FACTA UNIVERSITATIS
Series: **Working and Living Environmental Protection** Vol. 18, Nº 3, 2021, pp. 187 - 195
https://doi.org/10.22190/FUWLEP2103187B

Original Scientific Paper

THE IMPACT OF EXACERBATING CIRCUMSTANCES ON OCCUPATIONAL RISK IDENTIFICATION AND ASSESSMENT FOR MEMBERS OF FIRE AND RESCUE UNITS

UDC 331.45:614.84-057.036

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Abstract. *The job of a firefighter/rescuer is characterized by exposure to all types of mechanical, physical, chemical, and biological threats to life and health, and it is often performed in uncontrolled work conditions, which also involve stress. Their long-term effects on firefighters' health and ability to work are constantly emphasized, which is why the awareness of exacerbating circumstances, i.e. the factors contributing to risks and injuries, is an essential prerequisite for an efficient assessment of hazards and prevention of accidents and injuries. This paper discusses the results of a study on the factors influencing the outcome of a fire and rescue intervention, specifically the incidence of injuries among firefighters/rescuers. The examination of the influence of such factors will be used for a more precise risk identification, a more reliable risk assessment, a better understanding of "accident mechanism", and for more comprehensive database creation, which would improve the occupational risk management system for firefighters/rescuers.*

Key words: *firefighter/rescuer, fire and rescue intervention, risk, multi-risk, hazards, occupational injury*

1. INTRODUCTION

Firefighting activities involve active implementation of preventive fire and explosion safety measures, fire suppression, the rescue of people and property threatened by a fire or explosion, provision of technical assistance for accidents and hazardous situations, and performance of other tasks in different types of accidents. Since there are numerous

Received December 02, 2021 / Accepted December 6, 2021
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potential hazards, harms, and cases of exertion to which firefighters are exposed when they respond to a call and which can damage their health, the care for firefighters' safety and health needs to be all-encompassing and continuous in order to identify hazards and health threats in a timely manner and to prevent further damage. As firefighters/rescuers are exposed to a high level of physical and mental exertion, in addition to adequate equipment, continuous improvement, and training, they also need to be provided with professional psychological assistance (1). Hazards, harms, and exertion related to firefighters are classified according to the Rulebook on Risk Assessment Method and Procedure in the Workplace and the Work Environment (2).

During fire and rescue interventions, members of fire and rescue units (FRUs) are faced with a wide array of situations or events in which they are exposed to direct risk of injury. The aim of this paper is to establish the influence of key factors, i.e. exacerbating circumstances, on the safety of firefighters-rescuers. To better understand the issue, it is necessary to provide a brief overview of definitions of the terms *accident, incident*, and *occupational injury*. Scientific and professional literature defines an accident as an unplanned and unexpected event (instance) that causes a negative effect, halts work, and endangers human health [3]. Anđelković believes that the term *incident* can encompass minor injuries and situations in which workers avoided injuries; however, the term occupational incident is too weak to denote events resulting in serious injury or death. The same author also believes that *occupational incident* is the appropriate term to denote a state in which work has been disturbed in some way [3].

Shannon & Manning, for instance, define an accident as an uncontrolled energy transfer resulting in injury, while Farmer & Chambers claim that, from a psychological perspective, accidents are only an error in an otherwise correct action in a given situation. Brown defines an accident as an "unplanned product of inadequate behaviour" [4].

There are many theories on accidents: the iceberg model, the SHELL model, investigation of safety issues, the organizational theory, the pure chance theory, unequal initial liability, the stress theory, the alertness theory, psychoanalytical theories, the epidemiological and ergonomic theory, the domino theory, etc. Of the mentioned theories, the iceberg model (Figure 1) is the most commonly used (4).

