Reliability Engineering and System Safety 114 (2013) 75–91

Contents lists available at SciVerse ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

Modelling dwelling fire development and occupancy escape using Bayesian network

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ARTICLE INFO

Article history:
Received 3 October 2012
Received in revised form
7 January 2013
Accepted 9 January 2013
Available online 24 January 2013

Keywords:
Bayesian network
Dwellings
Human reaction
Fire growth/flashover
State of the occupant

ABSTRACT

The concept of probabilistic modelling under uncertainty within the context of fire and rescue through the application of the Bayesian network (BN) technique is presented in this paper. BNs are capable of dealing with uncertainty in data, a common issue within fire incidents, and can be adapted to represent various fire scenarios. A BN model has been built to study fire development within generic dwellings up to an advanced fire situation. The model is presented in two parts: part I deals with ‘‘initial fire development’’ and part II ‘‘occupant response and further fire development’’. Likelihoods are assessed for states of human reaction, fire growth, and occupant survival. Case studies demonstrate how the model functions and provide evidence that it could be used for safety assessment, planning and accident investigation. Discussion is undertaken on how the model could be further developed to investigate specific areas of interest affecting dwelling fire outcomes.

1. Introduction

In this paper, a Bayesian network (BN) model is presented to investigate the development of fires within dwellings and assess the probability of the associated consequences. A ‘dwelling’ can be defined as a house which is used solely for living in; it excludes any make-shift shelters, caravans, or buildings.

Managing fire safety within society is immensely complex due to the sheer number of different environments or situations that exist. Not only are there diverse types of locations, for example factories, warehouses, high rise buildings, dwellings, etc., but there are also many different circumstances within each type of location. In dwellings for example, variations will arise in terms of fire safety arrangements, geographical location relative to fire stations, characteristics of occupants, activities of occupants, characteristics of dwelling, culture among others. Should a fire occur, each incident will be unique in terms of the type of fire, time of the day, state of occupants, fire cues, etc. What all these variations signify is that the development of the next fire event and the magnitude of its consequences are generally unpredictable. The upshot of these complications is that a high degree of uncertainty is often attached to the management of fire safety, in particular within housing communities.

Fire statistics indicate that dwelling fires result by far in the greatest number of fatalities when compared to other types of locations across the UK [15]. Fatalities primarily result from being overcome by fire gases, or heat exposure and burns. The causes which actually lead to such tragedies are numerous. During nighttime fires for instance, many people do not awaken at all or in time to escape from the dwelling. This may be because of an absence of a smoke alarm, a non-operative smoke alarm, the occupant being intoxicated and not reacting to sounds, the physical condition of the occupant, or reasons relating to the characteristics of the dwelling. For cases when fire cues succeed in producing early warnings, occupant survival will likely be influenced by the decisions a person might take.

Fire risk assessment is undeniably a complex task due to the multiple variables and potential outcomes that must be examined in a holistic manner. Reasoning and decision making regarding what fire prevention and mitigating measures to reinforce, are often undertaken with a degree of uncertainty. In order to diminish some of this uncertainty and improve confidence in fire safety decision making, this paper presents a two-part BN. The first part of the model examines the early stages of a fire focusing on human reaction to fire cues; the second part of the model addresses, among other things, the follow-up actions an occupant may take in responding to the situation, as well as the intervention of the fire and rescue service (FRS). The model is designed for application in the UK but may be tailored for other locations should relevant data be obtained. The purpose of the study is to model the sequence of events which may occur during a fire at

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http://dx.doi.org/10.1016/j.ress.2013.01.001

a given location, and to examine the critical variables that intervene in human reaction, fire growth, and survival. Several case studies are presented in the paper to demonstrate how the model works and to investigate particular fire scenarios.

2. Background

2.1. Characteristics of dwellings fires

Dwelling fires are a significant focus of FRS activity both in response and prevention/education. Arguably the two main problems with dwellings are the constitution of the contents and the behaviour of people within. The latter of these is difficult to predict yet alone manage, and is briefly discussed towards the end of Section 2.5. Certain information will however be known about the former. Dwellings are typically filled with items that burn easily and relatively quickly such as furniture, carpets, fabrics, various sources of plastics, etc. Many of the items contained in a room will give out highly toxic fumes when burnt and hence are one of the principal causes of death. These materials are located in what are essentially enclosed compartments with one or two exits. The floor area is relatively small in comparison to the amount of material generally present.

