# ANALYSIS OF CAUSES AND CONSEQUENCES OF ELECTRIC CAR ACCIDENTS

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**Abstract.** The vision of a climate-neutral European continent directly relates to road transport, which represents an energy-demanding area. The annual increase in the share of electric cars also contributes to this vision in road traffic. Therefore, it is common that the driver of an electric car causes or is a participant in an accident. These electric powered vehicles require increased attention, especially in matters of the safety of emergency services in the event of accidents. The article is focused on the issue of electric vehicle accidents in terms of their causes and consequences. In this regard, it is important to understand all the risks, which result from accidents involving electric cars. The article is primarily focused on the analysis of the causes and consequences of accidents. For the purposes of risk analysis, the failure mode and effect analysis method is applied. In connection with the wide range of applications of the method in question in various systems and areas, the application of the method in the article is significant and unique. It is based on predefined scenarios of electric car accident events. Its application consists of identification and numerical phases. These are created and calculated on the basis of expert estimates and determine the level of risk of defined scenarios. The degree of risk in the form of a risk number defines the importance of an accident event. The article includes a diagram, which is based on Pareto analysis and points to the susceptibility of defined accident events. The importance of the analysis lies in the discovery of a small number of causes, which significantly influence the defined consequences of accident events.

**Keywords:** electric vehicle, risk, traffic accident, modelling, evaluation.

## Introduction

The green economy is an increasingly discussed topic in the world, and it is also transferred to the production of cars. More strict measures to reduce emissions led to the use of alternative energy sources. The current topic is electromobility, which has seen an increasing share in road transport in recent years [1; 2]. In 2050, according to the IEA, there will be a situation where only very few vehicles with combustion engines will be on the road [3; 4]. The development of electric vehicles is progressing, and new challenges are associated with each new technology, mainly for emergency services in the event of an accident. It means, that the area of safety is closely connected with the introduction of new energy sources into cars. As part of the procedures for performing rescue work in the event of an accident, it is important to be familiar with the risks in relation to the implementation of security procedures of the intervention units [5]. This is also related to the knowledge of the riskiest and most likely accident events of electric vehicles in road traffic. To compare the level of risk of individual defined scenarios of accident events of electric cars, the authors also focused on defining accident event scenarios of vehicles with an alternative energy source. Subsequently, a comparison of the risk level of selected scenarios of accident events for electric cars and other vehicles with an alternative energy source was carried out. The aim of the article is to analyse the causes and consequences of possible accidents involving vehicles with an alternative source of energy. Scenarios of accident events are developed for the purposes of risk analysis.

## Risk analysis of electric car accident events

Traffic accidents cause great material or financial damage, and the emergency services involved are exposed to various risks [6]. For the purposes of risk analysis, the method failure mode and effect analysis (hereinafter referred to as FMEA) was used. The goal is to identify the most risky event in the event of an electric car accident, which endangers people and emergency services. FMEA consists of two process phases. In the first stage it is necessary to identify and describe different scenarios of accident events. Their definition was based on the analysis of accident events and consultations with rescue services. In the second phase of the risk analysis, the degree of risk of the individual defined scenarios is determined, based on the calculation. The calculation takes into account the probability of an accident, the probability of its prevention and the significance of the traffic accident [7; 8].

Identification phase. Creation of accident scenarios of electric cars and vehicles with an alternative source of energy was based on real traffic accidents that occurred within the European Union in recent

years [6]. Accident events in the world were also taken into account. At the same time, consultations with members of the Fire and Rescue Service of the Slovak Republic were also used. Technology in the production of cars is constantly evolving, and new risks are associated with this, especially in the response activities of fire brigades [9-11].

Currently, the subject is a discussion about electric cars, the tactics of intervention in the event of a fire. Based on the analysis of accident events of electric cars, of vehicles with an alternative energy source and consultations, we identified four groups of accident events for electric cars and three accident events for vehicles with an alternative energy source. The scenarios of electric car accident events are as follows:

- **Electric vehicle fire.** A fire can be caused by several factors. In many cases of accidents, combinations of various factors occur. This event is characterized by high risk and danger for people as well as for rescue units.
- **Completely submerging the electric vehicle**. It represents a risk for the crew because their lives are at risk. Rescuers face various unexpected situations, which can be dangerous, as the vehicle is unstable in water. Water can also cause a short circuit in electrical wiring, or degrade the battery or other parts of the vehicle.
- **Freeing people from the electric vehicle**. People trapped in the car are exposed to the risk of electric shock if the high-voltage cables are damaged in the accident. If the car is not sufficiently stabilized, there is a risk of further injuries to the crew due to the possible movement of the vehicle.
- **Damage to the battery of the electric car**. If the vehicle hits an obstacle in a traffic accident, the battery can be damaged. As a result of burning, it releases electrolytes into the air, which are dangerous and cause health problems. An explosion can also occur in the event of a fire. Spontaneous ignition and battery explosion have been reported in some vehicles, which brings with it other consequences and threats [12].

