolonged power outages, the household can take useful activities to minimize food loss. In advance, the household should turn on refrigerator and freezer to their coldest settings. During power outage, the refrigerator or freezer door do not open. Most food requiring refrigeration can be kept safely in a closed refrigerator for several hours. An unopened refrigerator will keep food cold for about 4 hours. A full freezer will keep the temperature for about 48 hours. Also it can be filled a gallon container with water and place them in the freezer to help keep food cold. The household can buy special cooling bags.

If a person has medications that require refrigeration, he must to check with pharmacist for guidance on proper storage during an extended power outage.

It is necessary to review the process for manually operating an electric garage door.

The households should have an alternative to the house's electric security alarm.

The households should purchase ice or freeze water-filled plastic containers to help keep food cold during a temporary power outage.

Each household should insure your house against natural disasters, including the subsequent power outage.

5. Conclusion
A fuzzy logic model for level assessment of the negative socio-economical consequences to the household and each of its members in case of power cuts due to natural disasters is designed. The fuzzy logic model is designed as a hierarchical system with four inputs and one output in Matlab software environment using Fuzzy Logic Toolbox and Simulink. The four inputs are “Negative effects on domestic activities”, “Negative effects on ICT activity”, “Negative physical and psychological
consequences” and “Indirect economic costs”. The two intermediate variables are defined “Negative effects on daily activity” and “Negative social consequences”. The fuzzy logic system output gives information for level of Negative socio-economical consequences consequences to the household and each of its members in case of power cuts due to natural disasters. The appropriate preventive activities are proposed to help to reduce the vulnerability and to increase the preparedness against the negative impact of power cuts on households.

6. References

[1] Schmidthaler M, J Reichl, J Cohen 2014 Assessing the Socio-Economic Effects of Power outages in the European Union Ad Hoc Using www.blackoutsimulator.com, CIRED Workshop - Rome, 11-12 June 2014, Paper 0486.

[2] Anderson S., 2016 School Power Outages Mean More than Canceled Classes, Last updated on September 23, 2016, http://www.powerprotectionresource.com/articles/425439-school-power-outages-mean-more-than-canceled-classes.htm

[3] What You Need to Know When the Power Goes out Unexpectedly, https://www.cdc.gov/disasters/poweroutage/needtoknow.html

[4] Power Outage, Disaster Survival Resources, 2017, http://www.disaster-survival-resources.com/

[5] Massachusetts Emergency Management Agency (MEMA) 2006 Winter Power Outage Tips, www.mass.gov/mema. http://emergency.tufts.edu/weather/winter-power-outage-tips/

[6] Snowstorms & Extreme Cold, America’s PrepareAthon!, https://www.ready.gov/winter-weather

[7] Klinger C, Landeg O, Murray V. 2014 Power Outages, Extreme Events and Health: a Systematic Review of the Literature from 2011-2012. PLOS Currents Disasters, http://currents.plos.org/disasters/article/power-outages-extreme-events-and-health-a-systematic-review-of-the-literature-from-2011-2012/

[8] Prepare Your Home for Winter Weather, Page last updated: December 20, 2016, https://www.cdc.gov/disasters/winter/beforestorm/preparehome.html

[9] Heatilator, September 2015 Prepare Your Home with this Power Outage Checklist, http://www.heatilator.com

[10] Generator Mag Blog 2017 Prepare for a Power Outage Checklist, Last updated on October 12th, 2017, https://www.generatormag.com/prepare-for-a-power-outage-checklist/

[11] Power Outage Checklist 2009, BeRedCrossReady, American National Red Cross, RedCross.org

[12] Martin Cerny 2013 Economic and Social Costs of Power Outages, Charles University Prague, Faculty of Social Study, Thesis.

[13] Zlateva P, V Velev 2013 Complex risk analysis of natural hazards through fuzzy logic. Journal of Advanced Management Science, 1 (4), pp 395-400.

[14] Zadeh L 1965 Fuzzy sets. Information and Control 8, pp 338–353.

[15] Zimmerman H 1996 Fuzzy set theory and its applications. Kluwer Academic Publishers, Norwell MA, USA.

[16] Sivanandam S, S Sumathi, S Deepa 2007. Introduction to Fuzzy Logic using MATLAB. Berlin, Springer pp 277–320.

[17] Generator Mag Blog. Prepare for a Power Outage Checklist 2017 https://www.generatormag.com/prepare-for-a-power-outage-checklist/, Last updated on October 12th, 2017.

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