Acta logistica - International Scientific Journal about Logistics
Volume: 12 2025 Issue: 1 Pages: 157-166 ISSN 1339-5629

https://doi.org/10.22306/al.v12i1.606 *Received: 27 July 2024; Revised: 22 Nov. 2024; Accepted: 12 Feb. 2025*

Competitiveness supported by the analysis of risk factors of the recall of products process in the production logistics

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Keywords: competitiveness, automotive industry, risk factors, recalls.
Abstract: Nowadays, the automotive giants and the automotive industry are focused on increasing the performance of vehicles and reducing the number of calls to action, which means an increase in costs and loss of customers for automotive companies, which is reflected in reduced competitiveness. The main goal of this paper is to identify the consequences of recall actions in automotive companies, to identify risks, and to determine the dependence between criteria characteristics such as risk size, product quality, frequency of recalls, detection accuracy, and error rate. Within the research part, 5 hypotheses were set, based on which the individual dependencies of the criterion characteristics were determined. The most common cause of calls was electrical engineering and electronics. In terms of error rate, these were design errors. The most called vehicles were Citroen, and the error rate was 3.74%. The greatest risk to the supplier's structure was represented by car bodywork. Call-to-action is an effective tool for automotive companies to take corrective action. The main intention of automotive companies is to reduce the error rate on vehicles and minimize the number of calls to action to increase the competitiveness of automotive giants. The strategic intention of minimizing recall actions is also reflected in maintaining a good reputation with customers - goodwill.

1 Introduction

The recall process in the automotive industry represents a sector of poor quality. This sector is reflected in the poor quality of automotive components in vehicles, the software, electrical, and electronic areas of the vehicle, in the environmental quality, and in complex management and diagnostics of the products. These elements of poor quality must be solved during the design of the vehicles [1]. This article aims to identify the consequences of recall actions in automotive companies, to identify risks, and to determine the dependence between criteria characteristics such as risk size, product quality, frequency of recalls, detection accuracy, and error rate. One part of facility management is the process of call-to-actions of individual cars are carried out based on identified deficiencies that may endanger the health and safety of car users. This process creates a place for improvement of all processes in the automotive industry to fill in the requirements of customers [2]. These recall actions are a risk for car companies that threatens their competitiveness and dominant position in the automotive market and the loss of customer satisfaction [3]. Competitiveness, prosperity, and the ability to create added value in the automotive industry depend largely on the emphasis on the quality of production [4].

The important indicator is green and cleaner production connected with the good choice of suppliers. All those factors are part of the circular economy cycle in the frame of Industry 4.0 and Industry 5.0 [5]. Bates et al. (2007) commented on one of the characteristic features of the current automotive industry is the transfer of responsibility for the management and quality of deliveries from the manufacturer to suppliers [6]. Any errors identified outside the production plant in the form of recall actions can have devastating effects on the production company [7]. Thomsen et al. (2001) presented and commented the call-to-action is an important indicator of the efficiency of the automotive distribution network. The main intention of automotive giants is to reduce poor quality in the form of recall actions, which represent an increase in costs for automotive companies and their suppliers [8]. Fritz (2010) said that the best-known defects of the product in the automotive industry were recorded [9]. Potkany et al. (2022) demonstrated the factors of competitiveness for the automotive industry, and they presented quality management practices that are orientated to defective products [10].

Among the most common causes of recalls was the company BMW. This company banned charging plug-in hybrids from reason to short circuits. The other causes of recalls were recorded in the company Skoda Octavia. They solved a software problem with a malfunctioning emergency e-call. The company Peugeot caught two technical problems that can cause loss of control of the vehicle. The Swedish carmaker Volvo solved the problem in the autonomous brake system. Other automotive companies such as Nissan, Mazda, and Kia had problems with brake assistants. The companies Peugeot, Citroën, Opel, Ford, Range Rover, Jeep, and Bentley had problems with driving some models. Some Ford models had a problem with the risk of fire. The failure of the diagnostic module was solved by a Škoda car on superb models. Mazda had problems with fuel supply in Skyactiv-X systems and others [11]. Those defects in vehicles create risks in products. Those risks increase the cost of quality in the supply chain [12]. The supply chain creates the basis for an effective production process that results in quality products. The application of generally applicable logistics principles may result in increased quality of products. In addition, those principles can improve the efficiency, operability of the machines and equipment, profitability, and liquidity. Those economic indicators are the frame for competitiveness [13].

