DEVELOPMENT OF PASSENGER CAR SAFETY

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Abstract: The goal of the paper was to assess safety of passenger cars sold in the Czech Republic in terms of the development of both active and passive safety features of cars sold between 2020–2022. Using content analysis aimed at collecting secondary data, the sales of passenger cars and their safety ratings were examined. Cluster analysis and neural networks were subsequently used to classify vehicles into self-organizing Kohonen maps, within which the movement between individual clusters was monitored. It was found that more than 25 % of vehicles sold between 2021 and 2022 changed their position compared to the year 2020. When taking into account vehicles newly introduced to the market, the average level of safety of vehicles sold compared to the year 2020. Further research could focus on a more detailed analysis of factors affecting safety on roads and their quantification for making better predictions and prevention of road accidents. It should be considered that vehicle safety ratings are based on a specific methodology and criteria and can vary significantly.

Keywords: Traffic accidents, vehicle safety, development of vehicle safety, road traffic, safety features, Kohonen maps.

1 Introduction

Traffic accidents represent a significant public health problem affecting both social development and the public safety [1]. The accident rate and fatality rate related to traffic accidents are constantly growing every year all over the world; therefore, considerable efforts are made to prevent traffic accidents [2]. According to predictions, by 2030, traffic accidents will be the 7th most common cause of death [3]. The consequences of traffic accidents can be tragic and may affect not only the victims but also their families and society as a whole. In urban transport, traffic accidents represent the most common and serious risk to people´s lives and making vehicles safer is an important means to reduce the fatal consequences of accidents [4]. There are many causes of traffic accidents; besides the human factor, accidents are often caused by technical problems [5]. Car manufacturers and researchers thus focus on the development of car safety mechanisms. Automotive companies thus try to achieve evidence-based primary prevention, which includes the development of positive health behaviour that should prevent adverse health consequences and uses methods that reduce the number of injuries [6]. The development of vehicle safety features plays a significant role in the number of traffic accidents [7]. Governments and legislative bodies use information about the development of passenger car safety for the regulation and setting the requirements for vehicle safety features. The regulation includes e.g., requirements for vehicle testing or obligatory use of safety features, such as ABS [8]. Currently, the most studied subject of research is vehicle automation, in which large investments are made. However, conventional vehicles are equipped with many passive and active safety features [9], and more and more modern passive and active safety features are being developed [10]. The basic element for ensuring passenger safety conditions is the absorption of impact energy by passive safety features of the vehicle body [11]. In addition, passive safety features include seat belts, safety glass, head protection, etc. Vehicles are also equipped with active safety features, which automatically detect the risk of collisions and prevent them [12]. Modern vehicles represent complex systems of sensors, electronic control units and actuators interconnected by various types of networks inside the vehicle, which control and monitor the condition of the vehicle and thus ensure its safer use [13]. Compared to older ones, modern vehicles can be considered safer thanks to the development of safety features [14]. For this reason, it can be assumed that the modernization of vehicles used will reduce the accident rate on the roads.

1.1 Goal of the paper

The goal of the paper is to evaluate passenger car safety sold in the Czech Republic in relation to the development of active and passive safety features in cars sold between 2020–2022.

1.2 Research questions

To answer the first research question, it is necessary to find out how many new cars were sold in the Czech Republic in the last three years and to divide them into groups by models. This enables evaluating the individual models in terms of safety.

RQ1: What was the total number of newly sold vehicles in the Czech Republic between 1 January 2020 and 1 January 2023?

Thanks to answering the first research question, it will be possible to evaluate individual models in terms of safety and assign them a safety rating, which is different for each model.

RQ2: How are these vehicles evaluated in terms of safety?

The last research question aims to find out whether the potential modernization of vehicles has contributed to achieving greater safety for passenger car users as well as pedestrians, who are also affected by safety.

RQ3: Has the modernization of vehicles contributed to achieving greater safety of passenger cars in the Czech Republic?

