

ANALYSIS OF RISK AND NO-RISK INTERVENTIONS BY MEMBERS OF FIRE AND RESCUE UNITS UNDER MULTI-RISK CONDITIONS

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**Marijola Božović¹, Emina Mihajlović²,
Nenad Živković², Snežana Živković²**

¹Polytechnic School for Vocational Studies, Zvečan, Serbia

²Faculty of Occupational Safety in Niš, University of Niš, Serbia

Abstract. *The issue of occupational safety and health of the members of fire and rescue units has been continuously studied by numerous authors. Their interest stems from the constant need to improve the methods and procedures of occupational safety and health assessments for fire and rescue unit members, all for the purpose of preventing injuries, primarily the fatal ones. The fact that a certain number of high-risk situations in which firefighters avoid an injury or death remain unreported poses a serious threat to the firefighters' safety. This threat has been unjustifiably neglected and it is what motivated the research discussed in this paper, which reveals the results of three discriminant analyses.*

Key words: *safety, risk, multi-risk, fire and rescue members, fire and rescue intervention*

1. INTRODUCTION

In order to comprehensively approach the issue at hand, it is first of all necessary to determine the workplace risks and safety of fire and rescue members as the cornerstone of the integrated safety and rescue system in Serbia [1]. It is also necessary to study the accidents that result or may result in injuries, health risks, or death of firefighters who respond to emergencies.

Investigating the topic of occupational health and safety, Anđelković claims that injuries themselves are of secondary relevance in terms of the preventive component of a safety and protection system and that the primary goal is to establish their causes in order to undertake preventive action. For accident prevention to be successful, it is not enough

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Corresponding author: Snežana Živković

University of Niš, Faculty of Occupational Safety, Čarnojevića 10a, 18000 Niš, Serbia

E-mail: snezana.zivkovic@znrfak.ni.ac.rs

to study only the events that led to an injury, but also the events that pose a potential hazard [2].

Following Anđelković's claim and with the fact that there are innumerable risk events that remain unrecorded and in which firefighter injuries are only avoided by chance, it is crucial to study the accidents in which firefighter injuries were avoided in order to provide a detailed account of occupational risk involving the members of fire and rescue units (FRUs).

2. TYPES OF COMMUNICATION

The job of a firefighter/rescuer is characterized by exposure to various types of mechanical, physical, chemical, and biological threats to life and health, and is additionally often performed under uncontrolled work conditions. Risk and stress are inseparable parts of firefighting [3]. Their long-term effects on firefighters' health and ability to work are constantly emphasized but have still not been precisely defined. Considering that there are numerous 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 timely identify hazards and health threats and to prevent further damage. Hazards, harms, and exertion related to firefighters are defined and regulated by the Rulebook on Risk Assessment Method and Procedure in the Workplace and the Work Environment [4].

Due to highly specific work conditions and multiple risks, which cannot be fully avoided, it is crucial to keep proper records of all fire and rescue interventions and occupational injuries, should they occur. Keeping proper records of FRU interventions involves the input of all relevant data that describe the entire response procedure. Among other things, the relevant data can also be used to analyze whether the intervention was successful, as good practice and experience for the firefighters. Analyses of completed interventions can help identify potential oversights and irregularities that could prove crucial to the improvement of tactical operations and future interventions and thus also improve safety during interventions [5].

In order to properly assess to what extent the occupational risk to firefighters is dependent on the multi-risk of the reported accident, special emphasis should be placed on how to approach the issue of multi-risk because, during interventions, professional firefighters are often exposed to the negative impact of a variety of potential hazards.

For the purpose of the present study, multi-risk is defined as a situation in which two or more potential hazards are combined, if the hazards are simultaneous or consecutive, if they are interdependent or caused by the same triggering event or trigger, and if they pose a threat to the same elements (vulnerable or exposed elements) without chronological coincidence [6].

Multi-hazard risks represent the overall risks to which the population is exposed [7]. Multi-risk, which causes the occupational risk to firefighters during interventions, is a challenge to be faced through proper consideration of the possible side effects among the potential hazards, i.e. situations in which one potential hazard can cause one or more consecutive potential hazards [8].

