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Fire Risk Assessment: A Systematic Review of the Methodology and Functional Areas

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ABSTRACT

Fire is a physical and social phenomenon that affects both individuals and the environment. Fire risk assessment is a critical part of a fire prevention program. In this process, the fire risk associated with the possibility of occurrence and severity of damage resulting from the fire is estimated and calculated. In this paper, a classification scheme and a systematic literature review are presented in order to classify and interpret the current researches on fire risk assessment methodologies and applications. Based on the scheme, 93 scholarly papers from 13 journals are categorized into application areas and other categories. The application areas include the papers on the topics of environmental impact, production and industry, transportation, buildings, power industry, oil and gas industry, urban fires and other topics. Scholarly papers are also classified by (1) year of publication, (2) journal of publication, (3) year of publication and application areas and (4) authors' nationality. The survey results show that the largest number of papers was published during the period 2010-2012 with 31 (33.33%), the most of the studies have been carried out on environmental impact (47.31%), the journal of Forest Ecology and Management had the highest percentage of articles with 26.88%. It is hoped that the paper can meet the needs of researchers for easy references of fire risk assessment methodologies and applications. Therefore, this work would be able to provide useful insights into the anatomy of the fire-risk assessment methods, and suggest academic researchers and experts a framework for future attempts and researches.

Key words: Fire Risk, Fire Analysis, Fire Risk Assessment, FRA

INTRODUCTION

Fire is a key element for development of human society, and it has become an important part of human civilization. Among various types of disasters, fire constitutes a significant threat to life and property in urban and rural areas [1]. Fire is a physical and social phenomenon that affects both people and the environment [2]. Fire in assembly occupancies is likely to cause significant consequences, and large enormous losses, example expenses of rescue and Medicare, compensation for disability and death, and other damages [3]. Trends have emerged of increasing fire size, its severity and property damage over the past two decades. Today, there is significant public debate about how best to prevent fires and reduce property damage [4]. The majority of the departures of fire are related to the human activities; if we except arson causes, the majority of the departures of fire are due to the carelessness or negligence, so it is possible to act in prevention by the public awareness [5]. Annual fires are millions of dollars in damage. In 2002 only 53589 fires have been reported in Canada, which resulted in 304 deaths, 2547 injuries and damage are US$ 1,489,012,263. In order to the rational allocation of resources, the use of risk assessment is necessary. If have more information in hand after a fire occurrence, damages and injuries will be less [6]. Fire risk assessment is a critical part of a fire prevention program, since pre-fire planning facilities require objective equipment to survey when and where a fire is more prone to occur, or when it will have more negative effects. For instance, FAO defines fire-risk as "the probability of fire starting determined by the activities of causative agencies" [7]. The risk of fire is usually the product of two concepts: the possibility of a fire occurrence and the cost of its consequences. The consequences are including death, injury and property damage [8]. In the context of technical risk assessments, the term "risk" considers not only the probability of an event, but also includes values and expected losses. It is inappropriate to use the term severity to describe the behavior of the phenomenon of fire itself. Instead, we should limit its use to that relating only to a fire's effect [9]. By definition, risk management, including risk assessment and control. Different stages of Fire risk management methods at show in Fig. 1 [1]. Existing fire-risk management involves the identification of alternative fire safety design options, the regular inspection, maintenance of fire protection facilities and systems and evacuation training and drills [1, 10]. The risk assessment of a

system includes of the use of all existing information to estimate the risk to individuals or populations, property and environment from identified hazards, the comparison with targets, and the search for optimal solutions [1]. Due to the rapid spread of fire risk assessment methods in many scientific researches, this paper has done a comprehensive review of fire risk assessment methods and their applications. For this purpose, a reference bank based on a classification scheme includes 93 articles published in 13 prestigious scientific journals from 2004 to 2014 was used. The journals include:

- Applied Geography
- Ecological Modeling
- Environmental Modeling & Software
- Ecological Indicators
- Fire Safety Journal
- Forest Ecology and Management
- Forest Policy and Economics
- Journal of Loss Prevention in the Process Industries
- Procedia Engineering
- Reliability Engineering & System Safety
- Remote Sensing of Environment
- Safety Science
- Tunneling and Underground Space Technology

Articles in this study divided in a variety of functional areas and further have been distributed according to year of publication, journals, writer nationality. The first section of this paper provides a brief introduction of fire. The second section describes the method of fire-risk assessment and the process of implementing it. The third section of the research provides a scheme for classification of scientific articles. Section IV provides a review on functional areas of articles. Section V divided of the articles into several different categories. Finally, Section VI provides an overall conclusion from this study.

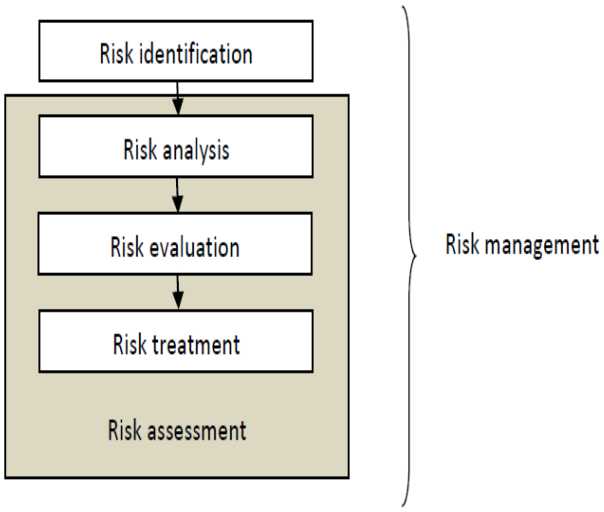

Fig. 1. The overall process fire risk management

A brief review of fire risk assessment

Fire- risk assessment process estimates and calculates the fire-risk associated with the possibility of occurrence and severity of damage resulting from the fire and determines the decision criteria against defined an acceptable level of risk. The different methods of risk assessment are used to determine the risks of fire load. The results obtained from the risk assessment methods are qualitative and semi-quantitative and quantitative. Fire Risk Assessment consists of four steps [1]:

Fire risks Identification

Fire-risk identification is the systematic process to understand how, when, and why fire could happen.