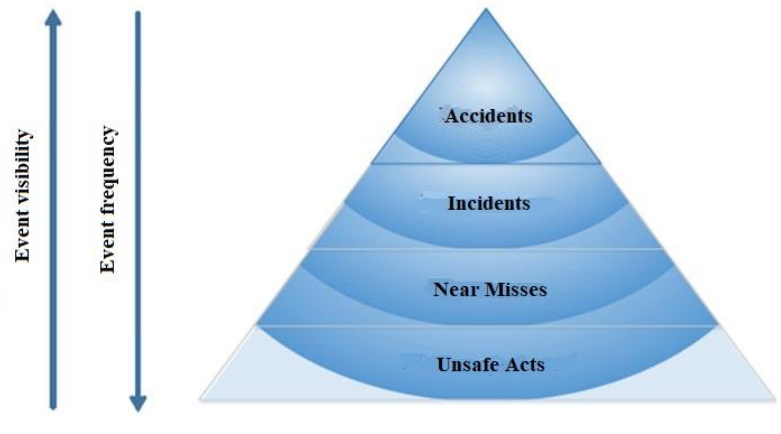

Fig. 1 Accident causation according to the iceberg model (4)

According to the iceberg model, unsafe acts constitute the key component that, in conjunction with other unfavourable circumstances or errors, leads to accidents. Therefore, analysis of errors and unsafe acts can significantly help reduce and prevent accidents. On the other hand, another factor influencing the safety of a technological system is the interrelationship between the technical and human aspects, as well as their relationship with the organizational structures of such a system (4).

Literature, as well as practice, often defines accidents as unplanned and unexpected events that have a negative impact on the work or natural environment. Thus, Heinrich defines an accident as “an unplanned and uncontrolled event in which the action or reaction of an object, substance, person, or radiation results in personal injury” (5). Neuloh defines an accident as “an undesired and unexpected disturbance of the normal completion of the work process, which is generally brought about by the combination of internal or external factors of a technical, physical, or social nature and which leads to injuries” (3).

Krug defines an injury as a bodily lesion affecting organs resulting from acute exposure to energy (mechanical, thermal, electrical, chemical, radiant) interacting with the body in amounts that exceed the threshold of physiological tolerance (3). Yet, without delving any deeper into the wide variety of occupational injury definitions, a satisfactory definition can be found in domestic literature, coined by Marković, Milutinović & Spasić: “An occupational injury involves the impairment of a person’s physical integrity in the work environment, manifesting as damage (or destruction) of some of its parts, as a being with body and organs, followed by the disruption of the harmonious functioning of different body parts or by the person’s death” (3). According to such a definition of injury, which is also referred to in the literature as *harm* and *trauma*, it is forcible damage to the body caused by the exertion of a force. Depending on the type of that force, injuries are divided into physical, chemical, biological, and psychological. Physical injuries are due to mechanical, thermal, and electrical energy, and radiation (3).

The Law on Pensions and Disability Insurance defines occupational injury as “an injury to the insured person that is spatially, temporally, and causally associated with the performance of the job on the basis of which the person is insured and that is caused by direct and short-lived mechanical, physical, or chemical effects, abrupt postural changes, sudden load to the body, or other changes in the physiological state of the body” (6).

2. Statistics of Fire and Rescue Interventions Regarding Injuries and Fatal Injuries

During firefighting interventions, members of FRUs face an array of situations or events in which they are exposed to immediate danger of injury (7). Despite all of these hazards, occupational accidents and injuries during interventions are fairly rare. Statistical data indicate that every year 2.8 fires break out per 1,000 people, two fire-related deaths occur per 100,000 people, 0.93 deaths occur per 100 fires, and 0.35 firefighters die per 10,000 fires (8).

Safety measures, the use of special protective equipment, and strict adherence to intervention procedures can significantly reduce the number of risk events, and if one does occur, its unwanted effects (structural damage or firefighter injuries/deaths) will be reduced. Yet, accidents do happen, albeit rarely, but the severity of the consequences (death or permanent work disability) requires that the high-risk situations and events are prevented and their effects, in the worst-case scenario, be mitigated (9). Knowledge of the factors contributing to risks and injuries is necessary for any efficient hazard assessment and accident and injury prevention.

Another domestic author, Dragan Mlađan, focused on fire and rescue units in Serbia and other countries and he obtained the following data: from 2009 to 2018 as many as 336,507 fires and explosions were registered in Serbia, 31,746.6 on average annually, in which 1,351 people died (84.5 on average annually), 4,568 were injured, and 4,414 were rescued. Individual fire risk (ratio of the number of fatalities to the population size) in Serbia is considered acceptable according to the globally recognized criteria (8).

Table 1 shows the annual average number of injuries and deaths from 2009 to 2018, both for firefighters/rescuers and other persons involved. The data refer to Serbia without Kosovo and Metohija.