3. HIGH-RISK SITUATION RECORD-KEEPING FOR FIRE AND RESCUE UNITS – 'LIGHT AND DARK FIGURE'

According to the Serbian Law on Occupational Safety and Health [9], the Rulebook on the Content and Issuing Procedure of the Occupational Injury and Disease Report [10], and the reports compiled within the FRUs, only the instances of occupational injuries that actually occurred are included in statistical records. The records usually include the consequences such as death, loss of ability to work, the extent of injury, and the extent of damage and they often list the probable causes of injuries. This information is commonly obtained from healthcare services and health insurance funds, which record injuries and diseases, from internal affairs services (police, fire and rescue), which keep the records through their reports on interventions, causes of fire, and responsibility for the injuries incurred, as well as from insurance companies, which maintain records of injuries relevant for potential loss or injury compensation cases.

A major issue with this system of security information sharing is that a certain number of high-risk situations remain unrecorded because firefighters were able to avoid injury or death. Since there are no fatalities or injured persons, no actions are taken to officially record situations that pose a serious safety risk.

By analogy with the so-called *dark figure* of crime, used in criminology, it is reasonable to speak of the dark figure of risk. It is first necessary to expound on the term *dark figure* as it is used by criminologists. Aćimović states that the actual number of crimes always remains unknown, and the difference between the number of crimes committed and those reported is called the dark figure (French *chiffre noir*, German *Dunkelfeld*) of crime or hidden criminality (French *criminalité cachée*) [11]. However, statistical records are problematic not only because they do not measure the actual criminality but also because the value of what they do measure is often dubious. The criticism of such statistics is generally twofold: one targets their inaccuracy due to inadvertent errors, while the other focuses on deliberate falsification of data.

The definition of the *dark figure* of crime indicates that the near-accidents that posed a serious risk to the safety of firefighters and that were avoided through force of circumstance will become a major problem, as they can lead to a faulty understanding of occupational risk by the firefighters.

The problem arises because a certain number of high-risk situations remain unrecorded since the firefighters did not suffer any injury. Thus, in the absence of injuries or fatalities, no actions are taken to record the situation that constitutes a serious safety threat. Under the given circumstances, the probability of potential consequences of such accidents was very high. The existence of the dark figure can also result in a faulty assessment of the role that specific factors play in the occurrence of high-risk situations.

Using the idea behind the dark figure of crime, this study analyzes occupational injuries as well as high-risk situations that were never officially recorded and in which firefighters narrowly avoided injury. Unrecorded accidents were statistically analyzed in order to find whether the influence of specific risk factors/sources in situations where injuries did happen differs from their influence in injury-free situations.

The aim of this study is to register and analyze situations that remained officially unrecorded in order to obtain results that could improve the way in which occupational risks to firefighters are currently dealt with, all for the purpose of taking additional preventive measures to ensure a safer work environment for FRU members.

4. RESULTS AND DISCUSSION

During response interventions, FRU members are faced with a wide array of situations or events in which they are exposed to direct risk of injury [12]. Despite all the risks, occupational accidents and injuries of FRU members during interventions are fairly rare. Statistical data show that 2.8 fires break out annually per 1,000 people, that there are 2 fire-related fatalities annually per 100,000 people, that there is an average of 0.93 human fatalities per 100 fires, and that 0.35 firefighters die per 10,000 fires [14]. Safety measures, use of personal and specialized protective equipment, and adherence to the rules during interventions significantly lower the number of high-risk situations, and even if an accident does occur, they help minimize the unwanted negative effects, such as death or injury to firefighters or property damage. Yet, accidents do happen, albeit rarely, and the seriousness of their effects (loss of life or permanent work disability) requires the prevention of high-risk situations and events and the mitigation of the effects if accidents actually happen [13]. Thorough knowledge of the factors contributing to risks and injuries is a prerequisite for any efficient hazard assessment and accident/injury prevention, which is exactly what this study is aimed towards.

The basic unit of analysis in this study is an FRU intervention. The basic set of investigated units comprises 7,668 interventions carried out by three FRUs in the northern part of Kosovo and Metohija between 2009 and 2018. The sampling plan was to use 3,985 interventions carried out over five years (2014-2018) in order to systematically randomly select interventions from the intervention records and to create a representative intervention sample of 400 units. The actual sample ended up with 355 interventions, which is 88.8% of the originally planned number. After 69 intervention had been excluded from the sample, as they did not involve any fire extinguishment operations, after six cases of injury had been added from the 2009-2013 period, and after another 26 cases of narrowly avoided injuries had been added, the definitive sample for the analysis contained 317 interventions (Table 1).