2 Literary research

Every year, about 1.2 million people are killed and more than 50 million people are injured in traffic accidents worldwide. As a result of urbanization and motorization, the number of traffic accidents is growing dramatically every year [15]. According to [16], traffic accidents represent a serious economic and social problem, given that the number of fatal accidents is still growing both at the national and international levels. [17] believe that information about factors causing accidents can contribute to minimizing the occurrence of traffic accident, if processed properly and used for making further steps that could ensure greater safety [18]. [19] examine factors associated with traffic accidents in South Korea using ratio analysis combined with descriptive analysis in order to identify relevant catastrophic factors. Data on traffic accidents include multi-dimensional dynamic and static factors, such as “people, vehicles, roads, and environment” at the moment of the accident, which is one of the important data sources for traffic improvement [20].

Modern automobiles are equipped with many safety features. ECU units collect diagnostic data from automobile components, such as engines, brakes, etc., which are able to evaluate and in the case of crisis even avert possible threats [21]. For this reason, it is necessary to develop further passive and active vehicle safety features, as both types help to reduce the risk of traffic accidents and increase the safety of drivers and passengers [22]. [10] deal with passive safety features. The simulation of a half-car model using selected algorithms of feedback vibration control, which is subsequently analysed, points to the improvement of driving safety features, such as road holding and vehicle handling. Safety systems and vehicle construction in real traffic accidents are evaluated using destructive crash tests [23]. However, [24] argue that these tests are a complicated, time-consuming, and costly part of the automobile development process and for reducing costs, they propose simulations using the finite element method, which simulates car crashes in a computational way. The formulation of priorities for future road safety strategies requires a supporting analysis to predict the future number of accidents and assess how already implemented countermeasures address the anticipated accident-related problems [25].

Much of the current research and development in the area of vehicle safety is focused on autonomous driving [26]. Nevertheless, [27] argues that the use of autonomous cars is often hindered by various limitations, such as drivers´ privacy or high costs related to their deployment. In recent years, a large number of tools have been used to predict the number of traffic accidents in the next period [28].

[29] use a big data mining method for predicting traffic accidents and thus help to take measures for preventing or reducing the number of traffic accidents in advance. They also mention that in recent years, the methods of predicting traffic accidents show low calculation accuracy. [30] state there are many factors affecting the incidence of traffic accidents. However, in the road transport system, there are two major problems in terms of predicting traffic accidents: first, how to evaluate the weight of the impact of individual factors or variables on the accident; second, how to model the prediction process for multiple interrelated variables. The prediction of the number of traffic accidents could be made using various neural networks; the selection of a suitable network depends on specific data and prediction requirements [31]. A convolutional neural network (CNN) is a model of deep feedforward neural network, which uses the principle of deep learning and shows excellent results in many areas of image classification, such as speech recognition, face recognition, movement analysis, and medical diagnosis [32]. A deep learning algorithm based on convolutional neural networks has achieved a number of breakthrough results especially in the field of objective detection [33]. Another option is the application of recurrent neural networks (RNN), which are particularly suitable for time series [34]. Recurrent neural networks are designed in a way so that they converge to the required equilibrium point for their applications [35]. Recurrent neural networks have introduced a directional loop, which is able to remember previous information and apply it to a real output, which is a major difference when comparing them with traditional feed-forward neural networks (FNN) [36]. For example, [37] propose a combination of deep learning method architectures consisting of CNN and long short term memory (LSTM) to analyse spatial and temporal features and predict traffic speed in several steps. In contrast, [38] compared various deep neural networks (DNN), including "deep belief network, standard recurrent neural networks (RNN), multilayer neural networks, and single-layer neural networks in terms of the accuracy of predicting seriousness of accidents involving motorcycles with the finding that RNN outperforms other three models of neural networks. Compared to other architectures, such as convolutional neural networks, recurrent neural networks can suffer extremely from longer fitting and evaluation due to their inherent sample-by-sample data processing, while traditional application of both of these architectures requires a fixed observation interval during both fitting ad testing; the ability of recurrent neural networks to process data sample by sample opens space for alternative approaches [39]. The main advantage of RNNs is that they are able to retain information about previous inputs, which enables a better understanding of the context and performance improvement when information in a sequence is interconnected. At the same time, RNNs are able to work with sequenced data [40].