2 Theoretical background

The automotive industry faces many challenges oriented on performance indicators that stabilize automotive sustainability. The base of automotive competitiveness is lean manufacturing, digitalization, and green economy and environment [14]. Industries such as automobiles, pharmaceuticals, medical devices, electronics, toys, and food have often announced recalls of defective products that introduce safety and health hazards to customers [15]. The quality of products is an important part of Quality 4.0 towards comprehensive product enhancement in the manufacturing sector of the automotive industry [16]. Product safety is a very important indicator of quality products and a main aim for customer satisfaction. The operational management's discovery of product recalls suggests that recalls, particularly those related to lack of safety, are increasing in various industries and sometimes in the automotive industry [17]. Customer satisfaction and product quality create the basis for the company's performance, strategic development and competitiveness [18].

The defective products that are dangerous for customers from various views need to be discovered in the frame of the supply chain. A recall due to a safety hazard occurs because of three main triggers. First, the firm may find the potential for a safety hazard due to a product defect. Second, consumers or downstream supply chain players may report this hazard to the firm. In either case, firms must report the safety hazard within 24 hours. Third, consumers, downstream supply chain players, and competitors may directly contact and inform about the safety hazard posed by a product [19]. In all three of these cases, the firms jointly investigate the product defect and take the necessary action to eliminate the hazard by recalling the product to repair it, replace it, or refund the purchase price [20]. The recall process highlights two main categories of recall strategies for the companies. In the praxis are two types of recall strategy: a preventive and a reactive recall strategy [21]. Govindaraj et al. (2004) explained recall strategies followed: a preventive recall strategy implies that a firm conducts quality checks and inspections. Based on the results of inspections may discover product defects that could potentially pose a safety hazard. Firms can adopt a reactive recall strategy in which they may not proactively scout for product defects that pose a safety hazard, but the investigation process for recalls may be initiated only after a safety hazard has caused injuries or deaths [22,23].

The poor quality of products is caused by a supply chain model that is not prepared for market demand and needs of the automotive assembly companies [25]. The increasing trend of various types of spare parts for automotive companies means more than 4000 outside suppliers, including company-owned spare parts suppliers. This approach needs a strategic global supply chain model [26]. From this view has been important to use instruments of crisis management and solve situations in the spare parts [27]. One of the instruments is predictive maintenance planning that it contents the order and storage of spare parts. This system creates a base for sustainable manufacturing [28]. Sustainable manufacturing in the automotive industry means recording the manufacturing phases during vehicle production. The reason is that the vehicle goes through many different steps during assembly [29]. The modern approach to sustainable manufacturing is implementing TPM (Total productive maintenance) that relates to man, machines, and materials. This synergy effects increase operational performance in the automotive industry, and it means lean production [30,31]. The recall process brings financial losses [32]. It means decreasing returns, increasing costs, and impacting equity. The loss of shareholder value is often substantially greater than the cost of the recall itself, including those associated with destroying or repairing defective products [33]. Product recall events impose costs, affect sales, raise manufacturing costs, dilute brand equity, and hurt the financial value, posing a significant threat to companies. Recall process must be a part of sustainable development with low economic and environmental effects [34]. The effective instrument for the recall process is controlling and its implementation [35].

3 Research objective, methodology and data

Part of the research was focused on recall processes in the automotive industry. The main hypotheses were established to identify the consequences of calls to action

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in automotive companies. Based on statistical analysis, the dependencies between the criteria characteristics - the size of the risk, the quality of the products, the number of calls to action, the accuracy of detection, and the error rate were determined. Part of the research was the collection of data on recalls and their processing for the preparation of statistical analyses and confirmation of hypotheses.

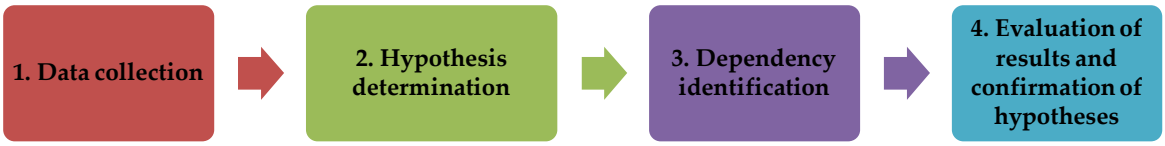

Figure 1 Algorithm of research, source: own research

1. Data collection: part of the research was the acquisition of relevant data for recalls in the automotive industry in the time interval 2005-2015. The research used Google Trends analytical tools, the web portal "vosa.gov.uk", statistical sources of information on the number of vehicles produced in the analyzed period OICA, 2014, as well as summary information obtained by analyzing calls for selected automotive companies VOSA, 2015.