Fire risk analysis:

Fire risk analysis is the process of estimating magnitudes of consequence and probabilities of the adverse effects on people and property [11]. The end result of fire-risk analysis is expressed in qualitative, hybrid or quantitative terms depending on the type of risk, the purpose of risk analysis, how detailed the analysis is supposed to be and the information resources available. However, different fire-risk assessment methods are usually limited in application, for example, explanation method as qualitative fire-risk assessment method evaluate fire-risk with explanation suggestion, only to be able to order general description to identify the most dangerous events, not quantify fire risk. The semi-quantitative fires risk assessment method, such as fire-risk index,

Gustavo method, matrix method, because semi-qualitative analysis can achieve a simple, relatively quantitative fire-risk even in case of incomplete fire data. Quantitative fire-risk assessment methods are able to absolutely quantify fire-risk with a huge amount of data as support, and the calculation is complicated, which required users to master probability theoretical and practical researches and more specialized mathematical knowledge [3]. Research in the field of fire-risk analysis is vital [7].

Fire risk evaluation:

Fire risk evaluation involves applying the developed risk criteria and making a decision about the level of fire risk.

Fire risk treatment: Fire risk treatment is the process of improving existing risk control measures, developing new risk control measures and implementing these measures to reduce fire risk [8].

RESEARCH METHODOLOGY

A literature review based on a study of scientific journals was conducted to build a framework for fire-risk assessment research. The aim was to identify those of the existing articles in scientific journals, which had been described the methods and applications in the field of fire-risk assessment. On this basis first list of journals with articles about the fire-risk assessment was prepared. Each journal that had at least two papers in the field of fire risk assessments was selected. In Search on site at any magazine archives, with front keyword search was conducted: "Fire-risk", "Fire-risk analysis"," FRA" and "Fire risk assessment ". It must be noted that search with this keywords was performed just in the article's title. The only journals were selected that had at least two articles related to fire-risk assessment. If articles had found with these keywords but not related to the fire-risk assessment were excluded from the study. The literature review was conducted to identify the articles in scientific journals, which provide most valuable information to researchers and practitioners studying the fire-risk assessment methods; hence conference proceeding papers, textbooks, and doctoral dissertations, master's theses, and unpublished papers were excluded from the literature review. All journals were studied from early 2004 until the end of 2014. Due to difficult accessing to data before 2004 as well as the lack of relevant articles before this year, articles published in the years before 2004 did not investigate. In the Library databases search, a total of 93 articles from 13 scientific journals on the subject of fire-risk assessment were obtained. Studies related to fire-risk assessment were in multiple and various fields, so it was difficult for researchers to find titles related to the issues. After detailed and deep analysis, functional areas of examined articles were identified, and were classified in eight categories: Environmental impact, production and industry, transportation, buildings, power industry, oil and gas industry, urban fires and other topics. Other topics contain articles that were not in any of the previous seven categories. Then the articles in the relevant category were selected. Although some of the papers were related to the several categories, but finally and according to the survey, each paper was placed in the most relevant category. In following sections, 93 articles compiled based on mentioned eight categories will be considered. At the beginning of each section referenced to several cases of related article, and then all the articles in each category will be presented in the form of summarized in tables.

The existing articles were identified, analyzed, classified, coded and were registered in a table (table 1). As each article was reviewed, it was classified by several categories: year of publication, authors, authors' nationality, and the application area, name of the article, tools/methodologies, fire risk assessment method and Journal of publication. Although this review cannot contend to be comprehensive, it covers a large portion of fire risk assessment publications, and therefore is a useful source for fire risk assessment researchers and experts.

Table1: The classification scheme for the literature review on fire risk assessment

No.	Year of publication	Authors	Authors' nationality	Application area	Name of the article	Tools/methodologies	Fire risk assessment method	Journal of publication
1								
2								
…								
93								

RESULTS AND DISCUSSION

Analysis of fire risk assessment application areas

Environmental Impact

Different studies have been conducted to assess the environmental impact of fires. Many of these studies are in areas such as Forest fires, Grassland and Wildlife. Forest fires play a critical role in landscape transformation, vegetation succession, soil degradation and air quality. So, improvements in fire-risk estimation to reduce the negative impacts of fires and identifying areas with high risk of fire in forest areas and understand how they can change over time

to prioritize forest management activities and reduce the risk of fire is essential [7]. Forest fire statistics in Poland show a clear growing trend. Overall, in the country, in 1999–2005, a surface area of 55,877 ha was burned in the course of 72,338 forest fires [12]. In Portugal, in the period 1990–2005 the total burned area was a value of approximately 2.2×106 ha, equivalent to nearly 25% of the country area [13].

