Analysis of the Grenfell Tower fire with Bayesian Networks

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Summary and Key Finding

Key Findings OpenCossan toolbox for Bayesian network allowed to analyse the Grenfell Tower fire by modelling the main components, hazards and factors that contributed to disaster. The developed model has allowed to study the following aspects:

1. **The highest influence factor for fire containment and fire escalation prevention.**
2. **Fire containment probability at Grenfell Tower conditions compared to standard building circumstances.**
3. **Human reaction conduct depending on the fire time occurrence.**
4. **Probabilistic-based risk report generated from outcomes obtained.**

The findings on the study take into account the uncertainty associated to the main variables involved in the Grenfell Tower fire from a probabilistic approach. Firstly, to raise awareness of the dangers of fires in buildings, and; secondly, to point out the key factors for fire contained and human reaction to fire occurrence.

Figure 1: Image of the Grenfell Tower fire during the early morning of 14 June 2017 Grenfell2018

1 Problem Description

1.1 The Grenfell Tower fire

The fire occurred on the 14^{th} June 2017 at the Grenfell Tower in West London (see Figure **??**) attracted considerable national and international attention. Due to the magnitude and the amount of media following the incident, numerous comments and opinions were pronounced trying to identify the causes of such tragedy. Several of the conclusions found lack of strong support due to the vagueness of the data analyses (if any), or the application of mathematical methods that do not take into account the complexity of such structure and its interaction with the fire phenomenon.

The Grenfell Tower Inquiry began on 14 September 2017 to investigate the causes of the fire as well as other related issues. An independent review of building regulations and fire safety was published on 17 May 2018, Hackitt2017 classifying the Grenfell Tower as a higher risk residential building due to the conditions of the infrastructure. It was published that the rapid spread of the fire was due to the building's exterior cladding. Such material is widespread used in residential buildings and it is 14 times higher combustibility level than that legally allowed, according to French authorities Reed2017.

2 Analysis

To raise awareness of the dangers of fires in buildings we proposed an analysis of the causes of the Grenfell Tower using Bayesian Network toolbox in OpenCossan Tolo2017$_AES.Themainpurposeistoshowhowthedifferentvariablesin$

The method allows using data from different sources like, police reports, experts elicitation (e.g. fire fighter head department) and historical records. The probabilistic information is put inside the so known Conditional Probability Tables and the network is generated with the Bayesian network toolbox of OpenCossan Patelli2015COSSAN,PatelliUNCECOMP2017.

2.1 Implementation

The present analysis has been performed using OpenCossan 2.0 [5, 2, 1]

The structure to built the Bayesian network model on OpenCossan is shown in Figure 2. The toolbox allows to work also with continuous distribution variables as well as with discrete variables [3]. New information can be input (evidence) and obtain as output the Marginal and/or Joint probabilities of the queried variables.