2. Hypothesis determination: [1] claim that the extent of call-to-actions is an important indicator of the efficiency of the automotive distribution network. This argument was the basis for establishing the following research hypotheses for call-to-actions in automotive companies (Table 1).

Table 1 Determination of research hypotheses, source: own research

Number of the hypothesis	Description of the specified hypothesis
Hypothesis number 1 (H1):	• There is a direct relationship between the growth of risk and the growth of stakeholder interest.
Hypothesis number 2 (H2):	• The quality of selected suppliers affects the quality of manufactured products.
Hypothesis number 3 (H3):	• There is an indirect relationship between the number of calls to action and the probability of detecting errors.
Hypothesis number 4 (H4):	• The pressure on accuracy and quality is directly proportional to the timeliness of error detection.
Hypothesis number 5 (H5)	• There is an indirect relationship between the error rate and the size of the risk.

The individual hypotheses were subsequently tested using the analysis of call-to-actions from 2005 to 2015. Various tools were used to analyze the hypotheses (H1) to (H5). The analytical tool Google Trends was used for the tested hypotheses (H1). Research worked with data from the years 2007 - 2015. The frequency of the search term was analyzed concerning the ratio of the total number of searches via Google Trends. For the testing of hypotheses (H2) to (H5), the source of information in the sector of calls was the web portal "vosa.gov.uk", where the sources for analysis were selected based on precisely specified criteria. It worked with recalls that met the basic characteristics of calls listed in Table 2 and Table 3.

Table 2 Basic characteristics of users calls-to-action, source: own research

Characteristic	Identification
Vehicle Age	Less than 8 years
Cost – Bearing	Vehicle manufacturer
Standard Length of Repairs	60 days
Invalidity of The Recalls	Lawsuit
Compensation In Case of an Accident	Not necessary
Impossibility of Repair	Financial compensation

Table 3 Identification of the sources of users calls-to-action, source: own research

Identification of the calling action
http://www.vosa.gov.uk/vosa/apps/recalls/
http://www.recalls.gov/nhtsa.html
http://www.safercar.gov/Vehicle+Owners
http://www.mycarstats.com/reports/recalls.aspx

3. Dependency identification: In this part of the research, the dependencies of the criterion characteristics were monitored through the analysis of the risks of the recalls according to the assembly groups and the analysis of the causes of car damage. (During testing hypothesis (H2)). Analysis of the timeliness of detection of faulty components was used in testing hypotheses (H3) and (H4). For testing hypothesis (H5), an analysis of error rate was performed (OICA, 2014), as well as summary information obtained by analyzing the recalls of selected automotive companies (VOSA, 2015).

4. Evaluation of results and confirmation of hypotheses: this phase of the research was processed using graphical methods and an error rate based on a relative number (1).

$$F_i = \frac{\sum_{2005}^{2015} ZA_{ij}}{\sum_{n}^{m} V_{ij}} \quad (1)$$

where: (Fi) - error rate, probability of error, (Aij) - called vehicles of individual brands of the analyzed period, (Vij) - total number of produced vehicles during the calling action period (n-m).

Error rate calculation, resp. the probability of error was obtained by dividing the sum of the individual brands of called vehicles (A) of the analyzed period (t) by the sum of the total number of vehicles produced (V) for the range of the period affected by the recalls (n-m) (2).

$$\bar{P}_{ZA} = \left(\sum_{i=1}^{n} \frac{manufacture\ year\ of\ the\ vehicle}{start\ of\ the\ call-to-action}\right) \div n \quad (2)$$

The average probability of error detection (PZA) – the probability of detecting an error represents a ratio of the production years of the vehicle to the time of the start of the vehicle call action. The higher probability and close to the value of p = 1 means the earlier period of error detection on the vehicle. (n) - represents the number of called vehicles.

4 Results and discussion

Within the research of the recall actions, after data collection and processing, it carried out the identification of the dependence based on the established hypotheses, and it evaluated the individual hypotheses based on statistical analyzes.

