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DETERMINING VEHICLE FIRE HAZARD USING MCDM METHODS BASED ON BIOECOLOGICAL CRITERIA

Abstract: *Multi-criteria decision making (MCDM) methods can be applied to determine the hazard of vehicle fires from the point of view of protecting people and the environment, if experimental data are known for different types and models of vehicles from the measurements of harmful gases, toxic metals and compounds, and hazardous substances in smoke, soot, and ash from fires. Weighting methods are used in order to determine the weights of these criteria. This paper presents the results of applying the BWM (Best-Worst Method) as a weighting method and the PROMETHEE (Preference Ranking Organization METHod for Enrichment of Evaluations) as a multi-criteria decision making method for determining the fire hazard in the case of ICEV (internal combustion engine vehicles) and BEV (battery electric vehicles) fires. The results show that BEV fires are more dangerous than ICEV fires from a bioecological point of view.*

Keywords: fire hazard, electric vehicles, multi-criteria decision making method, weighting method

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INTRODUCTION

Electric vehicle (EV) fires are very difficult to be extinguished and require a large amount of extinguishing material. EV fires are particularly dangerous because they can re-ignite suddenly, days after the initial fire. One way to prevent re-ignition is to allow the vehicle to burn completely, but this is not the case in practice, as fire suppression and extinguishment are often required. Large amounts of waste water, extinguishing agents dissolved in this water, and various toxic materials are the harmful consequences of vehicle fires for human health and the environment. If the data for released harmful gases, toxic metals, and hazardous substances in smoke, soot, and ash, for different types and models of vehicles (Lecocq et al., 2012) are known from the experimental measurements, then vehicle fire hazards may be ranked based on bioecological criteria.

Multi-criteria decision-making (MCDM) methods (Huang et al., 2011) can be applied to rank the vehicle fire hazard, from the point of view of protecting people and the environment (Javor, 2024). One of the MCDM methods is PROMETHEE (Preference Ranking Organization Method for Enrichment of Evaluations), developed by Brans et al. (1984). In this paper, the Best-Worst method (BWM) (Rezaei, 2015a;i 2015b; Rezaei, 2016), as the weighting method, and PROMETHEE II (Brans & Mareschal, 2005), as the MCDM method, are used.

PROBLEM FORMULATION

If water is used for extinguishing EV fire, it can suppress the fire and cool the vehicle, but it can cause electrical faults and react with the lithium in the Li-Ion batteries, thus releasing various toxic gases and leaving toxic water after extinguishment (Sun et al., 2020). Flammable gases can also be released, and re-ignition can also result in an explosion. Although the primary task is to reduce the temperature of a battery that is overheated, access to the batteries in EVs is a significant problem. The batteries are hermetically sealed to prevent moisture and dust from entering and armoured to ensure resistance to mechanical shock. Therefore, water used for extinguishing only affects visible flames and the external surface of the battery pack, as well as the materials surrounding it. Tests have shown that around 10,000 litres of water are needed to extinguish a fire in the entire vehicle, which also depends on the size, type, and location of the battery. The flow rate of about 200 l/min for cooling and extinguishing the fire is high. This can generate large amounts of wastewater. Large amounts of fire extinguishing agents will also be dissolved in this water, which is why it is necessary to find the optimal proportion of the agents used for extinguishing. In order to minimize wastewater and prevent it from polluting the environment in an uncontrolled manner, firefighting submersion pools and containers are used. The burning vehicle is transferred into them and immersed in a sufficient amount of water. The laboratory measurements (Truchot et al., 2016; Lönnermark and Blomqvist, 2006) of burning products usually include harmful gases, toxic metals and compounds, and hazardous substances in smoke, soot, and ash. Besides waste water, the environmental consequences of EV fires include toxic gases (CO_2, CO, NO, NO_2, HF, HCl, HCN, THC, etc.) and vapours released in the air, various metals in the soot (Al, Cd, Pb, Co, Cr, Cu, Li, Mn, Ni, Zn, etc.), as well as organic compounds of polycyclic aromatic hydrocarbons and water-soluble anions (F^-, Cl^-, Br^-), present in soot and ash. Multi-criteria optimization methods can be applied to determine the hazard of ICEV (internal combustion engine vehicle) and BEV (battery electric vehicle) fires, from the point of view of protecting people and the environment.

THE BEST-WORST METHOD

The BWM is a subjective weighting method used for determining the weight coefficients of the alternatives' criteria. It is based on the comparison of decision criteria, whereby the decision maker determines the best criterion (most desirable/important), the worst criterion (least desirable/important), and preferences between the criteria.