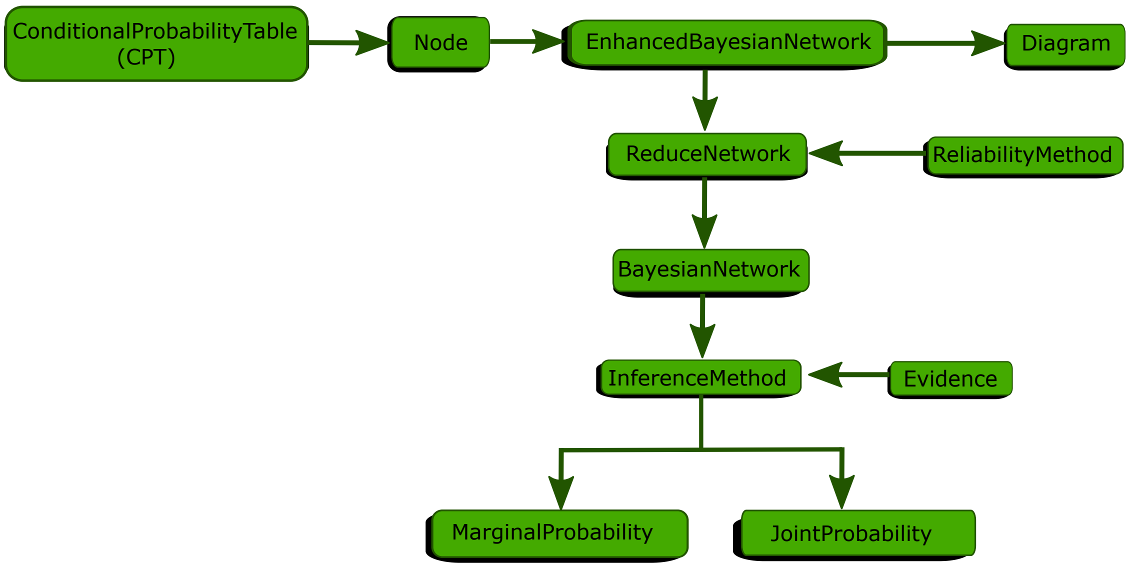

Figure 2: Bayesian network work-flow

An example of the code implementation can be observed in the Figure 3. The Object-oriented format of Matlab grants the advantage of creating each of the components in the network (e.g., nodes) by only redefining the values of a needed object. This, takes out of the map the requirement of coding from scratch.

```
%% Enanched Bayesian Network
% Example Grenfell Tower fire
% Author: Hector Diego Estrada Lugo - University of Liverpool

% Import libraries
import opencossan.bayesiannetwork.*
import opencossan.common.inputs.*

%% Define node of the Bayesian Network
% Define CPT
CPD_Human_Escalations{1,1}=0.038; CPD_Human_Escalations{1,2}=0.962;
% Node24: Human_Escalations (state 1= occurred; state 2= not occurred)
CXnodes{1,n}=Node('Sname','Human_Escalations','CPD',...
    CPD_Human_Escalations,'Stype','discrete',...
    'Nsize',2,'Lroot', true);
%% Define Enanched Bayesian Network
XFire=EnhancedBayesianNetwork('Sdescription','BN Fire','CXnodes',CXnodes);
% Visualize Network
XFire.makeGraph
%% Evaluate the network
% Compute probability of internal escalations event
Marginal_BNT=XFire.computeInference('CSmarginal',{'Internal_Escalations'},...
    'Lbnt',true,'Salgorithm','Variable Elimination');
%% What if analysis
% Insert evidense
XFire.Cevidence{strcmp(XFire.CSnames,'Gas_Pipline_Escalations')}=1;
% Compute probability of events internal escalations and gas pipeline
BNT_Evidence=XFire.computeInference(...
    'CSmarginal',{'Internal_Escalations','Gas_Pipeline_Escalations'});
```

Figure 3: Coding example of a Bayesian network in OpenCossan

2.2 Results

A Bayesian network containing nodes representing variables related to known possible general causes of a fire in a building, e.g., electric circuit fault, lightning, external fire, smoking, etc. Fire-escalation section collects the ways fire can escalate in the building structure both, internally and externally. The actions taken and the efficiency of the firefighters are considered on the group variables related to the Firefighting actions. In addition, the safety conditions, e.g., fire doors, fire alarms, etc., are put in the group of variables related to safety conditions. The graphical representation of the system obtained in OpenCossan is shown in Figure 4.

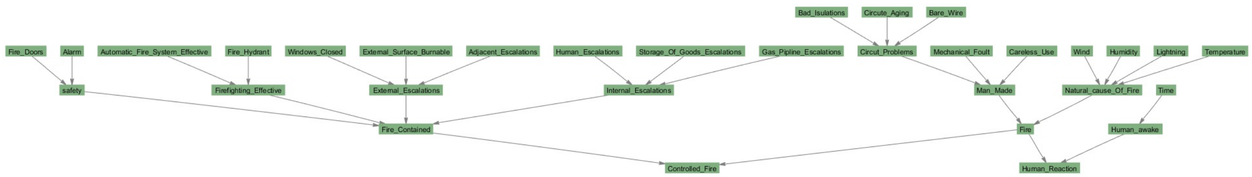

Figure 4: Bayesian network for the Grenfell Tower fire

The model can accept new information in the form of evidence which allows performing What if analyses. As part of these analyses, the model permits comparison of two different scenarios: fire containment in standard conditions and in Grenfell Tower conditions. After inserting the evidence found for the Grenfell Tower fire event in the network, it was found that the probability of containing a fire of such magnitude decreased from 80.73 % to 58.16% (compared to the standard building) due the poor safety conditions of the tower (Figure 5). This conclusion meets the report claiming that the Grenfell Tower failed safety checks on a number of occasions Reed2017.

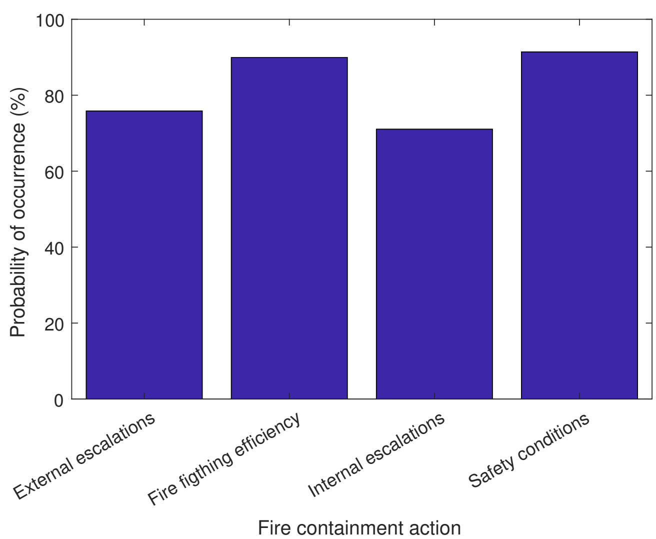

Figure 5: Overall analysis of the main groups of variables in the network.