Hypothesis number 1 (H1):	***There is a direct relationship between the growth of risk and the growth of stakeholder interest.***

In the process of the testing hypothesis (H1), there is a direct relationship between the growth of risk and the growth of interest groups (Figure 1). Google Trends was used. The results were surveyed in the period 2007-2015. The interest of interested groups in the recall actions of selected car brands is assessed based on the level of interest in the analyzed issues in a limited time horizon using the analytical tool Google Trends. The height of the values in the graph represents the frequency of the searching term to the ratio of the total number of searches on Google. The data in the graph are normalized and presented on a scale from 0 to 100. Descending, resp. the rising curve indicates a reduced, resp. increased search term frequency.

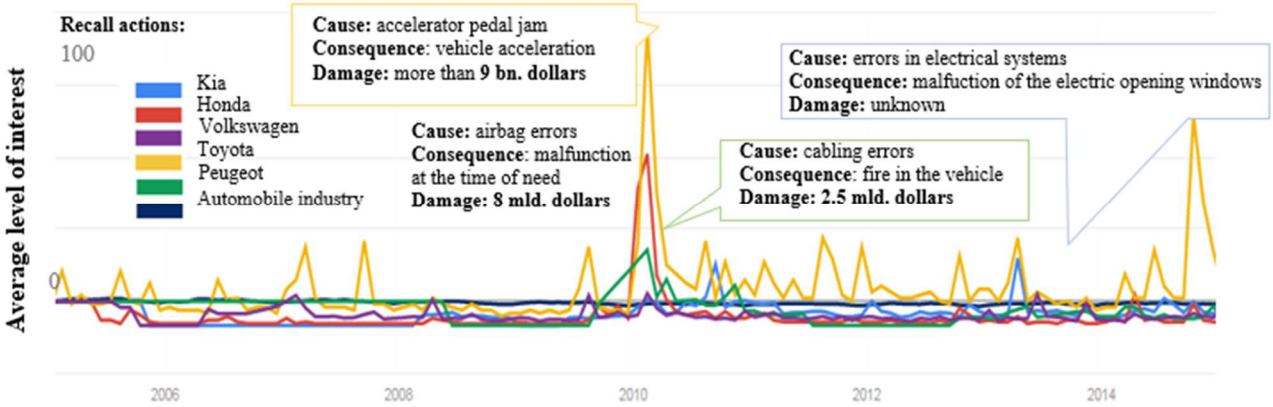

Figure 2 The interest of interested groups, source: own elaboration

Hypothesis H1 was confirmed.

Hypotheses (H2 –H5) were tested at user recall events that met criteria such as vehicle age, cost bearing, the standard length of repairs, the invalidity of the recall action, compensation in the event of an accident, inability to repair the vehicle. All these criteria have set limit values, which are listed in Table 2. During testing the hypothesis (H2), the risk analysis of the recall actions according to the assembly groups was used (Figure 2).

Hypothesis number 2 (H2):	***The quality of selected suppliers affects the quality of manufactured products.***

Based on a statistical analysis of the assembly groups of individual cars KIA, PSA, VW, the highest share of 26.35% was determined in electrical engineering and

electronics, which represent the riskiest error of vehicles of these brands and therefore recall actions are necessary. The least risky error is the chassis 3.59% and other vehicle errors in the share of 25.75%. Based on the more precise analysis of the structure of recall actions of individual cars, it can be stated that electrical engineering and electronics has the highest share (34%) in the KIA car company. In other car manufacturers, it is at the level of 18-27%, specifically VW 18%, PSA 27%. Based on the overall assessment of errors, the highest proportion of errors in KIA is 5-34%, in VW at 7-18%, in PSA at 3-28%. Risk errors based on the analysis of errors in individual cars include electrical engineering, electronics and the brake system.

