URBAN UTILITY IGNITION MODEL, A PROBABILISTIC APPROACH FOR MODELLING FIRE FOLLOWING EARTHQUAKE

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ABSTRACT:

This paper presents the methodology proposed for modelling ignitions caused by urban utility network following earthquakes. In this model ignition following earthquake is modelled probabilistically, being dependent on several parameters such as strong ground motions, volume of utility network, type of gas pipeline, type of power network and urban building density. In order to consider uncertainties associated with the parameters controlling urban utility ignitions, an analytical approach using logic tree and Monte Carlo simulation process is proposed here. A GIS-based computer program has been also designed and developed in this work which can estimate ignition probability for urban utility network following earthquakes. As a pilot study, the utility network for a city district in northern Tehran, the capital city of Iran is modelled in this work. Preliminary results for a scenario earthquake as well as probabilistic earthquake scenarios are shown in this paper.

KEYWORDS: Fire, Earthquake, Ignition, Urban, Utility, Probabilistic

1. INTRODUTION

Experiences from past earthquakes showed that urban utilities are among city infrastructures damaged by earthquakes. These facilities are vulnerable to most seismic hazards such as fault rupturing, liquefaction, landslide and above all strong ground motions. Excessive damages to certain utilities can themselves pose secondary hazards, examples are flooding, electrification, environmental pollution, etc. Fire Following Earthquake is major threat for cities with high pressured natural gas distribution network or air-drawn electrical transfer and distribution network. During an earthquake such systems can cause ignitions and generate wide spread fire following big earthquakes. Flammable materials such as automobile fuels, trees and even road asphalt, once exposed to such ignitions, can turn into big fires. Fire Following Earthquake (FFE) consists of many simultaneous and catastrophic fires which could result in widespread economic damages and loss of life. Example of such historical cases is the 1906 San Francisco Earthquake with destructive consequences. More recent examples are the 1994 Northridge and the 1995 Kobe Earthquakes.

Like other fire pattern, the FFE process consists of three main phases; ignition, spread and suppression. With regard to FFE hazard and risk modelling, most of researches in recent years have focused on modelling fire spread modelling and less attention is paid to modelling the sources of ignitions. Statistical correlations made between strong ground motion and ignition frequencies are mostly used as a mean to simulate this phase of an FFE model. Mizuno et al (1978) developed the first IFE models based on statistical analyses of FFE damage data from earthquakes in Japan. Scawthorn (1986) followed this approach and expanded this concept to develop probabilistic post-earthquake fire ignition and spreading model. Such models have been used to study the FFE pattern in jurisdictional scale and to estimate the aggregated economic FFE-related losses on regional scales. FFE damage data obtained from US earthquakes in twentieth century are used to model ignition mean rate as a function of seismic intensity and urban population density. Eidinger (2005) investigated the effects of gas distribution network on ignition following earthquakes. He stated that 26% of ignitions following Northridge earthquakes happened because of damages to gas distribution network. The studies carried out by Trifunace and Todorovaska (1998) related the number of ignitions following 1994 Northridge earthquake to MMI, number of breakages in water pipe lines, number of red-tagged buildings, peak ground velocity (PGV) and soil classes. They proposed several empirical relationships for such dependencies. Some studies later tried to involve other effective parameters controlling different types of IFE. For example, using statistical data, Tokyo Fire Department developed some curves which show the ignition mean rates as functions of PGA. These curves are based on buildings occupancy, building materials and earthquake occurrence time and date. Williamson and Groner (2000) conducted a research on FFE ignitions associated with the natural gas and power distribution systems. Their research also showed high ignition susceptibility rates for old and crowded buildings.

Computer loss models have been widely developed and used by many disciplines in recent years. FFE loss modelling has been also considered as one of the components for such catastrophe loss models. The approaches used for modelling ignition following earthquakes in most of such loss models are based on statistical data obtained from past earthquakes, ignoring many of the effective parameters controlling IFE. Such models also fail to distinguish between sources of intra-structure ignitions from those caused by urban utility network. Zolfaghari *et al* 2008 made an attempt to analytically model intra-structure ignitions following earthquakes using a probabilistic approach. This paper attempts to present similar approach for estimating ignition potential from urban utility network.