Primary data can be collected using content analysis [41], whose aim is to obtain data on the content of the material analysed and to identify the key elements or topics included [42]. Content analysis is traditionally considered a quantitative method but can also have a qualitative form. However, there is not much available methodological knowledge about the characteristics of qualitative content analysis compared to its quantitative form [43]. [44] describe content analysis as a method often used in scholarly papers and scientific research. The authors point out that the application of this method in the literature shows a lack of details about the method and the results of the analyses. [45] use a combination of content analysis of documentation from various localities in the Czech Republic and using cluster analysis, they try to find out whether there are groups with different approaches to evaluating various parameters. Cluster analysis represents one of the main directions of research in the field of data collection. Currently, it has spread into all areas and has made significant progress. With regard to the role of cluster analysis in data collection, a cluster analysis algorithm and its application in collecting primary data is proposed [46]. The importance of cluster analysis consists in the possibility to evaluate elements by clustering multiple homogeneous data. The main objective of the analysis is to collect the elements of one homogeneous group into several groups depending on many variables. This type of analysis is used for the reduction of data, making hypotheses and their testing, as well as for predicting and comparing various models [47]. Although the method of cluster analysis has not achieved the same level as e.g., chemometric analysis [48], it will be used for processing primary data obtained using content analysis.

3 Methodology

The data collection is aimed at obtaining information about the accident rate on the roads in the period between 1 January 2020 and 1 January 2023, the number of traffic accidents of diverse severity, the number of deaths and injuries related to traffic accidents, and the total damage caused by road accidents in these three years. For obtaining the statistical data published by the Ministry of Transport, access to an online database (Policie.cz, 2022) will be ensured and data from the Ministry of Transport websites (Ministerstvo dopravy, 2023) will be downloaded. Using quantitative content analysis, the data will be analysed in order to obtain secondary data relevant to the research. The obtained data will be classified using cluster analysis according to individual periods (the years 2020, 2021, and 2022). For these years, there will be found information about the number of traffic accidents in each year, the number of persons killed in each period, the number of seriously injured persons, the number of slightly injured persons, and the total material damage expressed in Czech crowns.

In order to monitor the evolution of the number of traffic accidents on the basis of innovations in the field of vehicle safety over time, it is necessary to obtain the necessary data on the evolution of vehicle safety. The data will be obtained from various sources, as it will be necessary to determine the number of newly registered vehicles in the monitored period. In terms of the development of vehicle safety, it is not necessary to monitor used vehicles, as this data would not affect the results of the study (used vehicles could appear duplicated in the list of newly registered and used vehicles and thus distort the results). The data on the number of newly registered vehicles is available on the Ministry of Transport websites (Ministerstvo dopravy, 2023), in the section of the Road Vehicle Register, which publishes monthly data on both new and used vehicles. The data include the type of the car, category, factory make, engine, fuel, colour, place of registration, etc. For the purposes of the research, it will be necessary to sort this data into the required format using cluster analysis and select relevant information. Only passenger cars will be used, for which the factory make, type and the number of cars sold in the given period will be selected. In order to reduce this large data volume, there will be monitored only the models of which more than 100 pieces were sold in the given period. This will reduce the time necessary for the data collection and processing and distortion of results will be avoided.

An important part of the data collection is the safety rating of individual vehicles sold in the given period. The server (EuroNCAP, 2023) publishes safety ratings of vehicles sold in the European Union. The ratings are created by an organization of German motorists, ADAC, together with the German Ministry of Transport. Using quantitative content analysis, the vehicles will be assigned secondary data concerning safety. This institution classifies vehicles according to make and model, which enables assigning each of the selected vehicles a rating for the safety of the driver of the vehicle, the safety of the passengers, the safety of vulnerable road users, and the rating of active vehicle safety features, which is of particular importance for the purposes of the research. The ratings will be given on a scale from 0 (the lowest one) to 100 (the highest rating). To obtain relevant data, it will be necessary to assign a current safety rating to each year of vehicle production. For the year 2020, the ratings may be largely different for the same vehicle model in the year 2022 due to the continuous evolution, the introduction of newer models with the same name or face-lift designs in the market.