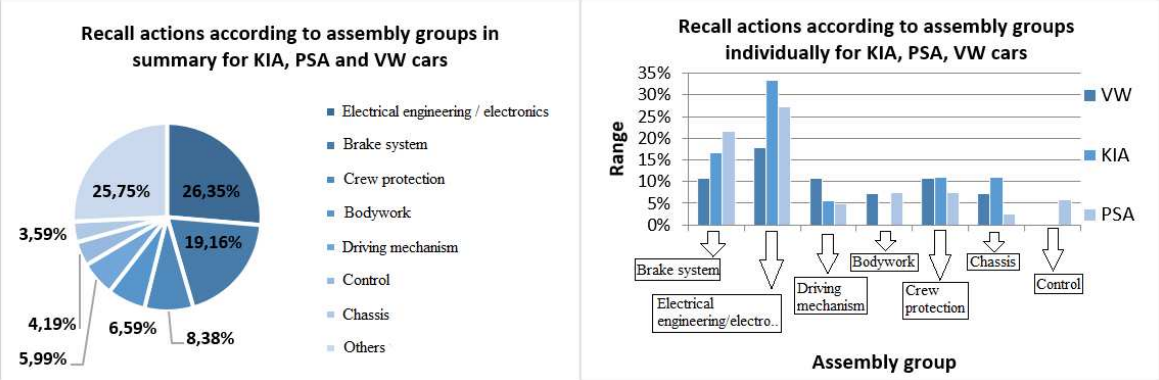

Figure 3 Analysis of recall actions by assembly groups, source: own research

Analysis of the causes of damage was used to test the hypothesis (H2) (Figure 3). The results of this analysis point to the causes of damage in selected car manufacturers in the sector of construction errors, which account for 38% of the total causes for calls. Other risk causes of vehicle damage are assembly errors at the level of 31%, material errors at the level of 14%, software errors at the level of 13%. Errors of assistance service and mechanical components range from 1.8-4%. In terms of approach to the causes of damage according to individual selected cars, it can be stated that in VW the causes in the sector of design error, material error, assembly error and software error are at the level of 10-32%, in KIA the causes of damage are oriented to the assistance service, design error, material error, assembly and software error in the range of 11-56%, in the car manufacturer PSA errors are mainly focused on design errors, assembly errors, software errors of 3-37%. The main cause of vehicle damage is structural errors, with which the KIA car company has a serious problem at the level of 56%. In conclusion, it can be stated that the biggest problem in the field of assembly groups is electrical engineering and electronics, in the field of causes of damage it is a design error. Based on both analyzes, it is possible to confirm significant deficiencies in the error rate at the KIA, in which electrical engineering represents 34% and design errors 56%.

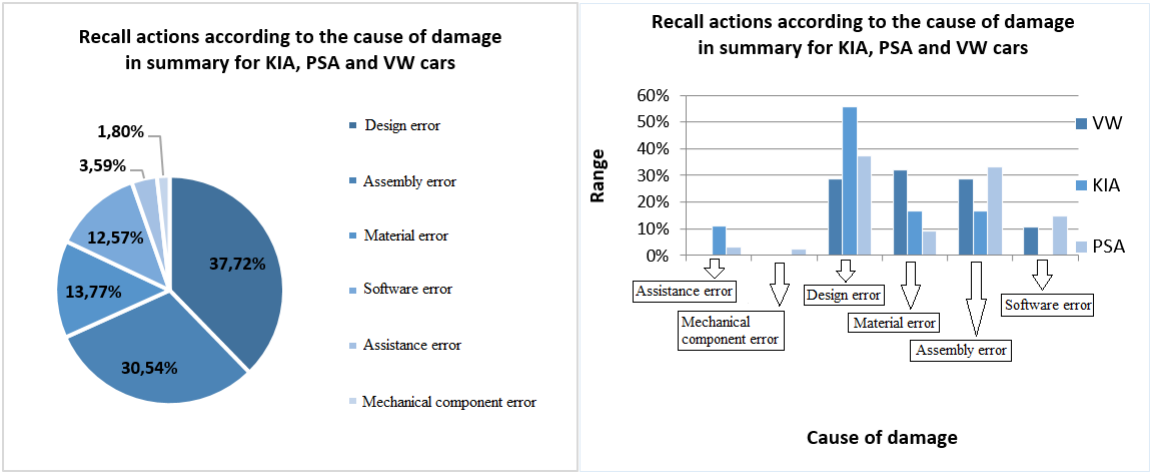

Figure 4 Analysis of recall actions according to the cause of damage, source: own research

Based on the analysis of risk factors of a selected group of automobiles in terms of assembly groups and causes of damage to vehicles, it was necessary to determine the risk of components in selected automotive companies and their relationship to the structure of supply companies for individual components. The results of this analysis indicate a high risk of components, but a small representation of suppliers for a given component. The average riskiness of

components in the distribution network of the Slovak Republic reaches relatively low values: 0.60% -19.16%. However, this fact does not guarantee a reduced risk in the distribution network of supply companies for selected components. The critical area is the risk of brake components at the level of 20% with a low number of suppliers at the level of 4.53%. Based on the analysis, it can be assessed that to ensure the quality of the final production - vehicles, it is necessary for car companies to focus their attention on suppliers in the field of brake systems, as the number of suppliers in this sector is low and the risk is relatively high.