2. 3. URBAN IGNITION FOLLOWING EARTHQUAKE

This study proposes and tests an analytical approach to model ignition potential for urban utility network following earthquakes, using probabilistic algorithm to model sources of uncertainties. Figure 1 summarizes the major components of an ignition following earthquake model, with emphasize on sources of urban utility ignitions. Earthquake hazards such as strong ground motions, liquefaction, faulting and landslide could result in disruptions and damages to buildings and lifeline systems. In the same way, such hazards and their consequences are the triggering events for ignitions and fires following earthquakes. A damaged building or disrupted urban system with ignitable materials such timber structure or gas pipeline, in the vicinity of spark sources such as damaged power line or bare flame, are highly susceptible source for ignition. Damages to urban utility system such as under-pressure gas network and overhead power lines and installations could cause outdoor ignition on streets and public open spaces. Such ignitions in the vicinity of fuel sources, such as automobile petroleum, trees and even road asphalt may turn into huge and destructive fires.

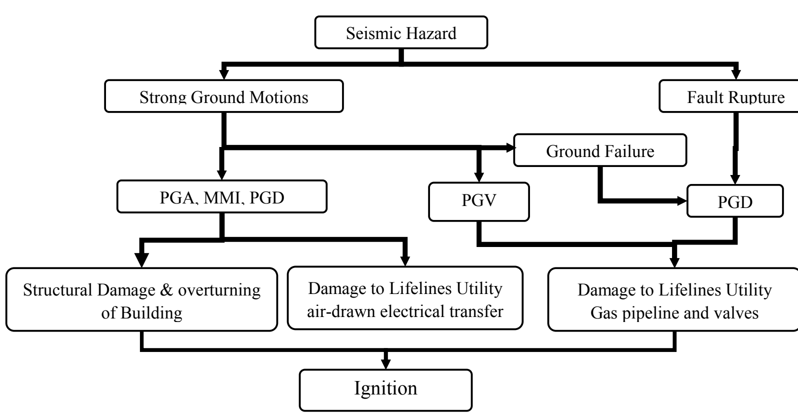


Figure 1. Major components of ignition following earthquake sources

Damage and disruptions caused by earthquakes could release or place large quantities of flamebale materials in the vicinity of spark sources. Example of such materials are cooking gas released form damaged gas distribution network. Direct seismic hazard such as faulting and strong ground motion and indirect seismic hazard such as liquefaction or land slides can result in damages to gas distribution network (Figure 1). Damaged cars or gas stations could also release such fuel and other flameable materials. Similarly, sparks could be generated as a result of damage underground or air-drawn electricity cables or from automobile starters.

4. MODELLING APPROACH

In the model proposed in this paper, each road or street is divided into several segments. The model estimates probability of ignition for each segment using the event tree algorithm shown in Figure 2. For simplicity, it is assumed that ignition in each segments is independent of neighbouring segments. For gas network with automatic shot-down system, the independency assumption is acceptable. The event tree algorithm shown in Figure 2 probabilistically links the parameters controlling ignition. The operators "AND" and "OR" show probabilistic multiplication and summation of respectively. According to this algorithm, existence of flameable material at each street segment depends on the leakage of natural gas, formation of ignitable mixture of natural gas-oxygen, and also existence of other flameable materials. Gas leakage itself depends on the potential damages caused by seismic hazards. In this model for simplicity seismic damages to pipe lines and elbow elements are considered only. Also as ground motion parameter, only PGV is used here, although both PGV and PGD (permanent ground deformation) could damage buried pipelines. Ground motion parameters are estimated using attenuation functions, earthquake source parameters and source to segment distance. Variation in the ground motion parameters are taken into account using a log-normal distribution. Using pipe-line fragility curves, the damages state likelihoods are estimated for pipelines in each street segment.