Table 1 Injuries and risks of injury during firefighter interventions

	Number	Percentage
No risk	260	82.0
Injury avoided	46	14.5
Injury occurring	11	3.5
Total	317	100.0

The first part of this study determined which factors influence the outcome of a fire and rescue intervention. This was achieved using the bivariate analysis of relations between the dependent variable and specific independent variables. The independent variables found to influence the outcome of the intervention (dependent variables) were then included (second part or second stage) in the creation of predictive models using logistic regression. The solution to the problem lies in the use of multivariate methods, which are used to examine the simultaneous influence of multiple variables on the dependent variable while isolating the individual influence of each independent variable. There is a fairly wide spectrum of multivariate methods to choose from and the one selected to analyze the problem in this study is discriminant analysis.

The following sections present the results of three discriminant analyses. In the first, intervention outcome is the dependent variable and the analysis is supposed to determine

which independent variables best discriminate three categories of interventions: interventions with no risk events, interventions with risk events, and interventions with injuries. The second analysis discriminates between interventions with and without injuries (regardless of whether any risk events occurred). Finally, the third analysis shows the best discriminants for interventions without risk events and interventions with risk events (regardless of whether any injuries were incurred).

4.1. First analysis: Differences between interventions without risk events, with risk events, and those with injuries

In order to better understand the relationship between predictor variables and intervention outcomes, all thirteen potential predictors were included in the analysis. The analysis was based on stepwise regression, which starts the analysis with all of the predictor variables and then excludes one by one insignificant variable until the most efficient discriminant function has been obtained. Out of thirteen variables initially included, ten of them did not meet the criteria for inclusion in the calculation of discriminant functions. The only three variables remaining were: number of exacerbating circumstances that hinder extinguishment (multi-risk), physical preparedness, and intervention duration.

The discriminant analysis yielded two discriminant functions based on which a maximum of three different categories of interventions were established: those in which injuries occurred, those in which there was a real danger of injuries but they were avoided, and those in which there was no risk whatsoever. The first of the two functions describes almost all of the differences between the intervention categories, shown in Table 2.

Table 2 Discriminant functions for intervention outcome

Function	Characteristic value	Variants described in %	Cumulative %	Correlation coefficient
1	0.730 ^a	98.5	98.5	0.650
2	0.011 ^a	1.5	100.0	0.104

The share of certain predictor variables in the discriminant function can be assessed based on standardized canonical discriminant function coefficients. The number of exacerbating circumstances for extinguishment (multi-risk) is the most important predictor in the model, and its standardized coefficient is 0.814. The second most important predictor is intervention duration, with the coefficient of 0.666, while physical preparedness has the coefficient of 0.477. To calculate the value of the first discriminant function for each intervention, the coefficients are multiplied by the standardized value of a corresponding variable. Low (negative) values of the first discriminant function usually characterize interventions without risk events. On the other hand, higher values of the first function are common in interventions with risk events and those with injuries. This discriminant function is fairly successful at discriminating between interventions without risk and those with risk or injuries but fails to discriminate between the latter two.

The value of an individual case (intervention) on the discriminant function can also be obtained from non-standardized data using non-standardized discriminant function coefficients (Table 3).

Table 3 Coefficients of discriminant functions

	Function	
	1	2
Number of exacerbating circumstances	0.792	-0.603
Intervention net duration	0.007	0.006
Physical preparedness	1.074	0.691
(Constant)	-6.774	-2.945

Example: If an intervention (n) lasts 90 minutes and if there are two exacerbating circumstances during its course (e.g. work at heights or presence of live electrical installations) and the response team's physical preparedness is assessed as 'excellent', the discriminant function score for the intervention will be

$$\begin{aligned} dn &= -6.774 + 2 \times 0.792 + 90 \times 0.007 + 5 \times 1.074 = \\ &= -6.774 + 1.584 + 0.63 + 5.370 = -6.774 + 7.584 = 0.81 \end{aligned} \quad (1)$$

Table 4 Average discriminant function scores for the three analyzed intervention categories