The data will be processed using neural networks in cluster analysis and Kohonen map analysis.

The process of creating a Kohonen map can be expressed in numbers, where specific values and calculations depend on specific implementation and algorithms used. An example of a simple mathematical representation of creating a Kohonen map is described below:

Initialization:
The assumption is there is a neural network with dimensions m x n.
Random initialization of the weights of the neurons is necessary [49]:

$$W = \{w_{ij}\} \text{ for } i = 1, 2,...,m \text{ and } j = 1,2,...,n. \qquad (1)$$

Repeated for each input vector from the input dataset:
If x is the input vector, the distances between the input vector and the neuron weights can be calculated as follows:

$$d_{ij} = \|x - w_{ij}\|, \qquad (2)$$

where $\|.\|$ is a standard.
The neuron with the shortest distance a is denoted as winner: (i_w, j_w).
Next, the weights of the winner and the neurons in its neighbourhood need to be updated using the Kohonen rule [50]:

$$w_{ij}(t+1) = w_{ij}(t) + \eta(t) * h_{ij}(t) * (x - w_{ij}(t)), \qquad (3)$$

where:
$\eta(t)$ is the learning speed in time [t]
$h_{ij}(t)$ is a function determining the degree of the winner´s influence on the neighbouring neurons.

The earning rate $\eta(t)$ and the size of the neighbourhood gradually decrease over time.

This way, the weights of the neurons are gradually adjusted on the basis of the input data, thus forming a Kohonen map. The specific values of the learning rate, the function of the function and standard depend on the particular implementation and algorithm used for creating a Kohonen map. This creates a visual representation referred to as a Kohonen map.

After creating a Kohonen map (10x10) and a cluster, the changes in the clusters occurring between 2020 and 2023 will be monitored. If there was any change affecting a position in the Kohonen map, such a change will be denoted “a big change” if the movement is > 2; the movement in the interval of > 0 and < 2; will be denoted “a small change”. If there is no change, it means that none of the vehicles increased or decreased the level of passive and active user protection between the years 2020 and 2023.

For the purposes of the research, the following hypothesis will be formulated:

H0a: In the period between 1 January 2021 and 1 January 2023, at least 25 % of the vehicles sold in the Czech Republic changed their position compared to their initial position in the Kohonen map.

H1a: In the period between 1 January 2021 and 1 January 2023, less than 25 % of the vehicles sold in the Czech Republic changed their position compared to their initial position in the Kohonen map.

The answer to the formulated hypothesis provides information on whether there were any changes in the development of vehicle safety.

4 Results

In the Czech Republic, all traffic accidents to which the police are called are recorded, which enables ensuring accurate results.

Tab 1. Traffic accidents in the Czech Republic between 2020 and 2023

Year	Number of accidents	Deaths	Seriously injured	Material damage	Number of newly registered cars
2020	94794	460	1 807	CZK 6 016 mil.	180 643
2021	99332	470	1 624	CZK 6 718 mil.	199 669
2022	98460	454	1 734	CZK 7 524 mil.	187 708

(Source: Authors according to Policie.cz, 2022)

Between 2020 and 2023, a total of 568,020 vehicles were sold in the Czech Republic, which represents one car for every twenty citizens. As seen in Table 1, there is a correlation between the number of traffic accidents and the number of newly registered vehicles. From the year 2020, the number of traffic accidents grew by an average of 4,500 accidents per year, which is nearly a 5% increase.