The study's results showed that the use of fire-risk assessment is a useful tool for managers to help improve the effectiveness of fire prevention, diagnosis and allocation of resources to fight during fire in the social and environmental areas [14]. Grassland fire is a cause of major disturbance to ecosystems and economies throughout the world, because these fires are the main sources of greenhouse gas emissions. Hongfeng and colleagues conducted a study to investigate the disruptive effects of grassland fire on the Hulunbuir grassland of China. The study selected factors for fire-risk assessment using a set of data collection and evaluation methods: remote sensing, geographic information systems, and statistical yearbook data. Their study showed that almost half of the regions studied (54.32%) are at risk [15]. Other studies in the field of environmental impact of fires are shown in Table 2.

Table 2: Studies related to fire risk assessment in the field of "environmental impact"

No.	Author(s)	Article Title	Other tools/methodologies used	The method used to fire risk assessment
1	He, Shang *et al*. [16]	Simulating forest fuel and fire risk dynamics across landscapes—LANDIS fuel module design	-	LANDIS fuel module (landscape-scale)
2	Keane, Drury *et al.* [17]	A method for mapping fire hazard and risk across multiple scales and its application in fire management	-	FIREHARM
3	Shang, He *et al.* [8]	Fuel load reductions and fire risk in central hardwood forests of the united states: a spatial simulation study	-	LANDIS fuel module (landscape-scale)
4	Adélia and Jorge [18]	Assessment of forest fire risk in the Serra da Estrela Natural Park (Portugal): Methodological application and validation	-	Methodological application and validation
5	Ager, Vaillant *et al.* [19]	A comparison of landscape fuel treatment strategies to mitigate wildland fire risk in the urban interface and preserve old forest structure	-	1.Landscape fuel treatment strategies 2.Quantitative risk analysis
6	Braun [20]	Wildland fire risk—Integrating community resilience or community vulnerability attributes and hazard assessments, to provide a comprehensive risk mode	-	Integrating community resilience or community vulnerability attributes and hazard assessments
7	Bugalho *et al.* [21]	Assessment of forest fire risk in Portugal combining meteorological and vegetation information	-	Combining meteorological and vegetation information
8	Carmel *et al.* [22]	Assessing fire risk using Monte Carlo simulations of fire spread	FARSITE, a two-dimensional fire growth and behavior model was activated, using ArcView VBA code	Monte Carlo simulations
9	Carreiras and Pereira [13]	An inductive fire risk map for Portugal	-	Fire risk map
10	Crecente-Campo *et al.* [23]	Impacts of thinning on structure, growth and risk of crown fire in a Pinus sylvestris L. plantation in northern Spain	-	1.Basal area of larger trees (BALMOD) 2. Model to estimate canopy bulk density (CBD)
11	Finney *et al.* [24]	The challenge of quantitative risk analysis for wildland fire	-	Quantitative risk analysis
12	Fiorucci *et al.* [25]	Power law distribution of wildland fires and static risk assessment	-	Static risk assessment
13	González-Olabarria *et al.* [10]	Integrating fire risk considerations in landscape-level forest planning	-	Landscape-level forest planning
14	González-Olabarria *et al.*[26]	Mapping fire risk in the Model Forest of Urbión (Spain) based on airborne LiDAR measurements	FlamMap	1. LiDAR derived data 2. fire behavior models
15	Hardy [9]	Wildland fire hazard and risk: Problems, definitions, and context	-	Synthetic scenario results in a "decision space"

16	Jappiot *et al.* [5]	Fire risk ignition: The integrated model "AIOLI"	Remote detection images and GIS	Integrated model "AIOLI"
17	Kambezidis *et al.* [27]	An investigation on forest-fire risk assessment in selected areas in Greece and Turkey	-	Fire Weather Index (FWI) and the Initial Spread Index (ISI)
18	Kim *et al.*[28]	Forest fire risk assessment through analyzing ignition characteristics of forest fuel bed	-	Analyzing ignition characteristics of forest fuel bed
19	Kruger *et al.*[29]	Classification of veldfire risk in South Africa for the administration of the legislation regarding fire management	-	Combinations of likelihood and consequences (semi-quantitative matrix)
20	Lampin *et al.* [30]	WUI and road networks/vegetation interfaces characterizing and mapping for forest fire risk assessment	Remote sensing ,GIS , ArcGis# 8.3 software	WUI and road networks/vegetation interfaces characterizing and mapping
21	Lee and Irwin [31]	Assessing risks to spotted owls from forest thinning in fire-adapted forests of the western United States	-	Combination of population data, canopy cover measurements, and forest simulation models
22	O'Laughlin [4]	Policy issues relevant to risk assessments, balancing risks, and the National Fire Plan: Needs and opportunities	-	1. Risk-based policies National Environmental Policy Act (NEPA) 2. Panelists and organizational missions
23	Fiorucci *et al.* [32]	Optimal preventive aerial resources relocation based on dynamic wildland fire risk assessment	-	Risk maps produced by a dynamic risk forecasting system
24	Paz *et al.* [33]	Post-fire analysis of pre-fire mapping of fire-risk: A recent case study from Mt. Carmel (Israel)	Fire-risk map, null model	Combination of Monte Carlo simulation of spatial spread of fire ignition with fire behavior model (FARSITE)
25	Shinneman *et al.* [34]	Can landscape-level ecological restoration influence fire risk? A spatially-explicit assessment of a northern temperate-southern boreal forest landscape	-	Forest landscape simulation model
26	Ubysz *et al.* [12]	Analysis of the trends in the forest fire risk for recent years in Poland against the background of long-term trends	-	The weather conditions and litter humidity
27	Verbesselt *et al.* [35]	Monitoring vegetation water content of grasslands and forest plantations to assess forest fire risk with satellite time-series	Normalized difference vegetation index (NDVI)	SPOT VEGETATION satellite data
28	Yebra *et al.* [36]	Investigation of a method to estimate live fuel moisture content from satellite measurements in fire risk assessment	Multiple linear regression equations (MLR), simulation models PROSPECT and SAILH, multi temporary empirical fittings and reflectivity simulation models	Method to estimate water content (FMC)
29	Calkin *et al.* [37]	Progress towards and barriers to implementation of a risk framework for US federal wildland fire policy and decision making	New analytical methods to measure wildfire risk to human and ecological values	Wildfire simulation technology
30	Gaither *et al.* [38]	Wildland fire risk and social vulnerability in the Southeastern United States: An exploratory spatial data analysis approach	-	Exploratory spatial data analysis approach
31	Herawati and Santoso [39]	Tropical forest susceptibility to and risk of fire under changing climate: A review of fire nature, policy and institutions in Indonesia	-	1.Future climate change 2. Climate change scenarios and current fire management practices
32	Riera and Mogas. [40]	Evaluation of a risk reduction in forest fires in a Mediterranean region	Contingent valuation method (CVM), travel cost method	The results of a referendum application
33	Maki *et al.*. [41]	Estimation of leaf water status to monitor the risk of forest fires by using remotely sensed data	-	Relationship between leaf water status and the normalized difference water index (NDWI)
34	Mbow *et al.* [42]	Spectral indices and fire behavior simulation for fire risk assessment in savanna ecosystems	LANDSAT-ETM images- FIRA algorithm-	Spectral indices and simulation