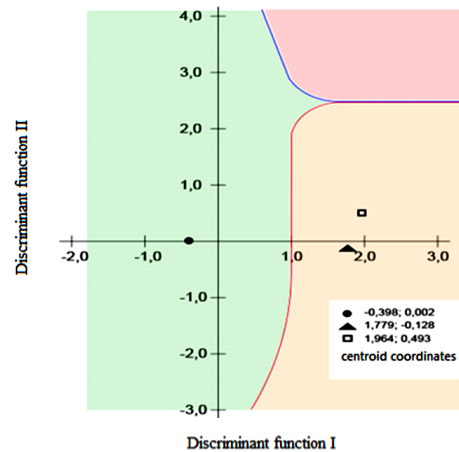
Occurrence of injuries or risks of injury during the intervention	Functions	
	1	2
No risks	-0.398	0.002
Injuries avoided	1.779	-0.128
Injuries incurred	1.964	0.493

As shown in Table 4, the discriminant function does not discriminate between interventions in which injuries were avoided and those in which injuries were incurred. Their scores are almost the same (the difference is 0.185), but they do differ compared to interventions in which there were no injuries or immediate risks of injury.

The second discriminant function discriminates between interventions with injuries and those in which injuries were avoided. Yet, the difference established from the sample is too small to pass the statistical significance test, so it can be disregarded and considered as non-existent.

The discriminant function scores used as coordinates enable the creation of a map that clearly delineates the regions dominated by interventions without risk, interventions with avoided injuries, and interventions with injuries, as shown in Figure 1.

The results of the discriminant analysis allow predictions to be made regarding the outcome of interventions, based on the knowledge of the values of predictor variables used. In this particular case, it means that if it is known how long the intervention lasted (or if its duration can be predicted with relative precision) and if it is known how many exacerbating circumstances accompanied the intervention and how physically prepared the

**Fig. 1** Territorial map

responders were, it will then be possible to predict if the intervention will end without risk, with risk, or with injuries to firefighters.

The territorial map above shows that interventions without risk occupy the largest region, shown in green, on the left side of Figure 1 (negative values on the first discriminant function and a small portion of the positive values, up to the score of 1). The centroid of these interventions, represented by a black bullet point, is at the centre of the region, which indicates that it is a fairly good representation of the entire category of interventions without risk. Interventions with risk but no injuries occupy the second largest region on the territorial map, in the right side of Figure 1 (values over 1 on the first discriminant function) and cover almost all of the right-hand portion of the map except for a small part in the upper right corner. The region is shown in orange. The centroid of these interventions (the black triangle) is at the centre of the region. The smallest region is that of interventions with incurred injuries. Its borders are not clearly delineated. In the graph, they are drawn in the space of high values on both discriminant functions (above 1.0; 2.5). However, the centroid of this intervention category is outside the region it refers to – it is placed deep within the region occupied by interventions with risk but no injuries. This indicates that it is very difficult to discriminate interventions with injuries as a clearly delineated and compact intervention category.

What is clear from the first discriminant analysis is that basically only one discriminant function discriminates between interventions with and without risk (regardless of whether any injuries occurred or were avoided in the former). The second discriminant function reveals very little and is practically ineffective.

The discriminant analysis also involves the prediction of the outcome based on discriminant function values and the comparison of the predicted outcome with the empirically verified actual intervention outcome. The results of the comparison are given in Table 5.

Table 5 Actual and predicted intervention outcomes

Occurrence of injuries or risks of injury during the intervention		Predicted outcome of the intervention			Total	
		No risks	Injuries avoided	Injuries incurred		
Actual outcome	N	No risks	250	7	3	260
		Injuries avoided	19	26	1	46
		Injuries incurred	4	6	1	11
	%	No risks	96.2	2.7	1.2	100.0
		Injuries avoided	41.3	56.5	2.2	100.0
		Injuries incurred	36.4	54.5	9.1	100.0

87.4% accurately classified

Out of 317 observed interventions, the outcome was accurately predicted for 277, which is 87.4% accuracy. The accuracy of the results was marred by the fact that prediction is not equally successful for all of the three intervention categories. The most accurate prediction was made for interventions without risks (96.2%), followed by interventions with risks but no injuries (56.5%) and interventions with injuries (only 9.1%).

4.2. Second analysis:

Differences between interventions with injuries and those without injuries

The attempt to model a discriminant function that discriminates between interventions with injuries and those without injuries (including the interventions with avoided injuries) resulted in the same selection of predictor variables from which the function was created. Once again, intervention duration, number of exacerbating circumstances, and physical preparedness of the response team were the variables that passed the test.