Moreover, another What if study shows that the probability of human reaction towards fire occurrence in two different scenarios (human awake, human sleep) is reduced by 7.8% when is asleep, compared to being awake Figure 6.

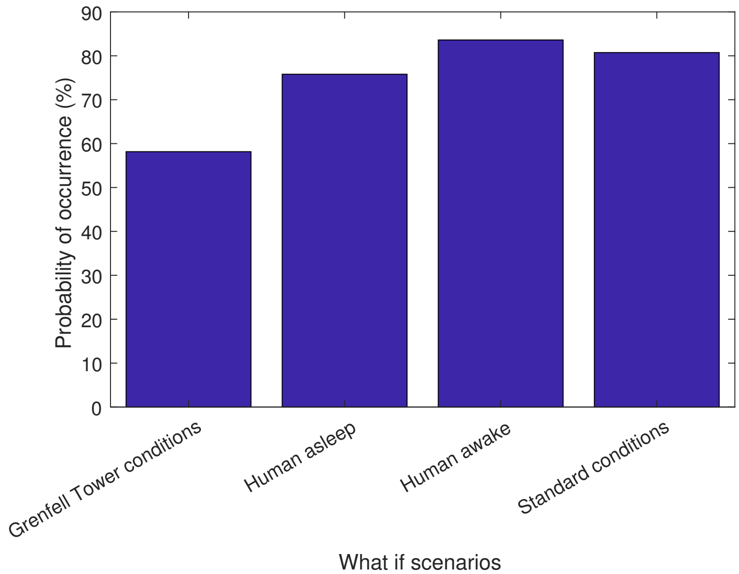

Figure 6: What if analysis results.

From this particular case study it can be observed that the toolbox is useful to integrate a complex arrangement and produce probabilistic results that can be further use by decision makers to take a more informed choice. The results show that safety conditions have the highest influence when it comes to fire containment. Meanwhile, the Internal Escalations variable is the one with less influence in the particular case of the Grenfell Tower.

Further details of the analysis and the methodologies adopted are available in [6, 4]

References

[1] Edoardo Patelli. “Handbook of Uncertainty Quantification”. In: ed. by Roger Ghanem, David Higdon, and Houman Owhadi. Cham: Springer International Publishing, 2016. Chap. COSSAN: A Multidisciplinary Software Suite for Uncertainty Quantification and Risk Management, pp. 1–69. ISBN: 978-3-319-11259-6. DOI: 10.1007/978-3-319-11259-6_59-1.

[2] Edoardo Patelli et al. “COSSAN software a multidisciplinary and collaborative software for uncertainty quantication”. In: *2nd International Conference on Uncertainty Quantification in Computational Sciences and Engineering*. Vol. Eccomas Proceedia ID: 5364. 2017, pp. 212–224. DOI: https://doi.org/10.7712/120217.5364.16982.

[3] Silvia Tolo, Edoardo Patelli, and Michael Beer. “An open toolbox for the reduction, inference computation and sensitivity analysis of Credal Networks”. In: *Advances in Engineering Software* (2017). ISSN: 0965-9978. DOI: https://doi.org/10.1016/j.advengsoft.2017.09.003. URL: http://www.sciencedirect.com/science/article/pii/S0965997816303015.

[4] Hector Diego Estrada-Lugo et al. “Bayesian networks with imprecise datasets: Application to oscillating water column”. In: *Safety and Reliability fffdfffdfffd Safe Societies in a Changing World*. Ed. by Stein Haugen et al. Vol. Proceedings of ESREL 2018, June 17-21, 2018, Trondheim, Norway. London: CRC Press., 2018, pp. 2531–2537.

[5] Edoardo Patelli et al. “OpenCossan 2.0: an efficient computational toolbox for risk, reliability and resilience analysis”. In: *Proceedings of the joint ICVRAM ISUMA UNCERTAINTIES conference*. 2018. URL: http://icvramisuma2018.org/cd/web/PDF/ICVRAMISUMA2018-0022.PDF.

[6] Hector Diego Estrada-Lugo, Marco de Angelis, and Edoardo Patelli. “Probabilistic risk assessment of fire occurrence in residentialbuildings: Application to the Grenfell Tower”. In: *13th International Conference on Applications of Statistics and Probability in Civil Engineering, ICASP13Seoul, South Korea, May 26-30, 2019*. 2019.