			fire area simulator (FARSITE)	
35	Verbesselt *et al.* [43]	Monitoring herbaceous fuel moisture content with SPOT VEGETATION time-series for fire risk prediction in savanna ecosystems	-	Monitoring herbaceous fuel moisture content with SPOT VEGETATION time-series
36	Castillo and Miguel [44]	The identification and assessment of areas at risk of forest fire using fuzzy methodology	-	Fuzzy methodology
37	Maeda *et al.* [45]	Fire risk assessment in the Brazilian Amazon using MODIS imagery and change vector analysis	-	MODIS imagery and change vector analysis
38	Raulier *et al.* [46]	Introducing two indicators for fire risk consideration in the management of boreal forests	-	Site index and relative density index and Fire cycle length
39	Turner *et al.* [47]	Spatial indicators of fire risk in the arid and semi-arid zone of Australia	NOAA-AVHRR satellite imagery	Conceptual framework which serves both to summarize existing knowledge and to reduce the complexity for a quantitative statistical analysis
40	Carvalho *et al.* [48]	Fire weather risk assessment under climate change using a dynamical downscaling approach	General circulation model (MUGCM) and a regional meteorological model (MM5)	The dynamical downscaling between global climate models and regional models
41	Iliadis [49]	A decision support system applying an integrated fuzzy model for long-term forest fire risk estimation	Fuzzy algebra	A triangular and a trapezoidal membership function, based on various aspects of fuzzy sets and fuzzy machine learning techniques

Production and industry

In this part, non-chemical process fires will be discussed. Cases applied under this title are in the field of mining, logistics warehouse, tanks (Tanks LNG and atmospheric storage tanks), physical processes and Hydraulic and magnesium production factory.

Fire occurs in most industries due to the explosion. Explosion is a process of very fast chemical or physical conversion of substance, which is accompanied by transition of its internal energy to mechanical work [50]. More than 100,000 tons of powdered or granular magnesium are produced annually in China in factories with high potential fire and explosion risk. A study by Gang and *et al.* was conducted to evaluate fire-risk in magnesium production factory. The results showed that spark caused by static electricity, mechanical friction, or impacts are the most likely ignition sources for fine magnesium powder fires and explosions [51].

Along with the development of socialist market economy, the logistics industry such as logistic warehouses has developed rapidly. Not only this warehouse type functions are different from the other places, but also it has different characteristics in terms of fire. At present, the assessment methods of the logistics warehouse fire safety aren't enough. With the development of society and science technology, risk problems are becoming the problem which people must face. In order to achieve fast and safe industrial logistics, a study by Ren, Shaoyun to review safety issues and fire-risk assessment was conducted in logistics warehouse. Firstly, based on the logistics warehouse fire accidents, the four aspects of the logistics warehouse fire-risk were gained. Secondly, the model was designed to assess the logistics warehouse fire-risk by means of expert investigation and using the method of AHP and fuzzy comprehensive assessment. Finally results showed that the assessment methodology of logistics warehouse fire-risk is reasonable, effective and feasible [52].

Fire disasters in the mining industry have very severe consequences. Prevention of the occurrence of these events is one of the most important requirements in safety in mines in all over the world. In a study that was conducted by Lin and *et al.* at the coal mine, the risk early-warning theory was regarded as the theoretical foundation for resolving the safety problems in coal mines. Establishment of the macroscopic model of risk early-warning on it deepens the researches on safety early-warning mechanism and technology [53]. Other studies in the field of production and industry are shown in Table 3.

Transportation

The complexities of modern societies are constantly rising. Hazardous materials are transported through different ways [57]. Road tunnels constitute essential public-works projects, from both a practical and an economic standpoint, because they limit the length of transportation and thus reduce transportation time and costs. Tunnels are particularly difficult to access during rescue actions. In heavy traffic conditions, it is hard for rescue vehicles to get around obstacles, and it is often impossible to get inside the tunnel to reach the scene of the fire. Furthermore, the enclosed nature of tunnel structures causes to fast temperature increases

during a fire and causes problems for ventilation and exhaust of fumes [58]. A study by Gandit *et al.* was conducted in the region of the French Alps Rvn- to assess the prevention of fires in tunnels. For this purpose a questionnaire was used to search of documents based on discussions with tunnels experts, and visiting the tunnels and analyzing videos of fires in tunnels was conducted. Finally, with according to the results obtained, Recommendations were suggested for long-term prevention policy bearing jointly on beliefs, behaviors, improved information and warning systems [58]. Other studies in the field of transportation are shown in Table 4.