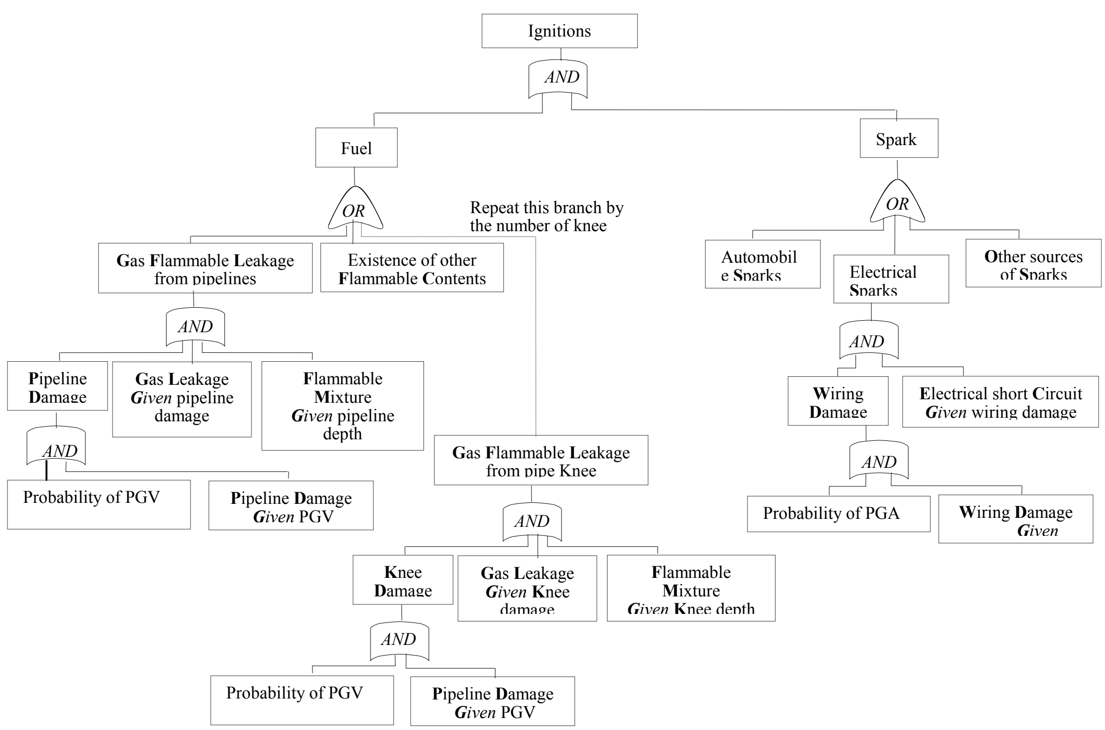


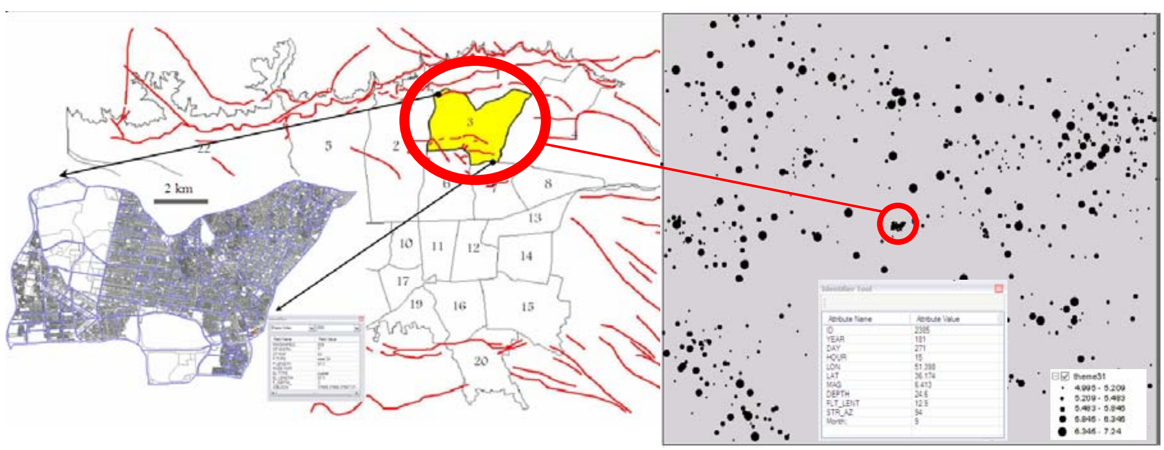
Figure2. Combination of major components and their relationships with regard to utility-related ignitions

Similarly, likelihood of electrical spark is linked to the likelihood of damage to overhead power system and sparks from automobile starter and other spark sources. As ground motion parameter, PGA is used and estimated from attenuation functions. The main purpose for this study is to introduce a probabilistic algorithm for convoluting uncertainties associated with different sources of ignitions taking place by urban utility network. Further discussions to quantify the variation and the degree of uncertainties auspicated with each element is beyond the scope of this paper and more statistical data, practical experiments and analytical modelling are required to measure such variation.