For the purposes of risk analysis of electric vehicle event scenarios, we also analyse alternative energy source vehicle accident scenarios, that is, LPG, CNG and hydrogen vehicles. Scenarios of accident events of vehicles with an alternative source of energy:

- **LPG vehicle fire and LPG gas leakage from the tank**. The main threat is when the vehicle catches fire in an accident, because there may be an increase in pressure in the tank, where flammable vapours begin to expand and eventually an explosion occurs, which threatens to cause a blowout effect. Burning gas produces poisonous gases and vapours that are harmful to the human body. These situations cause financial and material losses.
- **Hydrogen fueled vehicle fire.** Hydrogen has similar effects to heat burns when it comes into contact with the skin. In the event of a vehicle fire with a cryogenic tank, there is a possibility of BLEVE followed by a fire ball. As a rule, when hydrogen is released, its initiation occurs.

With different scenarios of accident events of vehicles on an alternative energy source, it should be remembered that in most cases several scenarios take place at the same time. There are combinations of several consequences of accidents. For example, as a result of the impact a vehicle caught fire in which people were stuck and had to be freed by rescue services. At the same time, an accident involving vehicles with different energy sources may occur.

**Numerical phase.** The result of the numerical phase is the calculation of the risk rate expressed using the RPN risk number according to the formula:

$$RPN = PV \text{ x } VV \text{ x } PO \quad (1)$$

where PV – probability of occurrence of an accident;
VV – significance of the accident;
PO – probability of preventing the occurrence of an accident.

The following table shows the values of the parameters using a scale of 1 to 5.

Table 1

**FMEA analysis identification table**

| Probability of an accident | Value | Meaning of the accident | Value | Preventing accidents | Value |
|---|---|---|---|---|---|
| Improbable | 1 | An accident cannot be predicted | 1 | High | 1 |
| Very small | 2 | Negligible accident | 2 | Medium | 2 |
| Small | 3 | Moderately significant accident | 3 | Small | 3 |
| Medium | 4 | Serious accident | 4 | Very small | 4 |
| High | 5 | Extremely serious accident | 5 | Improbable | 5 |

The degree of risk was evaluated by ten firefighters in a questionnaire, where they evaluated each accident scenario according to Table 1. Using the resulting RPN value (1), it is possible to compare individual scenarios in terms of their consequences and causes. Finally, according to the value of the RPN, the most risky scenario of a traffic accident can be determined and the safety measures and procedures associated with the event can be defined. The total RPN value and the nature of the risk is: RPN (1-30): Acceptable – the process is safe, RPN (31-50): Moderate – the process is safe, RPN (51-90): Undesirable – the process is dangerous, RPN (91 -125): Unacceptable - the process is unacceptable. Table 2 shows the risk analysis using the FMEA method for individual traffic accident scenarios.