Table 3: Studies related to fire risk assessment in the field of "production and industry"

No.	Author(s)	Article Title	Other tools/methodologies used	The method used to fire risk assessment
1	Moon *et al.* [54]	Fire risk assessment of gas turbine propulsion system for LNG carriers	-	Descriptive study
2	Alhussan [50]	Thermal Radiation of Explosion: Estimations of Risk of Thermal Defeat of People and Occurrence of Fires	-	The physical model, algorithm, and program code for modeling one-dimensional hydrodynamic processes
3	Larry Grayson *et al.* [55]	Pilot sample risk analysis for underground coal mine fires and explosions using MSHA citation data	-	Approach is given for analyzing the risks for fires and explosions based on the Mine Safety and Health Administration citation database
4	Crippa *et al.* [56]	Fire risk management system for safe operation of large atmospheric storage tanks	-	LastFire© methodology

Table 4: Studies related to fire risk assessment in the field of "transportation"

No.	Author(s)	Article Title	Other tools/methodologies used	The method used to fire risk assessment
1	Van de Linde *et al.* [59]	Fire protection for high speed line tunnels: Risk analysis and exceptional robotic application results	-	Risk analysis and exceptional robotic application results
2	Udor and Sfarlos. [60]	Fire risk management in public underground transport system – Bucharest Metro, Romania		
3	Soons *et al.* [61]	Framework of a quantitative risk analysis for the fire safety in metro systems	-	Framework of a quantitative risk analysis
4	Camillo *et al.* [11]	Risk analysis of fire and evacuation events in the European railway transport network	Events Trees	Design fire scenario (DFS)

Buildings

With ongoing development of economic, social and building technology, high-rise buildings are developing quickly; so fire issues are growing increasingly, too. Building functional diversification causes that prevention of this type of fire became more complex. The sizes of high-rise buildings, high concentration of people and property, make the firefighting and evacuation operations very difficult in fire cases. It is necessary to conduct the fire risk assessment for high-rise buildings to control of fire accidents. In evaluation of high-rise buildings fires, it is necessary to consider not only the prevention before the fire, but also firefighting, evacuation and spreading in fire cases. The high-rise buildings fire-risk assessment involves many factors. Quantifying of many of these factors is difficult, so there will be a certain ambiguity. For such system, it is difficult to compare the merits of the order of the factors. A study was conducted by Guang-wang *et al.* to assess fire risks in high-rise buildings using Fuzzy comprehensive evaluation model [62].

An appropriate design of fire engineering safety must ensure the safety of the residents of a building during a fire. In recent years, the urban population, the size of cities and urbanization are rapidly increasing. Many Large buildings, towers, high-rise buildings and underground buildings have increased dramatically. In the other words, due to large number of people and complex building spaces, once a fire occurs, residents' evacuation is difficult. Some studies have done by the development of performance based design to assess building fire risks. Chu and Sun were considered quantitative risk analysis for quantitative estimation of risk due to random factors. In some models and systems, the number of deaths and the risk of losing

people is considered as a risk assessment purpose. The results of this study were in relation to the decision on the replacement of various fire safety designs based on of buildings fire risk assessment [63].

With developing fire and smoke propagation, several factors, such as temperature, smoke, particles, carbon monoxide and dioxide, etc. can affect the safety of the residents. Some studies focus on single-factor injury and research results are used in some areas, especial in fire safety design of building, firefighter training, evacuation strategies, etc. With different dressing and physical condition the influence of temperature on occupant tolerance limitation time and evacuation speed is different. High concentration of carbon monoxide and dioxide can harm the ability of judgment and movement. Impact on human of high-temperature, smoke, carbon monoxide, carbon dioxide, etc. can be coupled with each other. In a study by Yan-yan *et al.* that was conducted in relation to the simulation fire and sensors in buildings, fire simulation was used to provide the information necessary for the calculation of mapping the comprehensive fire risk in buildings [64]. Other studies in the field of buildings are shown in Table 5.

Power industry

Along with the development of society economy and improvement of people's living standards, the requirement and demand of electricity become more than before. Meanwhile, fires caused by electricity significantly increased and are leading to enormous financial losses. Bad contact and short circuit of aluminum conductors took up high proportion among all electrical reasons which could cause fires. Wang *et al.* studied the fire risks associated with low-voltage circuits of aluminum conductors. As a result, it showed that the common combustible, such as paper and polyurethane foam can be inflamed under bad contact and short conditions [77]. In another study Wang *et al.* concentrated on neutral-line opening fault, simulated variegation of voltage and current according to a variety of load factors by means of MATLAB/Simulink software. Finally, in this study, based on simulated results, he provided the important references for exploring the reasons of electrical fires [78].