Table 1 Statistics of injuries and fatal injuries in Serbia from 2009 to 2018

Report for 2009-2018		Report for 2009-2018	
Injured in a fire		Died in a fire	
Firefighters	38.8	Firefighters	0.1
Others	373	Others	86.7
Total	411.8	Total	86.8
Injured in a technical intervention		Died in a technical intervention	
Firefighters	2.1	Firefighters	0
Others	787	Others	310.2
Total	789.1	Total	310.2
Injured in other interventions		Died in other interventions	
Firefighters	2.9	Firefighters	0.1
Others	23.3	Others	25.5
Total	26.2	Total	25.6

3. Factors Impeding Fire and Rescue Interventions (Multi-Risk)

Firefighting entails numerous hazards that directly threaten fire and rescue units during interventions. The hazardous factors include the following:

Hazards during movement at the intervention site. The movement of firefighters/rescuers during an intervention needs to be particularly careful in areas with reduced visibility. Movement carries the risk of falling through openings in the floor or weakened parts of the floor, of stumbling and falling over a variety of obstacles in the way, or of hitting one's head on the hanging beams or parts of the ceiling. Movement up and down the stairs poses the danger of slipping and falling. Movement on the roof or other high points of a building poses the danger of falling through weakened parts of the roof or falling due to slippage or reaction force from the nozzle carried by the firefighter (10).

Hazards due to structural collapse during the intervention. In this case, structures refer to load-bearing walls, columns, staircases, and all parts of the building that bear the load of other structures built on top of them. Structural collapse during a fire usually occurs in the flare-up stage, when temperatures rise to a level that reduces the load-bearing capacity of structures. Whatever the cause, structural collapse poses immense danger to anyone participating in fire suppression actions or, during an evacuation, to both firefighters and the persons being evacuated (10).

Hazards due to heat and high temperatures. Presence of heat during fire interventions considerably impedes the work of firefighters and poses a threat of sustaining burns. The heat generated during a fire affects firefighters not only in terms of high temperature but also in terms of radiation from the flames (10).

Electric shock hazards. Electricity always poses a risk of electric shock, injury, or death of firefighters/rescuers. The hazard is further augmented when the body of a person sustaining an electric shock is propelled back upon contact with electrically charged water, leading to a potential fall and injury. Electrical hazards are present during almost every firefighting intervention. Likewise, substation fires are very hazardous, since the voltage is much higher than in households. Finally, improperly installed electrical wiring inside a building (power supply from two sides) poses a particularly serious hazard (10).

Hazards due to combustion products. The quality of combustion is measured in terms of the presence of products of incomplete combustion. In complete combustion, all combustible elements involved in the process emerge as 'true' combustion products CO_2, SO_2, and H_2O and residual O_2 and N_2. In incomplete combustion, in addition to the aforementioned products, there are also CO, H_2, C_mH_n, C_{fix}, and the inert N_2 component. Complete combustion generates more heat than incomplete combustion. Combustion products are responsible for many hazards, such as reduced visibility and reduced oxygen concentrations in the air, which often leads to suffocation and sometimes affects the skin and other organs (11).

Explosion hazards. Hazards of explosions are present whenever a fire breaks out in spaces containing pressurised vessels or vessels containing explosive materials. Particularly hazardous explosions are those due to chemical reactions. Explosions can also occur when water comes into contact with high-temperature objects, leading to water thermolysis and the appearance of explosive oxyhydrogen gas. Dust explosions in the food, wood processing, metalworking industries and the like are another common occurrence (12).

Hazards due to aggressive and toxic materials. Aggressive and toxic materials can cause various injuries and even death to firefighters. Hazards occur when aggressive and toxic materials are released from the vessels in which they are stored (tanks, tank trucks, tank wagons, etc.). Their vapours and direct action threaten firefighters and make their work all the more difficult (12).

The firefighting process is primarily a set of activities requiring a precisely defined organisation and sequence of procedures and often proceeding in difficult conditions, which include lack of water for fire suppression, fire suppression at low temperatures, fire suppression during strong winds, or fire suppression during the night.