A scenario-based approach is used to model probability of ignition in this work. This is to avoid the correlation effect while convoluting ignition probabilities from many different sources. To derive full probabilistic results, the model is developed to calculate potential ignition probabilities as results of earthquake catalogues, consisting of many small to large earthquakes in a given region. The catalogue could be a compiled regional historical earthquake catalogue or alternatively synthetic earthquakes developed using a seismotectonic model and Monte Carlo simulation process.

5. RISULT FOR A PILOT STUDY

The proposed methodology is designed and implemented into a GIS-based hazard computer software. This analytical tool is well designed inside an open-source GIS platform which provides powerful spatial analysis as well as effective visualization capabilities. This software is capable of running one or several earthquake scenarios versus built environment, gas and power network data for a given region. For this purpose, built environment, population, gas network and power network data of a district in Tehran is used. District 3 in northern Tehran is an extension to the city, mostly developed in the last few decades (Figure 3a). From socioeconomic point of view, the district accommodates mostly middle to high class citizens with many newly developed apartment blocks. In this database, each poly-line represents one street consisting of several street segments. For each street segment, information on population, pipelines type and length, number of elbows and length and type of overhead power lines are input to the program.



(a) (b)

Figure 3a. Tehran city district map and major tectonic faults. Blue lines are representing main streets, b. 1000 year catalogue of simulated earthquakes in Tehran city and earthquake locations among district 3

Figure 4 shows the analysis results for a scenario earthquake of Mw=7.0 at a distance of 10 km form the district centre. The probability of occurrence of at least on ignition in each street segment is shown on this map. The sensitivity of the analysis results to the information and modelling assumptions used in this pilot study are presented in Figure 5. Figure 5 shows the variation of the probability of at least one ignition versus PGA, PGV, gas pipeline length and power line length. The analysis results for 1000 year synthetic earthquake catalogue are also presented in Figure 6. This figure shows the probability of occurrence of at least one ignition with occurrence annual mean rate of 0.01 (100 year return period).