Tab 2. List of newly sold vehicles in the year 2020

MAKE	MODEL	2020_NOVE
ŠKODA	OCTAVIA	19 191
ŠKODA	FABIA	16 264
ŠKODA	KAROQ	8 111
ŠKODA	KAMIQ	7 587
HYUNDAI	I30	7 419
ŠKODA	KODIAQ	6 523
KIA	CEE´D	4 482
HYUNDAI	TUCSON	4 451
VOLKSWAGEN	GOLF	4 152
DACIA	DUSTER	3 536
RENAULT	CLIO	3 496
VOLKSWAGEN	TIGUAN	2 622
TOYOTA	YARIS	2 381

(Source: Authors according to Ministerstvo dopravy, 2023)

Table 2 shows an overview of the ten best-selling vehicle makes in the Czech Republic in 2020, with the highest representation of the domestic carmaker Škoda, which took the first four places in the table and appears five times in the table. In 2020, Škoda delivered a total of 60,497 cars on the domestic market. The second best-selling make is Hyundai with a total of 16,989 cars. The third place is occupied by one of the models of Volkswagen, which sold a total of 16,759 (13 models), of which the best-selling model was golf.

Tab 3. Overview of best-selling vehicles in 2021

MAKE	MODEL	2021_NEW
ŠKODA	FABIA	15653
ŠKODA	OCTAVIA	14099
ŠKODA	KAMIQ	10505
HYUNDAI	I30	10307
ŠKODA	KAROQ	9703
ŠKODA	SCALA	8678
ŠKODA	KODIAQ	6258
HYUNDAI	TUCSON	5698

ŠKODA	SUPERB	5224
VOLKSWAGEN	GOLF	4678
KIA	CEE´D	4407
DACIA	DUSTER	3444
SEAT	ARONA	2884
PEUGEOT	2008	2691
VOLKSWAGEN	TIGUAN	2375
TOYOTA	PROACE	2265
TOYOTA	COROLLA	2082
TOYOTA	RAV4	1908
FORD	PUMA	1585
TOYOTA	YARIS	1564

(Source: Authors according to Ministerstvo dopravy, 2023)

Table 3 shows a list of twenty best-selling vehicles in 2021. As in the year 2020, the domestic car manufacturer Škoda is most represented here; compared to the previous year, the number of cars sold grew to 70,854, with a total of 7 models. Hyundai´s position in the market was also stronger, selling a total of 20,073 vehicles, which represents an increase of over 3,000 vehicles compared to the previous year. On the other hand, Volkswagen showed a slight decline in the market, as the number of cars sold decreased by 150 vehicles. The year 2021 saw the highest number of newly registered passenger cars in the monitored period, specifically 199,669.

Tab 4. Overview of newly sold vehicles in 2022

MAKE	MODEL	2022_NEW
ŠKODA	OCTAVIA	13988
ŠKODA	FABIA	13275
HYUNDAI	I30	8255
ŠKODA	KAROQ	8005
ŠKODA	KAMIQ	6926
ŠKODA	SCALA	6529
ŠKODA	SUPERB	6467
ŠKODA	KODIAQ	6401
HYUNDAI	TUCSON	5817
DACIA	DUSTER	4046
VOLKSWAGEN	GOLF	3152
TOYOTA	YARIS	3037
DACIA	SANDERO	2599
TOYOTA	PROACE	2471
KIA	SPORTAGE	2281
TOYOTA	COROLLA	2184
TOYOTA	RAV4	2116
CUPRA	FORMENTOR	1998
SEAT	ARONA	1955
FORD	KUGA	1797

(Source: Authors according to Ministerstvo dopravy, 2023)

As seen in Table 4, the year 2022 was worse in terms of sales compared to the year 2021, as the decrease in the number of cars sold was more than 12,000. The first three positions are again occupied by Škoda, Hyundai, and Volkswagen. Škoda occupied the first position with a total of 62,247 cars sold, which is a decrease of more than 8,000 cars compared to the previous year. A decrease was also recorded in the case of Hyundai, which sold 1,230 vehicles less than the previous year. Similarly, Volkswagen sold more than 4,000 cars fewer, and its position was occupied by Toyota, which sold a total of 12,162 vehicles.