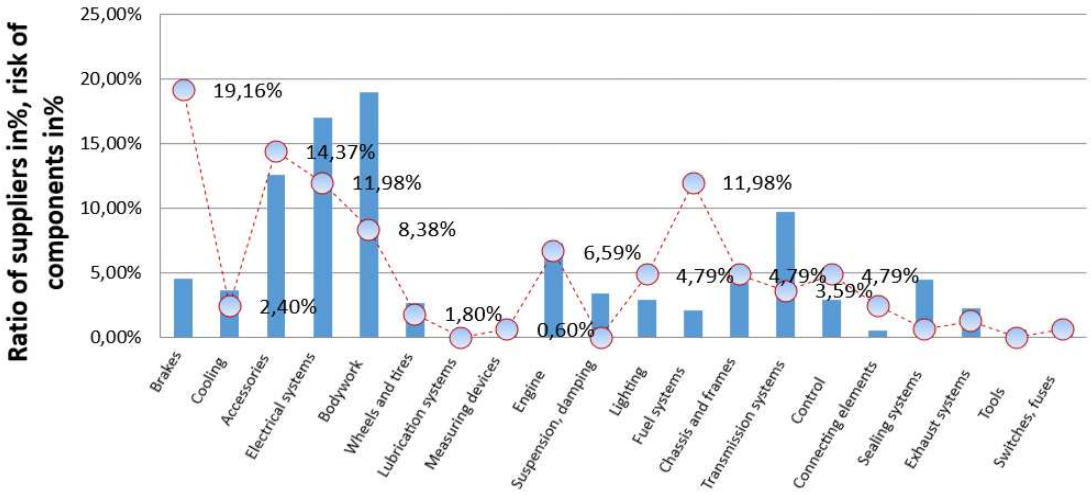

Figure 5 Comparison of the riskiness of components in the distribution network of the Slovak Republic, source: own research

In conclusion, it can be stated that the quality of selected suppliers does not affect the quality of manufactured products - vehicles.

Hypothesis H2 was not confirmed.

Hypothesis number 3 (H3):	**There is an indirect relationship between the number of calls to action and the probability of detecting errors.**

The highest average probability of detecting errors (Figure 5) is for Škoda (0.9993), Citroen and Peugeot (0.9992) vehicles. In contrast, for vehicles such as the Lamborgini, the probability of early error detection was lowest (0.9972). An analysis of the detectability of the error revealed that the most recall was recorded for Citroen and Peugeot vehicles, with the longest error detection time for Hyundai-Kia and Volkswagen Group brands. Overall, it can be confirmed that the number of recall actions, which was 890 333 vehicles, had a high average error detection rate of 0.999216212, but not the highest, which means that the number of called vehicles is not related to the probability of error detection, as declared by PEUGEOT, where 346 707 vehicles were called, but the probability of detecting errors was 0.999269888. This indicator was the highest for the Peugeot brand.

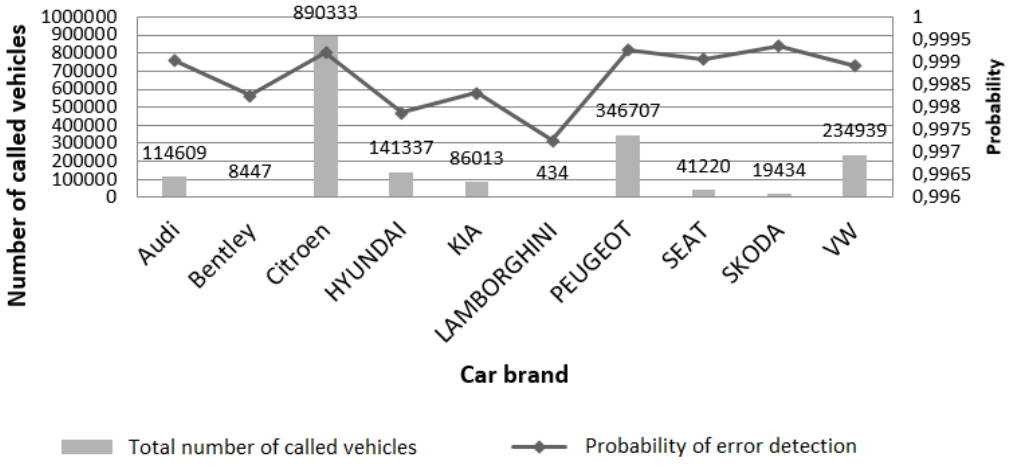

Figure 6 Error detectability analysis, source: own research

Hypothesis H3 was confirmed.