4. Research Results

The analysis involved three FRUs, located in Kosovska Mitrovica, Leposavić, and Zubin Potok, from 2009 to 2018. During this period, all three FRUs recorded a total of 7,668 interventions in their intervention registries for every fire station (13). A multi-risk analysis was performed, specifically, the analysis of increased risk due to a build-up of various circumstances that can impede interventions or increase the hazards of injury (14). Multi-risk, which is a result of the professional risk to firefighters during interventions, is a challenge to be faced through proper consideration of undesirable effects among potential hazards or situations in which a single potential hazard can produce one or more subsequent potential hazards (15).

Movement obstacles and exposure to smoke and high temperatures are constant work conditions of FRU members during interventions. Movement obstacles are listed as work interference in 94.3% of interventions, exposure to high temperature in 93.4% of interventions, and exposure to smoke in as many as 99.1% of interventions. What is of special interest here is the other circumstances, which do not occur as frequently, but when they do, they additionally impede work and increase risk. The reported incidence of such circumstances is shown in Table 2.

Table 2 Circumstances additionally impeding work during fire interventions

Circumstance	Incidence
Work near live electrical installations	36.9%
Structural collapse hazard	35.3%
Unfavourable meteorological conditions	25.2%
Work with hazardous materials	18.9%
Explosion hazards	18.0%
Work at height	14.5%

The multi-risk variable is created as an index with values ranging from zero to nine based on the data obtained from interviews with fire and rescue responders. The responders were asked to assess whether there had been any exacerbating circumstances during their interventions. For each circumstance reported by the responders, the index value was increased by one. The collected data were used to create the multi-risk index, whose values range from zero (no additional exacerbating circumstance apart from smoke, high temperature, and hindered movement) to six (presence of all circumstances listed in Table 2). The incidence of specific index values and the mean index value are given in Table 3.

Table 3 Multi-risk index

Multi-risk index	Incidence	Percentage	Cumulative percentage
0	67	21.1	21.1
1	110	34.7	55.8
2	82	25.9	81.7
3	36	11.4	93.1
4	20	6.3	99.4
5	2	0.6	100.0
Total	317	100.0	
Arithmetic mean = 1.49		std. deviation = 1.16	median = 1

The relation between intervention outcomes and multiple hazards measured by the multi-risk index is shown in Table 4.

Table 4 Multi-risk index average value according to intervention outcome

Were there any injuries or risks of injury during the intervention?	Arithmetic mean	N	Std. deviation
No risk	1.23	260	1.00990
Avoided injury	2.74	46	1.10423
Injuries occurred	2.36	11	1.12006
Total	1.49	317	1.16545

$F = 46.234$ ss = 2.314 sig. < 0.001 Eta = 0.477 $Eta^2 = 0.227$

The very high Eta coefficient indicates a strong relation between intervention outcome and multi-risk index. Almost a quarter of the multi-risk index variance (22.7%) can be explained by means of intervention outcome. The relation is statistically significant at the level of 0.001, which means that the probability of error is 1:1000 if it is claimed that there is a relationship between multi-risk and intervention outcome.

Analysis was also performed to determine if the strength of the relation between multi-risk and intervention outcome differs if only the outcomes in which injuries occurred are considered as risk outcomes, as opposed to high-risk interventions and those in which injury hazard was present but injuries were avoided. If only the interventions in which injuries occurred are considered to be risk interventions, then the relation between multi-risk index and intervention outcome (expressed as the difference of arithmetic means) is statistically significant. The correlation coefficient of 0.143 is significant at the level of 0.05 (all data are shown in Table 5).

Table 5 Multi-risk index in interventions with and without injuries

Was any firefighter injured?	N	Multi-risk index		
		Arithmetic mean	Std. deviation	Std. error
No	306	1.4575	1.15652	0.06611
Yes	11	2.3636	1.12006	0.33771

t = 2.556 ss = 315 sig. = 0.011 95% confidence interval from 1.60 to 0.21

The difference of arithmetic means of 0.9061 is statistically significant at the level of 0.05.

If risk interventions also comprise interventions in which injury hazards were present but injuries were avoided (Table 6), the correlation coefficient is significantly higher (0.474) and has a significance level of 0.001. This finding also indicates that multi-risk is one of the key factors influencing the intervention outcome and that the risk assessment model will differ if risk interventions include interventions with avoided injuries in addition to interventions with injuries.