Table 2

**Numerical phase of accident scenarios**

| **Electric vehicle fire (FE)** | | | | | | | |
|---|---|---|---|---|---|---|---|
| No consequences traffic accident (FE1) | | | | With consequences traffic accident (FE2) | | | |
| Meaning | Occurrence | Prevention | RPN | Meaning | Occurrence | Prevention | RPN |
| 3.7 | 4.1 | 4.1 | 62.197 | 4.8 | 3.6 | 4.5 | 77.760 |
| **Immersion of an electric car in water** | | | | | | | |
| No consequences traffic accident (EI1) | | | | With consequences traffic accident (EI2) | | | |
| Meaning | Occurrence | Prevention | RPN | Meaning | Occurrence | Prevention | RPN |
| 3.8 | 2.6 | 1.9 | 18.772 | 4.6 | 2.6 | 2 | 23.920 |
| **Freeing people from the electric car** | | | | | | | |
| No consequences traffic accident (EP1) | | | | With consequences traffic accident (EP2) | | | |
| Meaning | Occurrence | Prevention | RPN | Meaning | Occurrence | Prevention | RPN |
| 4.1 | 3.1 | 3.0 | 38.130 | 4.7 | 3.9 | 4.3 | 78.819 |
| **Damage to the battery of the electric car** | | | | | | | |
| No consequences traffic accident (DE1) | | | | With consequences traffic accident (DE2) | | | |
| Meaning | Occurrence | Prevention | RPN | Meaning | Occurrence | Prevention | RPN |
| 4.2 | 3.3 | 3.4 | 47.124 | 4.8 | 1.8 | 3.7 | 31.968 |
| **LPG vehicle fire** | | | | | | | |
| No consequences traffic accident (LPGF1) | | | | With consequences traffic accident (LPGF2) | | | |
| Meaning | Occurrence | Prevention | RPN | Meaning | Occurrence | Prevention | RPN |
| 3.1 | 4.5 | 2.1 | 29.295 | 4.7 | 3.7 | 2.4 | 41.736 |
| **Leakage of LPG gas from the tank** | | | | | | | |
| No consequences traffic accident (LPG1) | | | | With consequences traffic accident (LPG2) | | | |
| Meaning | Occurrence | Prevention | RPN | Meaning | Occurrence | Prevention | RPN |
| 2.2 | 2 | 3.2 | 14.080 | 4 | 1.6 | 4.3 | 27.520 |
| **Fire of a vehicle powered by hydrogen** | | | | | | | |
| No consequences traffic accident (VF1) | | | | With consequences traffic accident (VF2) | | | |
| Meaning | Occurrence | Prevention | RPN | Meaning | Occurrence | Prevention | RPN |
| 4.2 | 1 | 3.8 | 15.960 | 5 | 1 | 3.6 | 18.000 |

After processing the questionnaires and determining the average values of the probability of occurrence of an accident, the severity of the accident and the prevention of the occurrence of an accident, the resulting RPN value was obtained for each scenario of the accident event. Figure 1 shows the results of the FMEA analysis graphically. It is obvious that the riskiest is an accident in which people are rescued from a crashed electric car.

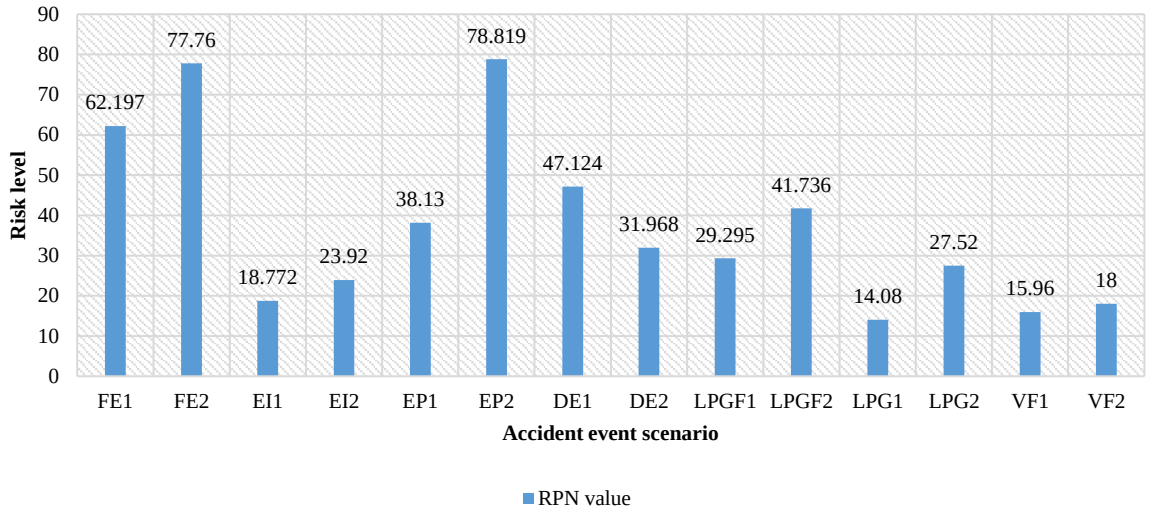


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Fig. 1. **Results of risk analysis using the FMEA method**

At the end of the risk analysis, the Pareto analysis is used. Using it, we create a diagram that points out the severity of specific scenarios of accident events. The purpose of this analysis is to reveal a small number of causes that significantly affect the overall result, specifically the consequences of traffic accidents.