Hypothesis number 4 (H4):	**The pressure on accuracy and quality is directly proportional to the timeliness of error detection.**

During testing the hypothesis (H4), the analysis of the timeliness of the detection of defective components was used, which represents the optimal time of detection of the error on the vehicle and the implementation of corrective measures. The optimal period for detecting an error on vehicles is at the level of 3 - 11 years, which depends on several other factors, such as the year of manufacture of the vehicle, the number of recall actions and its beginning.

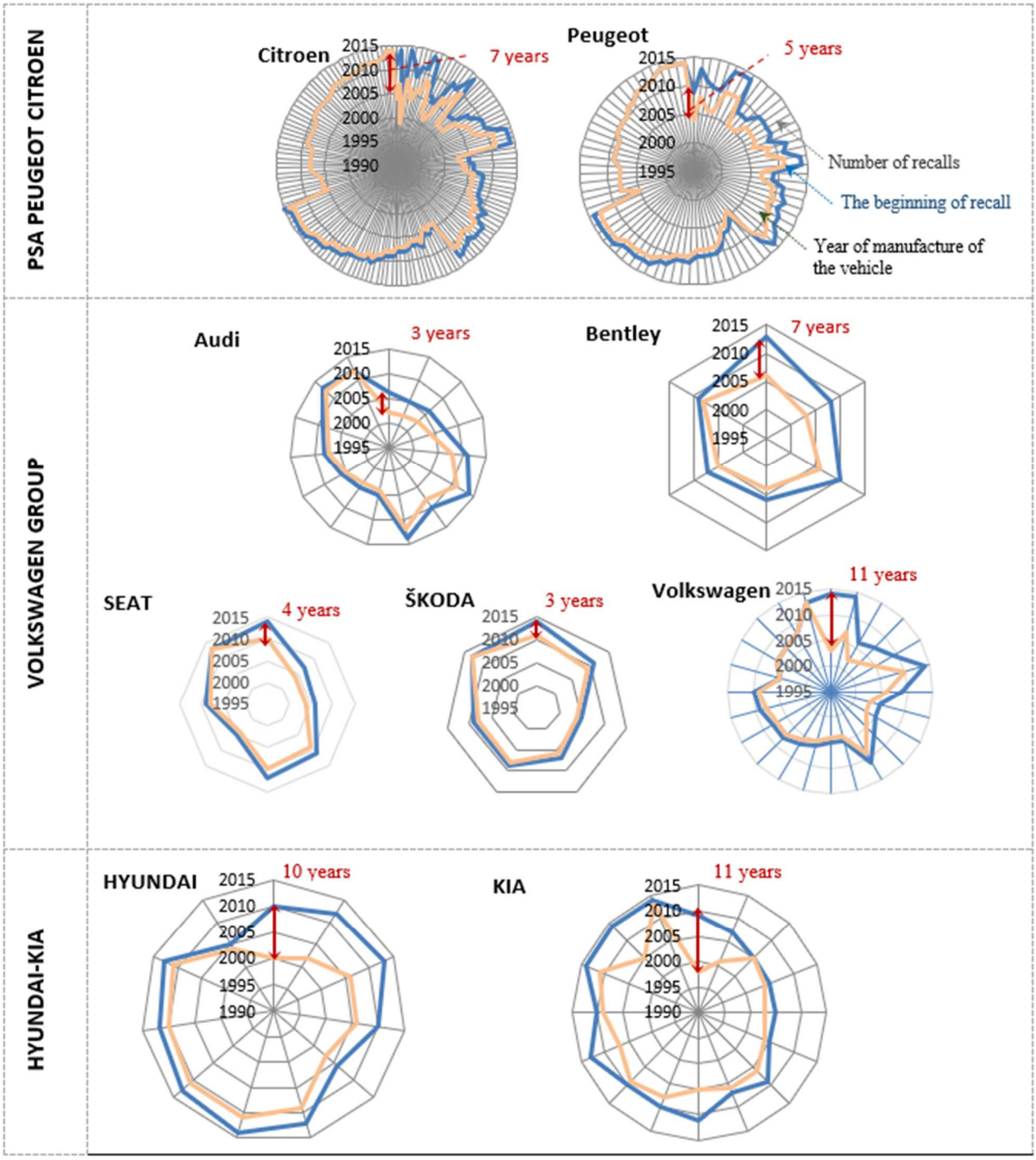

Figure 7 Error detection timelines, source: own research

Hypothesis H4 was not confirmed.