The rate of growth of fire is another important factor which will affect the probability of survival of occupants. The British Standards Institution [4,51] has produced figures of typical fire growth rates for different sites (Table 1). The data is given in Mega Watts (MW) which is a measure of the heat release rate; a value of 1 is typical of a fully developed sofa fire. The fire growth rate for dwellings is relatively average compared to the other locations.

2.2. Fire fatality numbers in the UK

Fires in the UK cause around 300 fatalities and 9000 injures per year [15]. Fig. 1 provides a time-series of fire fatalities and dwelling fire fatalities in which a downward trend can be appreciated, with both data sets having fallen by *circa* 55% between 1996 and 2010. A third data set representing the 'number of dwelling fires per fatality' is also shown on the chart. This provides an indication of how many fires need to occur before a fatality is registered. The data has been plotted towards the bottom of Fig. 1; it shows a slight increase between the years 1996 and 2000, from which point there is little change. This indicates that the probability of surviving a dwelling fire should it occur has remained relatively constant between 2000 and 2010; this is backed-up by a forth series (right *y*-axis) representing the percentage of dwelling fires leading to a fatality, which remains relatively constant at approximately 0.7% over the time period. In 2010 dwelling fires represented just 16% of all fires however dwelling fire fatalities accounted for 79% of total fire fatalities. These statistics indicate that although fire safety has generally improved with time, significant work remains to be done on reducing the impact of dwelling fires when they do occur.

Table 1
Typical fire growth rates at various sites.

Occupancy	Time (s) to reach 1 MW	Fire growth rate
Picture gallery	600	Slow
Offices	300	Medium
Dwellings	300	Medium
Shops	150	Fast
Industrial storage	75	Ultra fast

Source: Adapted from British Standards Institution [4].

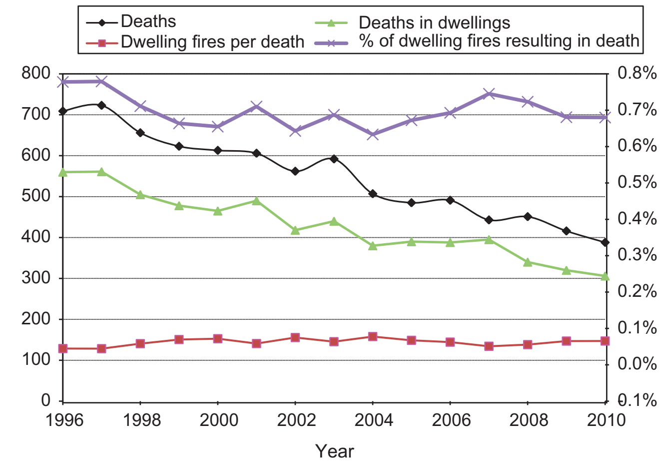

Fig. 1. Number of fire fatalities, number of dwelling fires per fatality, and percentage of dwelling fires leading to fatality in the UK.
Source: Adapted from Communities and Local Government [9,11,13,15].

2.3. Fire mitigation

It is virtually impossible to stop fires from occurring. Consequently part of fire safety is being prepared to deal with such a situation. There are various passive and active fire protection measures which can be taken to reduce the impact of a fire. In dwellings passive fire protection might include the installation of fire doors, having fire resistant upholstery, installing an emergency escape ladder, and so forth. Active measures would include alarms (smoke and heat), sprinklers systems, and fire extinguishers. The impact from fire can also be reduced by people knowing how to react to a fire; essentially people must take the decision to escape, but they must also know which way to escape and have a 'plan B' should their escape route be blocked. People may also need to think what to do in case children are present, which phone to use to call the emergency services, and so forth.

The majority of dwellings in the UK have at least one smoke detector installed; the problem faced by FRSs is educating people not to tamper with the devices and replace the batteries when needed. Similarly the majority of new homes today are built with doors that provide a degree of fire resistance; however the issue with these is that occupants nearly always keep the doors permanently open [33]. The most effective fire response measure for a dwelling is a sprinkler system; the problem in this instance is the elevated cost and impracticality of installation in existing dwellings. Very few homes in the UK have sprinkler systems and this is unlikely to change.

2.4. Fire and rescue service response

Aspects of the model developed in this research assess the impact FRSs have when they arrive at a fire scene. The response times established in the model are based on the response standards provided by Merseyside fire and rescue services (MFRS), who have collaborated in this research. Distribution of fire stations, appliances and personnel are planned by MFRS according to levels of risk established for areas of similar population within Merseyside. These areas are known as lower layer super output area (LSOA) and are actually part of a nationally established distribution of similar sized population areas with fixed boundaries on which various measurements and data collection programmes are undertaken. MFRS's risk methodology assigns either a "High", "Medium", or "Low" level of risk to each