Overcurrent is conditions where a larger than intended electric current exists through a conductor, leading to excessive production of heat, and the risk of fire or damage to equipment. Possible causes for overcurrent include incorrect design, excessive load, short circuits or a ground fault. If the magnitude and direction of the overcurrent are enough to heat the wire to a temperature, the overcurrent would cause a fire. Overcurrent is one of the main causes of cause of fires in homes. Gao *et al.* were conducted a study to evaluate the fire potential that may result from overcurrent faults on a copper wire used in ordinary life in China. Results of their tests showed that the overcurrent fault divided into three stages, i.e. smoking, redness and breakdown. It also showed that the time of smoking, redness and breakdown reduced as the power of the electrical applications increasing [79]. In a study conducted by Ding, fire-risk has been analyzed to the daily electric power utilization, communication cabinet, battery cupboard and distribution cabinet installed in a communication room, Based on the results of the study the fire protection system in such kind of places, the design principles are offered. Also some suggestions to prevent fire attack from the daily electric power utilization, communication cabinet, battery cupboard and distribution cabinet in such kind of places are offered [80].

Oil and Gas industry

Petroleum chemical processes usually are performed by a combination of chemical and physical reactions. Raw materials and products of these processes are in liquid and gaseous components. These substances are toxic, flammable and corrosive. For reasons such as spills during transport, accidental combustion, operator unsafe operation, and other reasons may be a large explosion or fire accidents occur during oil and chemical process in the production. These accidents could easily lead to property loss and environmental damage. In recent years, the explosion and fire accidents in China show a growing trend. Liu *et al.* conducted a study in a petrochemical company based on the fire risk prediction analysis. The results of this study help the petrochemical companies to realize dynamic security fire risk management [81]. Among all the accidental process-related accidents occurring offshore, fire is the most frequently reported. Therefore it is necessary to study the behavior of fires and quantity the hazards posed by them in order to complete a detailed quantitative risk assessment. In the study was conducted by the Pula *et al.* fire risks were assessed in the offshore oil and gas platforms by using fire consequence modeling [82]. Today in the Russian Federation and other countries large oil terminals (volume of one tank exceeds 100 000 m^3, total volume of tanks exceeds 300 000 m^3) are designed and constructed. Therefore fire safety of them becomes a very important task, solution of which is hardly possible without detail fire-risk assessment. A study that conducted by Shebeko et al. was aimed to order a solution for this problem. Risk assessments done according to the calculation of the potential, individual and social risks, and finally the risk values obtained from this study were consistent with practice of the best oil companies [83]. Other studies in the field of oil and gas industry are shown in Table 6.

Table 5: Studies related to fire risk assessment in the field of "buildings"

No.	Author(s)	Article Title	Other tools/methodologies used	The method used to fire risk assessment
1	Asgary *et al*. [6]	Modeling the risk of structural fire incidents using a self-organizing map	-	A Self-Organizing Map (SOM)
2	Hanea and Ale [57]	Risk of human fatality in building fires: A decision tool using Bayesian networks	-	Bayesian networks
3	Hasofer [65]	Modern sensitivity analysis of the CESARE-Risk computer fire model	Fourier Amplitude, Sobol and Morris method	CESARE-Risk computer fire model
4	Jennings and Charles [2]	Social and economic characteristics as determinants of residential fire risk in urban neighborhoods: A review of the literature	-	Multiple regression modeling
5	Sekizawa [66]	Risk Analysis in Building Fire Safety Engineering	-	-
6	Xin and Huang [1]	Fire risk analysis of residential buildings based on scenario clusters and its application in fire risk management	-	Scenario clusters
7	Yao *et al.* [67]	Fire risk mapping based assessment method applied in performance based design	-	1 .The fire hazard map 2. Global fire risk indices
8	Chu *et al*. [68]	Integrated Risk Analysis of a High-rise Building Fire based on Cluster Method	Fire simulation experiments-fire risk map	Two-step cluster analysis method
9	Gałaj *et al.* [69]	Interactive Modular Platform for Fire Risk Assessment of Buildings as a Supporting Tool for Buildings and Infrastructures Design	-	Interactive Modular Platform
10	Hai-yun [3]	Research on Standardization Method of Risk Assessment for Fire Public Liability Insurance in Assembly Occupancies and Underwriting Auditing	-	Standardization method selections of fire risk assessments for public liability insurance
11	He [70]	Probabilistic Fire-risk-assessment Function and Its Application in Fire Resistance Design	-	Performance-based building codes and the advancement of fire safety engineering.
12	Ibrahim *et al.* [71]	The Development of Fire Risk Assessment Method for Heritage Building	ExperChoice2000 software	Analytical Hierarchy Method (AHP)
13	Ibrahim *et al.* [72]	Fire Risk Assessment of Heritage Building – Perspectives of Regulatory Authority, Restorer and Building Stakeholder	-	A survey questionnaire was developed based on the identified criteria of fire risks
14	Li *et al*. [73]	Fire Risk Analysis of a 6-storey Residential Building Using CU risk	-	Quantitative fire risk analysis computer model CU risk
15	Tofiło *et al.* [74]	Expert System for Building Fire Safety Analysis and Risk Assessment	-	Performance based design
16	Guanquan and Wang. [75]	Study on probability distribution of fire scenarios in risk assessment to emergency evacuation	Markov Chain is proposed to combine with ETA	ETA is performed to construct probable fire scenarios
17	Hanea *et al.* [76]	Quantitative and qualitative analysis of the expert and non-expert opinion in fire risk in buildings	-	Quantitative and qualitative analysis of the expert and non-expert opinion