Table 6 Discriminant function for injuries/no injuries: main characteristics

Function	Characteristic value	Variants described in %	Cumulative %	Correlation coefficient
1	0.098 ^a	100.00	100.0	0.299

This time, however, the obtained discriminant function has a low characteristic value of 0.098. Interventions with and without injuries have different average scores on this function, even though predicting the outcome of individual interventions is quite problematic. The share of certain predictor variables in the discriminant function is somewhat different compared to the first analysis. Intervention duration is now the best predictor, with a standardized coefficient of 0.732. The other two predictors are almost equally important – a number of exacerbating circumstances (multi-risk) with 0.467 and physical preparedness with 0.449.

The non-standardized coefficients that can be used to calculate the discriminant function scores for each intervention are given in Table 7.

Table 7 Discriminant function coefficients

	Function 1
Number of exacerbating circumstances	0.404
Intervention net duration	0.007
Physical preparedness	1.039
(Constant)	-6.096

The attempt to predict whether or not injuries will occur in each intervention using the discriminant function was unsuccessful.

Table 8 Actual and predicted intervention outcomes

Were any firefighters injured?		Predicted outcome		Total	
		No	Yes		
Actual outcome	N	No	302	4	306
		Yes	10	1	11
	%	No	98.7	1.3	100.0
		Yes	90.9	9.1	100.0

95.6% accurately classified

The analysis began with 317 interventions, 306 of which were without injuries, while 11 resulted in injuries. If the only criterion were the distribution of the dependent variable, the prediction for each individual intervention would be 'no injury', and such a prediction would

be accurate in 96.5% of the cases. The prediction would be successful if, based on the discriminant function, interventions with injuries were to be accurately reclassified from the no-injury category to the one with injuries, without wrongly reclassifying the interventions that actually had no injuries. In the presented case, however, the exact opposite happened. Only one intervention was accurately reclassified from no injury to injury, while four interventions without injuries were wrongly reclassified as ones with injuries. The end result was 95.6% of accurately classified interventions, which is less than the prediction based entirely on the dependent variable distribution.

4.3. Third analysis: Differences between interventions without risk and those with risk (injuries and avoided injuries)

As opposed to the previous two analyses, in the discriminant analysis where the dependent variable has two values – (1) interventions with risk (injuries and avoided injuries) and (2) interventions without risk – as many as six variables passed the test for inclusion in the analysis. In addition to the variables that had already been proved to discriminate well between no-risk and all the other interventions (intervention duration, number of exacerbating circumstances, and physical preparedness), the third analysis also added the following variables: number of FRUs involved in the intervention, use of ‘other larger equipment’, and time of day with increased risk of injury.

Table 9 Discriminant function for risk/no risk: main characteristics

Function	Characteristic value	Variants described in %	Cumulative %	Correlation coefficient
1	0.808 ^a	100.00	100.0	0.669

This time, the discriminant function is a linear combination of six predictor variables. Their relative importance is expressed by standardized discriminant function coefficients, shown in Table 10.

Table 10 Standardized discriminant function coefficients

	Function 1
Number of exacerbating circumstances	0.763
Intervention net duration	0.618
Physical preparedness	0.465
Time of day with increased risk of injury	0.181
Number of fire and rescue units	-0.256
Use of ‘other larger equipment’	0.225

The first three predictors, which had already shown that they significantly contribute to the strength of the discriminant function, did so in this analysis, as well. Their order and relative importance are similar to those from the first discriminant function in the first analysis. In this instance, however, the value on the discriminant function is slightly modified by the three newly-added variables.

The non-standardized discriminant function coefficients, used to calculate the discriminant function score from the unprocessed values of predictor variables, are given in Table 11.

Table 11 Non-standardized discriminant function coefficients

	Function 1
Number of exacerbating circumstances	0.743
Intervention net duration	0.006
Physical preparedness	1.118
Time of day with increased risk of injury	0.517
Number of fire and rescue units	-0.538
Use of 'other larger equipment'	0.457
(Constant)	-6.408

When discriminant function values are calculated for every observed intervention and when the distribution of those values is considered separately for each intervention category according to the outcome, the results are noteworthy, as shown in Figure 2 below.