Tab 5. Overview of cars sold by car manufacturers in the CR between 2020 and 2022

MAKE	2020 _NEW	2021 _NEW	2022 _NEW
ŠKODA	60497	70854	62247
HYUNDAI	16989	20073	18387
TOYOTA	7843	10326	12162
VOLKSWAGEN	16759	16609	12065
DACIA	9747	4161	7324
FORD	6642	5578	7276
KIA	7127	9732	6552
MERCEDES-BENZ	5790	7941	6387
BMW	4478	4414	3886
OPEL	2251	4449	3762
RENAULT	7220	2624	3753
PEUGEOT	7455	7633	3716
SEAT	4237	6306	3700
CITROEN	4473	4055	2740
AUDI	1834	2123	2654
SSANGYONG	160	923	2341
VOLVO	1900	2410	2168
MAZDA	1646	2343	2002
SUZUKI	2379	2442	1877

(Source: Authors according to Ministerstvo dopravy, 2023)

Table 5 shows sales by individual car manufacturers. As can be seen from the table, Škoda has the largest presence on the domestic market and its sales exceed the sales of other car companies several times over. The second most successful make in the Czech market is Hyundai, which occupied the second place in every year of the monitored period, followed by Volkswagen (third place), Toyota (fourth place), and the Romanian car manufacturer Dacia (fifth place).

Important information is the data about the safety of the vehicles sold. For this reason, content analysis was used to obtain data on the ratings based on the results of crash tests performed for each of the models. On the basis of the ratings, neural networks were used to sort the cars into a Kohonen map, where each model was assigned a specific position (see Table 6). The changes in the positions represent changes in the vehicle rating.

Attachment1 shows a list of selected vehicles with information about the year of manufacturing, the model, the number of pieces sold in a given year, driver´s safety, passenger safety, pedestrian safety, active safety features, neuron ID, and the position in the Kohonen map. The last column shows if there have been any changes. For simplicity, this table does not contain vehicles for which no change has been recorded.

It can be seen that there were changes; however, the results in this table are skewed for the above reason. The table presents predominantly major changes, which apply to the best-selling models, such as Škoda Octavia, Volkswagen Golf, and Kia Cee´d. Škoda Octavia changed its position twice, from (10,5) in 2020 to (8,8) in 2021 and (8,7) in 2022. In contrast, the position of one of the best-selling models, Hyundai I30, did not change during the whole monitored period. Another big change can be seen in the case of Dacia Duster, whose position changed from (1,10) in 2020 to (3,8) in 2022.

Tab 6 Average values in the years 2020, 2021 and 2022

Year	Driver´s safety	Passenger safety	Pedestrian safety	Active safety features	Average value
2020	87.59	81.92	65.56	64.62	74,93
2021	89.27	85.94	71.38	70.43	79,25
2022	88.28	82.78	70.58	70.85	78,12

(Source: Authors)

As seen in Table 6, the safety features of passenger cars sold in the Czech Republic underwent considerable development from the beginning of the monitored period. The table shows the values of the average vehicle sold in a given year. In 2020, the average passenger car showed the following values: 87.64 for driver´s safety, 81.92 for passenger safety, 65.56 for pedestrian safety, 64.62 for active safety features; the overall average value for the vehicle was 74.93. With the gradual evolution, the values recorded in 2022 were 88.28 for driver´s safety, 82.78 for passenger safety, 70.58 for pedestrian safety, 70.85 for active safety features; the overall average for the vehicle increased by more than 3 points, reaching 78.12.

In 2021, a total of 199,669 cars were sold, out of which 43,118 vehicles changed their position in the Kohonen map compared to the situation in 2020. In 2022, a total of 178,708 vehicles were sold; 53,145 changed their position on the Kohonen map. Based on these results, it is possible to accept the null hypothesis:

H_{0a}: In the period between 1 January 2021 and 1 January 2023, at least 25 % of the vehicles sold in the Czech Republic changed their position compared to their initial position on the Kohonen map.

Out of 378,377 vehicles sold, 96,263 changed their position on the Kohonen map = 25.44 % > 25 %. The alternative hypothesis H_{1a} is thus rejected.