Urban fires

With increasing urban population, buildings will be highly concentrated, and the distribution of the road traffic and energy facilities will be more complex. In addition, with the rapid economic development, cities are faced with more sources of risk. In this context, the fire risks assessment is quite significant in urban fire planning and the making of fire requirements, which is an effective factor in promoting the coordinated social and economic development in the cities. In a study Zhang presented a comprehensive analysis on the urban fire-risk from the respects of risk of fire accidents in urban areas, urban vulnerability and sensitivity and urban anti-fire capability. Based on the analysis, the Analytic Hierarchy Process was used in this study to establish an urban fire-risk assessment system [88]. In another study that was done by Nishino *et al.* for urban post-earthquake fire-risk, an evaluation method is presented. Urban fires and urban emergency evacuations are dependent on uncertain factors, such as the number and locations of fire outbreaks, the population distribution, and the wind velocity and direction. To implement effective measures to ensure the buildings and individuals safety in fires, a method to evaluate the effectiveness of the various safety measures that consider the influence of the uncertain factors is essential. In this study fire-risk was calculated by a combination of Monte Carlo

simulation and fire-spread/evacuation simulation [89]. Considering that, the relevant papers in the field of urban fire in this study were 2 cases, therefore table for this section is not provided.

Table 6: Studies related to fire risk assessment in the field of "oil and gas industry"

No.	Author(s)	Article Title	Other tools/methodologies used	The method used to fire risk assessment
1	Arshad *et al.* [84]	A risk-based method for determining passive fire protection adequacy	-	Quantitative risk assessment method
2	Duarte [85]	A performance overview about fire risk management in the Brazilian hydroelectric generating plants and transmission network	CIGRE failure data, fire accident reports and CHESF maintenance experience on equipment	Performance analysis
3	Huang and Li. [86]	Assessment of Fire Risk of Gas Pipeline Leakage in Cities and Towns	-	Estimation of gas leakage quantity and estimation of heat radiation flux and estimation of damage range and damage area
4	Li and Huang. [87]	Fire and Explosion Risk Analysis and Evaluation for LNG Ships	-	Dow method, BLEVE model and VCE model

Other topics

In this section, we briefly consider to total articles found during the search as related to fire risk assessment but not included in any of the studies categories. The studies are in areas such as fire departments and rescue, fire in fighting ships, the use of fire resistant materials to protect against fire and the fire engines. Large number identified risk methods are used in fire and rescue service in Britain. All of centers in Britain are required to provide an integrated risk management plan in accordance with the national guidelines. A study by Hawkins *et al.* was conducted with the participation of Merseyside Fire and Rescue Service and Liverpool John Moores University. The aim of this study was to examine ways and means of developing and implementing a spatial model to be used to target services based on the needs and risks. These are community profiles that based on a cluster analysis approach, identify individuals most at risk of fire using data gained through information sharing agreements [90]. International Maritime Organization (IMO) provided and approved a systematic and structured method for risk assessment which was named Formal Safety Assessment (FSA). During the war, Navy ships potentially would be hit by contact explosion and non-contact explosion. Although non-contact explosion does not directly hit the vessel, but it could cause a fire by a shock wave. This method was initially used in IMO rulemaking process, and then for ship fire-risk assessment. A Ship Fire Safety Engineering Method (SFSEM) was developed from Engineering Method for Building Fire Safety by U.S. In this method, all relevant aspects of fire safety are considered, including the growth and spread of fire, the effectiveness of passive and active fire protection measures.

To assess the damage caused by non-contact explosion in warships, a study was conducted by Jia and Lu. They developed a mission-oriented risk assessment methodology. The results of this study showed that the severity of fire damage depends on the occupancy rate and fire load. In addition, the results of further investigation determined that the fire damage could be reduced by using some measures such as reducing leakage, reducing reaction time and so on [91]. Fire-fighting equipment is the material basis of the firefighting and rescue, and also is an important part of the public fire protection infrastructure. In a study Yang and Liang, analyzed the influence of fire engines on fire-risk qualitatively. Fire engine could affect fire damage to a certain extent. In this study, the relationship between fire engine and fire risk is explored qualitative and quantitative. The results of this study provided the basis for the fire department to carry out fire-fighting equipment planning and management [92]. Passive fire protection by the application of fireproofing materials is a main safety barrier in the prevention of the escalation of fire scenarios. Available methodologies for fireproofing application in on-shore facilities do not consider the effect of jet-fires. In a study that conducted by Tugnoli *et al.* a risk-based methodology was developed aimed at the protection from both pool fire and jet fire escalation. The method is mainly oriented to early design application, allowing the identification of fireproofing zones in the early phases of lay-out definition [93].

Other classification results

In the previous sections, 93 papers in 7 applicable areas were presented. In this section, 93 related papers will categorize under the following titles:

Distribution by year of publication

Table 7 shows studies distribution of based on year of publication since the beginning of 2004. The survey results show that, the largest number of papers were published during the period 2010-2012 with 31

(33.33%) and during 2004-2006 with 29 (31.18). During 2007-2009 only 13 papers have been published that this was the lowest numbers of papers (13.97%). In recent two years namely in 2013 and 2014, 20 papers (21.50%) have been published related to fire risk assessment. Thus, it can be concluded that the risk of fire has been very important in the early years of this study.

Table7: Frequency of papers by year

Year	N	%
2004-2006	29	31.18
2007-2009	13	13.97
2010-2012	31	33.33
2013-2014	20	21.50
Total	93	100

Distribution of the papers by application areas

In the table 8, Results of the survey have been brought based on the distribution of papers in various fields. As can be seen in this table, most of the studies have been carried out on environmental impact (47.31%) and buildings (21.50%) respectively. In the meantime, in order of studies of in the field of production and industry and oil and gas industry with 7.52%, transportation with 5.37%, power industry and other studies with 4.30%, and finally urban fire with 2.15% have papers in the field of fire-risk assessment.