When applying BWM, the best criterion is taken as the most important from the point of view of protecting people and the environment from vehicle fires, and the worst is taken as the least important. Fire hazard criteria may be grouped, for instance, into: (1) toxic metals, (2) combustion and heat release, (3) harmful gases, and (4) anions of halogen elements in soot and ash. The first group has 9 criteria: Al, Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn. The second group has 6 criteria: PAHG (polycyclic aromatic hydrocarbons in gas), DMS (dry mass in soot), Li (lithium as a light alkali metal that affects the explosiveness of fire), PAHS (polycyclic aromatic hydrocarbons in soot), THR (total heat released), and EHC (effective heat of combustion). The third group includes 9 criteria: CO_2, CO, THC, HF, HCl, HBr, SO_2, NO, and NO_2. The fourth group has 6 criteria: FS (F^- anion in soot), ClS (Cl^- anion in soot), BrS (Br^- anion in soot), FA (F^- anion in ash), ClA (Cl^- anion in ash), and BrA (Br^- anion in ash).

There are 30 criteria in total. For individual criteria in the groups, weight coefficients were obtained by applying BWM Linear Solver v2.0, and afterwards, also using BWM, weight coefficients were obtained for each of the 4 groups. The resulting weight coefficients were obtained by multiplying the group coefficient with the individual weight coefficient of the criterion. The consistency of the solution is achieved, because the consistency ratio (CR) is less than the corresponding threshold, for each group of criteria (Figure 1).

In the first group of criteria (toxic metals), Cd was selected as the most important criterion, and Al as the least important. The order of metal toxicity was taken based on biological and chemical specifications (Nieboer and Richardson, 1980). Preferences were determined for all other criteria in relation to Cd, and then in relation to Al, using ratings from 1 to 9. The results are obtained for the weights of 9 criteria and the consistency of the solution is achieved.

In the second group of criteria (combustion and heat release parameters), THR was selected as the most important criterion, and PAHS as the least important. Preferences were determined for all other criteria in relation to the most important criterion, and then in relation to the least important criterion, using ratings from 1 to 9. The results are obtained for the weights of 6 criteria.

In the third group of criteria (harmful gases), CO was selected as the most important and CO_2 as the least important. Preferences were determined for all other criteria in relation to the most important criterion, using ratings from 1 to 9. Then, preferences of the other criteria in relation to the least important criterion were determined, using ratings from 1 to 9. The results are obtained for the weights of 9 criteria. Ranking of vehicle fires based only on harmful gases is presented in Javor et al. (2024) for other experimental data.

In the fourth group of criteria (halogen metal anions in soot and ash), FA (anion F^- in ash) was selected as the most important criterion, and BrS (anion Br^- in soot) as the least important. Preferences were determined for all other criteria in relation to them, using ratings from 1 to 9. The results are obtained for the weights of 6 criteria.

Group Number = 4	Group 1	Group 2	Group 3	Group 4
Name of the group of criteria	TOXIC METALS	COMBUSTION AND HEAT RELEASE	HARMFUL GASES	HALOGEN METAL ANIONS

Select the Best	COMBUSTION AND HEAT RELEASE

Select the Worst	HALOGEN METAL ANIONS

Best to Others	TOXIC METALS	COMBUSTION AND HEAT RELEASE	HARMFUL GASES	HALOGEN METAL ANIONS
COMBUSTION AND HEAT RELEASE	6	1	3	9

Others to the Worst	HALOGEN METAL ANIONS
TOXIC METALS	4
COMBUSTION AND HEAT RELEASE	9
HARMFUL GASES	7
HALOGEN METAL ANIONS	1

Weights	TOXIC METALS	COMBUSTION AND HEAT RELEASE	HARMFUL GASES	HALOGEN METAL ANIONS
	0,119170984	0,590673575	0,23834197	0,05181347

Input-Based CR	0,208333333	Consistency level is acceptable
Associated Threshold	0,2681	

Figure 1. *Grades and weights of the criteria groups and consistency ratio*

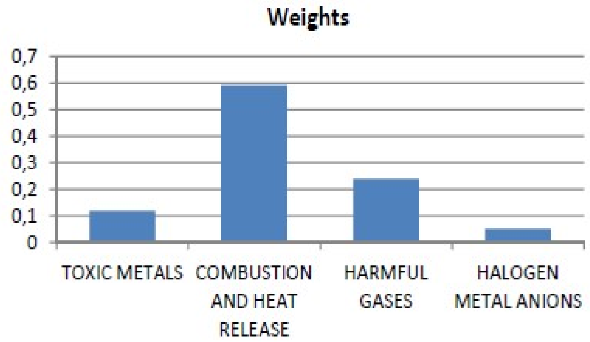

Figure 2. *The weight diagram of groups*

For the groups of criteria, BWM was applied and the second group was selected as the most important and the fourth group as the least important. Preferences were determined for the remaining groups in relation to them, using ratings from 1 to 9. The results obtained for the group weights are shown in Figure 2. The consistency of the solution was achieved.