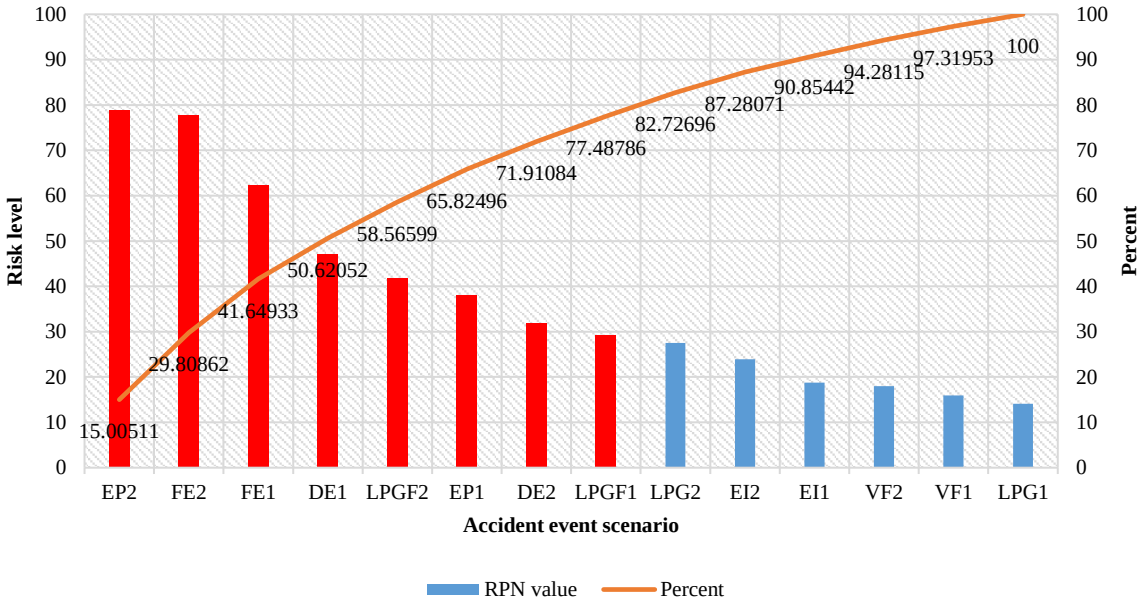


Fig. 2. **Pareto analysis**

The result of the Pareto analysis is that every scenario of an electric car accident event, regardless of whether it is the result of a traffic accident or not, has a high level of risk. Freeing people from an electric car in the event of an accident represents the most serious risk. This activity is associated with observing a wide range of safety measures, such as: stabilizing the vehicle against movement, disconnecting the high-voltage traction system, taking the vehicle keys to a distance of min. 15 meters and below. Another significant risk with electric cars is a fire, in which the explosion of the high-voltage

traction battery is not excluded due to the relevant security technology (battery safety elements). There is also a high risk of damage to the battery of the electric car. In case of damage, any handling is prohibited. In the event of an accident, electrolytes can escape from the battery, which are generally irritating, flammable and potentially corrosive substances. The high level of risk is concluded and subsequently divided into serious and less serious accident events in Figure 2, the fire of vehicles with LPG drive. In this case, the tank and multivalve, which is the main safety element, are very important. During the intervention, the rescuers face various threats. LPG is a flammable gas and, being heavier than air, there is a risk of it leaking into lower places. The concentration of gas with air forms an explosive mixture (1.8-10%) and there is also a risk of BLEVE. Burning produces irritating and poisonous fumes. After opening the safety valve, there is a risk of the flame blowing out. At high concentration LPG is suffocating. All scenarios of accident events can cause a serious threat to the health and life of people.

## Conclusions

New technologies are closely linked to the field of security. In the event of an electric car accident, it is necessary to understand all the risks related to the execution of rescue work. Individual scenarios, which are the content of the article and were subject to risk analysis, represent a useful tool for identifying the most risky and most likely accident events. The result of which is the use of information in the training of fire brigades, but also in humans. In the case of intervention, it is necessary to realize that the procedure for carrying out an effective intervention is very demanding in the framework of electormobiles and with the increasing number of these vehicles it is inevitable. Emergency services are perfectly familiar with ordinary vehicles, as well as people, but vehicles powered by other energy sources present different types of risks and require a higher level of access, which means for fire departments beyond normal training and education.

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## Author contributions

Conceptualization, M.B.; methodology, M.B.; software, J.K.; validation, M.B. J.K.; formal analysis, M.B.; investigation, M.B., J.K.; data curation, M.B and J.K. writing – original draft preparation, M.B. and J.K.; writing – review and editing, M.B.; visualization, J.K.; project administration, J.K; funding acquisition, M.B, J.K. All authors have read and agreed to the published version of the manuscript.

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