Table 6 Multi-risk index in risk (injuries and avoided injuries) and no-risk interventions

Was any firefighter injured or at risk of being injured?	N	Multi-risk index		
		A.S.	Std. dev.	Std. error
No	260	1.2308	1.00990	0.06263
Yes	57	2.6667	1.10733	0.14667

t = 9.551 ss = 315 sig. < 0.0 95% confidence interval from 1.14 to 1.73

The difference of arithmetic means of 1.4359 is statistically significant at the level of 0.001.

5. Discussion

Knowledge of the factors contributing to risk events and injuries is necessary for efficient hazard assessment and accident and injury prevention. The analysis determined which factors affect the intervention outcome, which was the dependent variable in this study. Three values were included: no-risk intervention, intervention with a risk event, and intervention with an injury. Independent variables were classified into several groups of factors. This study particularly focused on the *multi-risk* factor. The influence of factors on the intervention outcome was determined using bivariant analysis of relations between the dependent variable and specific independent variables. The examination of the influence of multi-risk on injuries of firefighters/rescuers yielded the results presented below.

Multi-risk analysis is actually the analysis of increased risk due to a build-up of various circumstances that can impede the intervention or lead to injury hazards. The analysis involved movement obstacles, exposure to high temperature, exposure to smoke, structural collapse hazards, work at height, work near live electrical installations, presence of hazardous materials, explosion hazards, unfavourable weather conditions (wind and/or precipitation). If risk interventions included only those with reported injuries, the relation between the multi-risk index and intervention outcome (expressed as the difference of arithmetic means) was statistically significant. The correlation coefficient of 0.143 was significant at the level of 0.05. If risk interventions also included those with injury hazards but in which injuries were avoided, the correlation coefficient was significantly higher (0.474) and had a significance level of 0.001. This finding also indicated that the risk assessment model would differ if risk interventions included interventions with avoided injuries in addition to interventions with injuries.

The presented part of the analysis showed which variables are connected with the dependent variable when observed in isolation, without the influence of other independent variables. Each of these variables could be a good predictor of the dependent variable – multi-risk. The analysis not only determined which factors influence the occurrence or high probability of injuries during interventions, but also emphasised the importance of performing risk assessments by including situations in which injuries could have occurred but were avoided, in addition to situations in which injuries really occurred. The results showed that specific conditions of fire and rescue interventions require a modification and improvement of models for fire and rescue occupational risk assessment.

Occupational safety and health of firefighters/rescuers is a challenge that requires special attention because their job cannot only be seen as a means of livelihood, but also as an opportunity for personal growth and professional fulfilment, including positive expectations and recognition by the organisation, acknowledgement for achieved results, and equal opportunities to develop and advance.

Acknowledgement: *The paper presents the results of research supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Agreement No. 451-03-9/2021-14/200148).*

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UTICAJ OTEŽANIH OKOLNOSTI NA IDENTIFIKACIJU I PROCENU RIZIKA NA RADU ZA PRIPADNIKE VATROGASNO-SPASILAČKIH JEDINICA

Posao vatrogasca/spasilaca karakteriše izloženost svim vrstama mehaničkih, fizičkih, hemijskih i bioloških opasnosti po život i zdravlje, a često se obavlja u nekontrolisanim uslovima rada, koji podrazumevaju i stres. Stalno se naglašava njihov dugoročni uticaj na zdravlje i radnu sposobnost vatrogasaca, zbog čega je svest o pogoršavajućim okolnostima, odnosno faktorima koji doprinose opasnostima i povredama, suštinski preduslov za efikasnu procenu opasnosti i prevenciju udesa i povreda na radu. U ovom radu se razmatraju rezultati istraživanja o faktorima koji utiču na ishod vatrogasno-spasilačke intervencije, odnosno učestalosti povreda među vatrogascima/spasilacima. Ispitivanje uticaja ovakvih faktora koristiće se za precizniju identifikaciju rizika, pouzdaniju procenu rizika, bolje razumevanje „mehanizma udesa", kao i za stvaranje sveobuhvatnije baze podataka, čime bi se unapredio sistem upravljanja profesionalnim rizikom za vatrogasce/spasioce.

Ključne reči: *vatrogasac/spasilac, vatrogasna i spasilačka intervencija, rizik, višestruki rizik, opasnosti, povreda na radu*