RANKING OF VEHICLE FIRE HAZARDS BY USING THE PROMETHEE II METHOD

The PROMETHEE method was introduced by Brans and Mareschal in 1982, and they developed the program PROMETHEE-GAIA (Brans and Mareschal, 2014-2024). The result of the ranking of the three alternatives of vehicle fires using the PROMETHEE II method is shown in Figure 3.

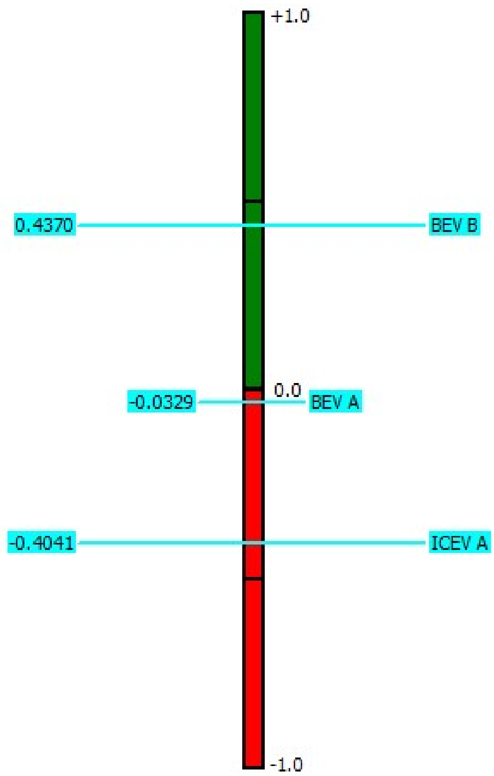

Figure 3. *Fire hazard ranking of ICEV A, BEV A, and BEV B vehicles using the PROMETHEE II method*

Fire of the BEV B is the most hazardous case, whereas fire of ICEV A is the least hazardous case. The net flows are calculated from the positive and negative flows, for each alternative *i*, as given in

$$Ph_i = Ph_i^+ - Ph_i^- . \qquad (1)$$

The results are presented in Table 1.

After applying the PROMETHEE II method, the result of vehicle fire ranking shows that the most dangerous fire from a bioecological point of view is the BEV B vehicle fire, followed by the BEV A vehicle fire, while the ICEV A vehicle fire is the least dangerous for people and the environment. The complete ranking of these fires is given in Figure 3.

It should be noted that when conducting experiments, fires of different vehicles may have different durations, as well as different mass losses (Willstrand et al., 2020), which can significantly affect the ranking results. This difference was pronounced in fires of BEV B and BEV A vehicles, but not between ICEV A and BEV A.

Table 1. *Ranking of vehicle fire hazards*

Rank	Alternative	Ph_i	Ph_i^+	Ph_i^-
1	BEV B	0.4370	0.7128	0.2758
2	BEV A	-0.0329	0.4835	0.5165
3	ICEV A	-0.4041	0.2923	0.6963

CONCLUSION

Multi-criteria decision-making method PROMETHEE was applied in this paper for ranking the vehicle fire hazards, from the point of view of protecting people and the environment. Besides waste water due to extinguishment, the environmental consequences of vehicles fires included toxic gases (CO_2, CO, NO, NO_2, HF, HCl, HCN, THC, etc.) and vapours released in the air, various metals in soot (Al, Cd, Pb, Co, Cr, Cu, Li, Mn, Ni, Zn, ...), as well as organic compounds (polycyclic aromatic hydrocarbons) in gas and soot, and water-soluble anions (F^-, Cl^-, Br^-), present in both soot and ash.

Experimental results of three vehicle fire tests for burning products in smoke, soot, and ash, as well as the total heat released and effective heat of combustion, were used as criteria for ranking by the PROMETHEE method. BWM was used as the weighting method of 30 criteria classified into 4 groups. The criteria were weighted based on metal toxicity, total heat release and effective heat of combustion, and the concentrations and harmfulness of gases and halogen metal anions.

The results of the three vehicle fire tests were used to present the procedure. The result of the ranking, based on the applied method, confirmed that, from the bioecological point of view, fires of electric vehicles are more dangerous than fires of conventional vehicles.

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