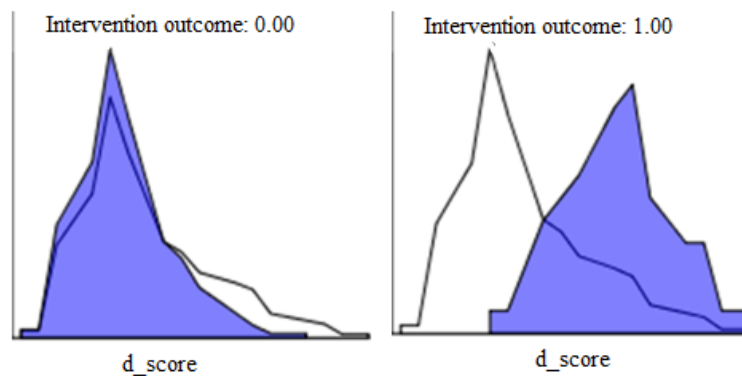


Fig. 2 Distribution of scores on the discriminant function for interventions without risk 0.00 (left) and interventions with risk 1.00 (right)

Note: White-filled (unshaded) graph, which looks the same in both charts, is the distribution of scores for all cases. Blue-filled (shaded) graphs are the distributions of discriminant function scores for interventions without risk (left) and interventions with risk (right).

The majority of safely completed interventions, i.e. those that ended with no injuries or risks of injury (avoided injuries), have negative scores on the discriminant function, as shown in Figure 2 (left). On the other hand, almost all interventions with injuries or risk events (avoided injuries) have positive discriminant function scores, as shown in Figure 2 (right). It can be seen already at the first glance that the two intervention categories are fairly well discriminated according to their discriminant function scores.

5. CONCLUSION

Three discriminant analyses were performed in this study. In the first, the dependent variable was the intervention outcome with three values: interventions without any risk events, interventions with risk events, and interventions with injuries. The second analysis

maximally discriminated between interventions with injuries and those without injuries (not necessarily without risk events). The third analysis maximized the difference between interventions without risk events and those that involved risk events (both with and without injuries).

All three discriminant analyses shared the following three predictor variables: number of exacerbating circumstances that hinder extinguishment (multi-risk), intervention duration, and physical preparedness assessment. The third discriminant analysis added another three variables to the model: time of day with increased risk of injury, number of fire and rescue units involved in the intervention, and use of 'other larger equipment'. The number of exacerbating circumstances (multi-risk) was the most important predictor, followed by intervention duration and the assessment of the responding team's physical preparedness. This ranking was disrupted only in the second analysis, with intervention duration being the most important predictor, followed by multi-risk. According to all success indicators of discriminant functions, the third analysis yielded the best results, discriminating between interventions without risk and those with risk.

The performed discriminant analyses led to the conclusions that fire and rescue interventions with injuries to the firefighters are extremely rare, that their prediction is unreliable and insufficiently precise due to the small number of analyzed cases, and that instances of injuries or avoided injuries during interventions do not occur if there are no risk events.

In addition, it is possible to relatively successfully model and predict interventions with risk events. According to the existing records, approximately every fifth intervention with a risk event results in an injury of at least one responder. Since it is possible to predict interventions with risk events with a fair amount of certainty, it is also possible to predict that an injury to a responder will occur in one in every five such interventions. This information can be used to considerably improve fire and rescue intervention planning and decision-making during the course of an intervention.

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ANALIZA RIZIČNIH I NERIZIČNIH INTERVENCIJA PRIPADNIKA VATROGASNO SPASILAČKIH JEDINICA U USLOVIMA MULTIRIZIKA

Problematika bezbednosti i zdravlja na radu pripadnika vatrogasno-spasilačkih jedinica neprekidno se izučava i predmet je interesovanja brojnih autora. Razlog je u permanentnoj potrebi za unapređenjem metoda i procedura procene bezbednosti i zdravlja na radu pripadnika vatrogasno-spasilačkih jedinica, radi predupređenja povreda, pre svega onih sa fatalnim ishodom. Imajući u vidu, da izvestan broj veoma rizičnih situacija ostaje neregistrovan kada pripadnici vatrogasno-spasilačkih jedinica izbegnu povredu ili pogibiju, to u suštini predstavlja ozbiljan rizik po bezbednost vatrogasaca koji je nepravedno zanemaren i koji nam je poslužio kao smernica za istraživanje u ovoj oblasti. U radu će biti prikazani rezultati tri diskriminantne analize.

Ključne reči: bezbednost, rizik, multirizik, vatrogasci-spasioci, intervencije