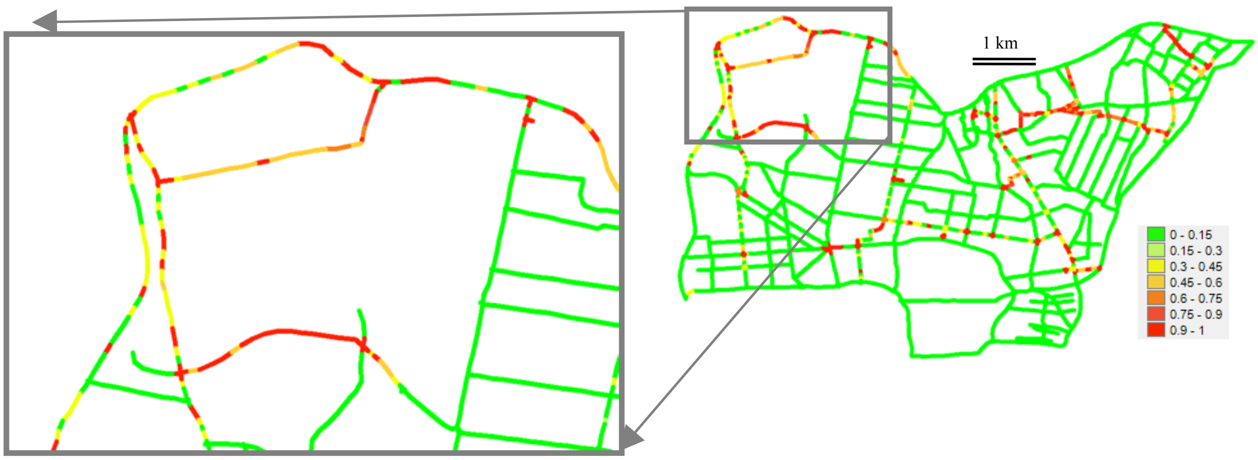


Figure 4. Geographical distribution of the probability of at least one ignition

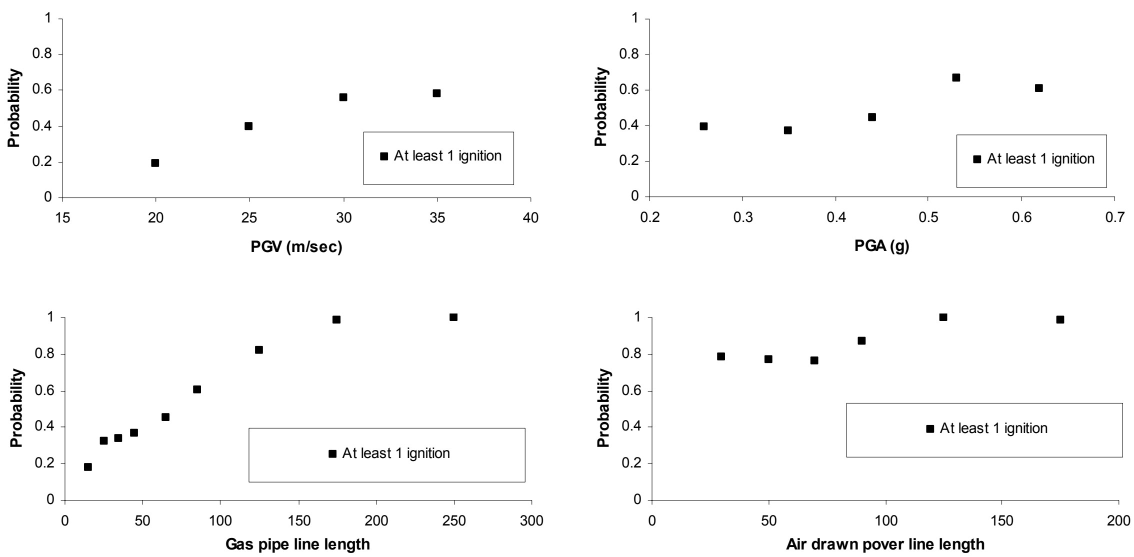


Figure 5. Sensitivity of analysis results to controlling parameters

CONCLUTION

In this paper, an analytical method is proposed to estimate the probability of occurrence of urban utility ignition following earthquake. In this model, the effective factors controlling ignition occurrence such as peak ground velocity and peak ground acceleration, population, overhead power network and natural gas network are considered. A computer code is developed based on the proposed method to simulate utility ignitions following earthquake. This analytical tool is well designed inside an open-source GIS platform which provides powerful spatial analyses as well as effective visualization capabilities. The proposed method is introduced as an alternative to the statistical models being used for FFE loss modelling. The paper in particular shows how uncertainties from many sources of ignition following earthquake can be combined. The main objective of this study is to develop a methodology to probabilistically convolute different sources of uncertainties associated with factors controlling urban IFE. However, detailed studies towards quantification and calibration of probability functions used in this study are beyond the scope of this paper and require further statistical data and investigations.

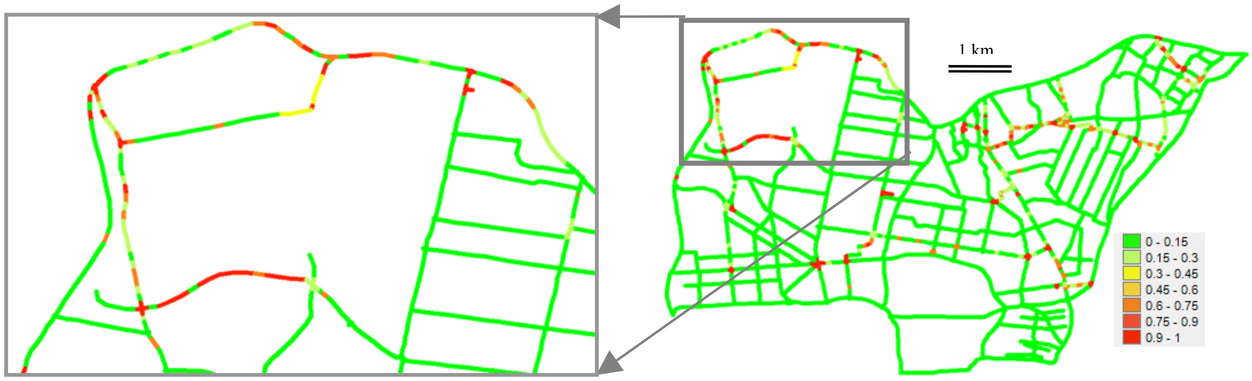


Figure 6. Geographical distribution of ignition probably (Probability of at least one ignition with 100 year return period) in Tehran District 3

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