Distribution by journal of publication

Table 9 shows the frequency of papers by journals and Table10 shows the number of papers published in various fields at timescales ranging. As can be seen environmental effects with 24 papers in 2004-2006, 15 papers in 2010-2012 and buildings with 8 papers, in 2010-2012 and 2013-2014 have the highest number of articles respectively.

Table 8: Frequency of the papers by application areas

Application areas	N	%
Environment Management	44	47.31
Buildings	20	21.50
Oil and gas Industry	7	7.52
Manufacturing and industry	7	7.52
Transportation	5	5.37
Power industry	4	4.30
Urban fire	2	2.15
Other Topics	4	4.30
Total	93	100

Distribution by year of publication and application areas

Table10 shows the number of papers published in various fields at timescales ranging. As can be seen environmental effects with 24 papers in 2004-2006, 15 papers in 2010-2012 and buildings with 8 papers, in 2010-2012 and 2013-2014 have the highest number of articles respectively

Table 9: Frequency of papers by journals

Journal name	N	%
Forest Ecology and Management	25	26.88
Procedia Engineering	23	24.73
Fire Safety Journal	12	12.90
Journal of Loss Prevention in the Process Industries	6	6.45
Ecological Modeling	5	5.37
Forest Policy and Economics	4	4.30
Reliability Engineering & System Safety	3	3.22
Remote Sensing of Environment	3	3.22
Safety Science	3	3.22
Tunneling and Underground Space Technology	3	3.22
Environmental Modeling & Software	2	2.15
Ecological Indicators	2	2.15
Applied Geography	2	2.15
Total	93	100

Table 10: Frequency by year of publication and application areas

Application areas / year	Environment Management	Manufacturing and industry	Transportation	buildings	power industry	Oil and gas Industry	Urban fire	Other Topics	Total
2004-2006	24	0	3	0	0	2	0	0	29
2007-2009	3	4	1	4	0	1	0	0	13
2010-2012	15	2	0	8	1	2	1	2	31
2013-2014	2	1	1	8	3	2	1	2	20
Total	44	7	5	20	4	7	2	4	93

Distribution by authors' nationality

Table11 shows the nationality of the authors of the 93 papers. Authors' nationality of our study has been distributed among 29 countries. As can be seen, most authors' nationality is from the Chinese (22.58%), America (15.05%), Spain (6%), Italy and Portugal (5.37%) respectively. In other words, from the 24 countries remaining, 4 countries have 16 papers (each country has 4 papers), one country has 3 papers, 5 countries have 2 papers and finally 13 countries have only one paper.

Table 11: Frequency of papers by authors' nationality

Country	N	%
China	21	22.58
USA	14	15.05
Spain	6	6.45
Italy	5	5.37

Portugal	5	5.37
Canada	4	4.30
France	4	4.30
Netherlands	4	4.30
Australia	4	4.30
Poland	3	3.22
Belgium	2	2.15
Greece	2	2.15
Japan	2	2.15
Malaysia	2	2.15
Saudi Arabia	2	2.15
Other 13 countries with one paper	13	13.97
Total	93	100

CONCLUSION

This paper presented a comprehensive review of the literature on fire-risk assessment methodologies and applications consisting of 93 papers from 13 scholarly journals. For this purpose, a classification scheme was developed to organize each paper into several categories. The fire-risk assessment papers in the proposed scheme were categorized into application areas and then were classified by year of publication, application areas, journal of publication, year of publication and application areas and authors' nationality. Moreover, papers under application areas were sub-classified into 7 different topics.

The results show that the most articles have been published in the field of environmental management and the most articles have also been published by the Chinese and USA researchers. The reasons for the publication of the most articles in the field of environmental management and in two mentioned countries can be as following:

1. China and USA are at the largest industrialized countries. Industries in both countries are producing significant greenhouse gases. The number and variety of industries in both countries also play a significant role in the destruction of the environment. One possible outcome of extensive industrialization can be ecosystems and climate change. As a result of these changes is a natural and man-made fires increase. So it is natural that researchers and specialists of the two countries be sensitive to environmental issues.
2. Severe fires in recent decades in various countries including China and USA have caused that many public and private organizations plan to reduce the likelihood or severity of fires and protect people and property and the environment [17].

Most papers have been published in the Forest Ecology and Management journal. It could be due to the fact that this journal is exclusive journal in the field of environment and according to the aforementioned reasons the most articles have been published in it.

Publication in different years has not specified trend. This shows that there is no systematic approach to fire and fire-risk assessment.

Our study has some limitations. The first was that the findings are based on the data gathered from scientific journals, which do not include master's theses, textbooks, doctoral dissertations, conference proceeding papers, and unpublished working papers in the fire-risk assessment literature. The second is that the findings were focused on English journals; hence the journals in the non-English languages were not concerned. Although this means that the review is not all-inclusive, the authors believe that it provides a comprehensive review, and includes the majority of papers that were published by scientific journals. Finally it can say that in many countries fire-risk assessment is not in consideration. As well as municipal and industrial fire-risk assessment studies have been ignored. More attention is recommended to scientific study about municipal and industrial fire risk assessment.

ETHICAL ISSUES

Ethical issues have been completely observed by the authors.

CONFLICT OF INTEREST

Authors of the manuscript did not have conflict of interest.

AUTHORS' CONTIBUTION

Authors contribute on this study as following items:
Parisa Moshashaei: Collecting and revising the data and drafting the manuscript
Seyed Shamseddin Alizadeh: Study design and revision

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