5 Discussion

RQ1: What was the total number of newly sold vehicles in the Czech Republic between 1 January 2020 and 1 January 2023?

The number of cars sold in the Czech Republic in the last three years has evolved to a large extent. Between 2020 and 2022, there was a gradual increase in the number of traffic accidents, although the number of newly registered vehicles decreased. These findings show that an increase in the number of vehicles on roads can have an impact on the safety situation and increase the risk of traffic accidents. For this reason, it is necessary to develop safer vehicles. The year 2022 saw a slight decrease in the number of cars sold. This could be due to the high inflation and financial crisis in the Czech Republic, as confirmed also by [51], who attributes this crisis to the war in Ukraine.

As seen in Tables 2, 3, and 4, Škoda is the dominant make in the market of new car sales; it is also the best-selling make and has the most models in the list of best-selling vehicles. This confirms the strong position and popularity of Škoda with Czech motorists. In the last three years, Škoda has sold more than 190,000 cars; as [52] believe, this is due to the fact that the Czech Republic has revived and supported its automotive industry, which has led to increasing the production and export of cars.

There was a significant increase in the sales of Hyundai vehicles. The figures show that Hyundai increased the number of cars sold in the monitored period, which indicates the growing popularity of this make among Czech customers. This trend may be attributed to the supply of competitive models with a good price/performance ratio as well as the credibility of the brand.

The last finding is the decrease in the number of Volkswagen cars sold in the year 2022. Table 5 shows that Volkswagen dropped to fourth place in the number of cars sold, while in the previous years, it occupied third place. This could be attributed to many factors, including the competition (other makes), changes in customer preferences, or new models on the market.

RQ2: How are these vehicles evaluated in terms of safety?

The vehicles are assigned a score according to EuroNCAP rating (EuroNCAP, 2023) in four categories: driver´s safety, passenger safety, pedestrian safety, and active safety features. Based on these criteria, TESLA model Y achieved the best rating, with values of 97, 87, and 82. The best score was achieved in the case of active safety features (98). It is thus a very safe vehicle; however, in 2022, only 184 of these luxury cars were sold in the Czech Republic. This model is followed by models such as LEXUS RX450H, Mercedes-Benz model A, Volvo XC90, and Volkswagen Arteon.

This is also confirmed in the study by [53], who argue that vehicle safety varies depending significantly on vehicle size. More expensive cars are usually equipped with advanced safety technologies and systems that minimize the risk of accidents and protect both the driver and the passengers, as well as other road users. These vehicles are also often equipped with modern driver assistance systems, such as adaptive cruise control, lane departure warning, emergency braking, and blind spot monitoring system. In contrast, vehicles with lower prices usually do not have such a range of safety features. They may lack advanced systems that would minimize the risk of collisions and provide protection in accidents. These cars typically have lower quality construction and materials, which can affect their crashworthiness.

Cheaper cars, such as Fiat Panda, Dacia Duster, Dacia Sandero, or Renault Clio showed the worst results, which is mainly due to the fact that these car manufacturers try to produce affordable vehicles and pay more attention to the vehicle price rather than vehicle safety features. Autonomous cars, which are the future in terms of road safety according to [54], are usually much more expensive than conventional passenger cars produced for the lower and middle class. This is confirmed by [55], who mention the costs of producing autonomous and electric vehicles.

In the Czech Republic, the best-selling models of Škoda have achieved relatively high ratings. The best-rated model of Škoda was the Škoda Rapid with an average score of 82.25 points. Its production, however, was discontinued and the model has been replaced by the Škoda Scala, which achieved the same ratings, although the number of points for the category of pedestrian safety was fifteen points less compared to the Škoda Rapid. The Škoda Octavia and Škoda Fabia achieved higher average values; in 2021, vehicle safety score achieved 83 points on average.

RQ3 Has the modernization of vehicles contributed to achieving greater safety of passenger cars in the Czech Republic?

Based on the changes in the positions in the Kohonen map, it can be stated that vehicles have evolved in recent years in terms of safety.

The authors agree with [26], who stated that the development of vehicle safety plays a significant role in the number of traffic accidents, as the results indicate that although e.g., in the year 2021, the number of sold vehicles grew by 10 % compared to the situation in the year 2020, the number of traffic accidents grew by 5 % only. The same trend can be seen in the year 2022 when a 3.6% increase in the number of accidents was recorded, while more than 10 000 vehicles were sold. However, this indicator needs to be monitored in the long term, as according to the Association of Car Importers [56], more than 6,425,000 vehicles are registered in the Czech Republic. Newly registered vehicles (2020-2023) thus represent only 10 %.

Despite the growing number of traffic accidents, the number of serious injuries and deaths in traffic accidents shows a different trend. In 2020, 460 deaths in traffic were recorded in the Czech Republic; in 2022, it was 6 deaths fewer. As the number of registered vehicles is growing, there can be seen a link between the modernization of vehicles and their safety. This could be demonstrated by the number of serious injuries, which shows a downward trend despite the growing number of vehicles as well as traffic accidents. It is thus possible to agree with [22], who state that active safety features of vehicles contribute to reducing the risk of traffic accidents and protecting drivers and passengers.

The development as such can be described as positive, since compared to the year 2020, the rating of the average vehicles sold in the years 2021 and 2022 increased. In 2020, the average safety value of a vehicle was calculated at 74.93, which grew to 79.25 in 2021. This can be linked to the trend of best-selling cars in the Czech Republic. The rating of the best-selling model, the Škoda Fabia, increased by two points, while the rating of the second best-selling model, the Škoda Octavia, grew by 14 points. The change in ratings caused by introducing a new model in the market resulted in a higher safety score in 2021.

In contrast, the year 2022 showed a decrease in safety compared to the previous year. The rating of the average vehicle was 0.9 points fewer than in the previous years. Again, this was due to the changes in the safety features of best-selling models. Škoda added a face-lift to its best-selling vehicle, the Octavia, which achieved a lower safety rating than the previous version and extended the sales with the RS version.

6 Conclusion

The goal of the paper was to assess the safety of passenger cars sold in the Czech Republic in terms of the development of active and passive safety features between 2020-2022. To achieve the goal, research questions and hypotheses were formulated and answered.

The paper analysed the trend of traffic accidents in the Czech Republic between 2020 and 2023 and its correlation with the number of newly registered vehicles. The results show that there is a demonstrable correlation between these two factors.
Furthermore, the best-selling car makes and models in the Czech Republic in the period 2020-2022 were examined. The make with the highest representation was Škoda, which dominates the domestic car market. Hyundai came second, followed by Volkswagen and Toyota. Vehicle safety was assigned a score from 0-100, which showed that higher class vehicles achieve higher safety ratings, while lower class vehicles are less safe for their users and public. The findings are significantly influenced by the development of safety features in the Škoda automotive company, whose share in the total number of cars sold in the Czech Republic is more than 35 %. In the monitored period, Škoda launched upgraded models of the Octavia and Fabia and new models, Eniaq and Scala, which achieve high safety ratings.
However, the research has confirmed the existence of differences between individual automobiles and their safety features. Some models show a decrease in some categories, especially in the category of pedestrian safety. This may indicate that despite improvements in the categories of driver´s and passenger safety, manufacturers still need to focus on improving the protection of pedestrians.

The results obtained show that although there is an evolution in terms of vehicle safety, a more modern version of the same model does not necessarily mean higher safety. This has also been confirmed by the results of the analysis performed, which showed that the average vehicle showed better safety ratings in 2021 than in 2022.

The results of this paper show the importance of monitoring the trend in the number of traffic accidents, sales, and vehicle safety ratings. This study contributes to a better understanding of the links between these factors and can be used as a basis for formulating road safety measures. Further research could be focused on a more detailed analysis of factors affecting road safety and their quantification for better prediction and prevention of road accidents. The results can also have important implications for consumers, as available information on car safety ratings enables them to make an informed decision when choosing a new car.

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