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Hypothesis number 5 (H5)	**There is an indirect relationship between the error rate and the size of the risk.**

The relation between risk and error was monitored using the error rate indicator. Error rate calculation, resp. probability of error (Table 3), was obtained by dividing the sum of individual brands of called vehicles in the analyzed period by the sum of the total number of vehicles produced over the range of the period affected by the recall. Due to the mismatch of production capacity, only a relatively low error rate of Hyundai-Kia compared to PSA Peugeot-Citroen can be expected. These two car companies are relatively similar in terms of diversity and production volume, and they are relatively comparable. However, they cannot be compared with the car company Volkswagen Group, which significantly differs from the previous two companies in terms of production volume and diversity. The results show the lowest error rate in KIA with the lowest number of called vehicles.

Table 4 Error rate analysis and probability of error, source: own research

Company*(i)*	**Analysis period of call-to-actions** *(t)*	**Number of called vehicles** *(ZA)*	**Production period** *(n-m)*	**Number of manufactured vehicles** *(V)*	**Error rate** $F_i = \frac{\sum_{2005}^{2015} ZA_{ij}}{\sum_{n}^{m} V_{ij}}$
Hyundai-Kia	2005-2015	238 260	1998-2013	59 688 494	**0.399%**
PSA Peugeot Citroën	2005-2015	1 819 021	1999-2014	48 552 952	**3.746%**
Volkswagen Group	2005-2015	4 58 519	2002-2014	89 446 088	**0.513%**

Hypothesis H5 was confirmed.

As part of the research of recalls, we identified the dependence based on established hypotheses and evaluated the individual hypotheses as follows (Table 5):

Table 5 Evaluation of hypotheses of calling actions, source: own research

	Established hypotheses	**Interpretation**	**Rating**
H1:	There is a direct relationship between the growth of risk and the growth of stakeholder interest.	↑ risk = ↑ interest	✓
H2:	The quality of selected suppliers affects the quality of manufactured products	quality of deliveries = production quality	✖
H3:	There is an indirect relationship between the number of calls to action and the probability of detecting errors.	↑ frequency of errors ≠ ↑ error detection	✓
H4:	The pressure on accuracy and quality is directly proportional to the timeliness of error detection.	↑ accuracy = fast reaction	✖
H5:	There is an indirect relationship between the error rate and the size of the risk.	↑ error rate ≠ ↑ risk	✓

✓ Confirmed hypothesis, ✖ Unconfirmed hypothesis.

In the process of the testing hypothesis (H1), there is a direct relationship between the growth of risk and the growth of interest groups. The results of the hypothesis (H2) point to the fact that the quality of selected suppliers does not affect the quality of manufactured products - vehicles. Based on the overall assessment of errors, the highest proportion of errors in KIA is 5-34%, in VW at 7-18%, in PSA at 3-28%. The frequency of errors is inversely proportional to the probability of error detection. Risk errors based on the analysis of errors in individual cars include electrical engineering, electronics and the brake system. In terms of approach to the causes of damage according to individual selected cars, it can be stated that in VW the causes in the area of design error, material error, assembly error and software error are at the level of 10-32%, in KIA the causes of damage are oriented to the assistance service, design error, material error, assembly and software error in the range of 11-56%, in the car manufacturer PSA errors are mainly focused on design errors, assembly errors, software errors of 3-37%. The biggest problem in the sector of assembly groups are the items of electrical engineering and electronics, in the sector of causes of damage, it is a design error. To ensure the quality of the final production - vehicles, it is necessary for car companies to focus their attention on suppliers in the field of brake systems, as the number of suppliers in this sector is low and the ratio of risks is relatively high. There is no direct relationship between the error rate and the size of the risk. The number recall actions, which represents 890 333 vehicles, had a high average error detection rate of 0.999216212, but it is not the highest, which means that the number of called vehicles is not related to the probability of error detection, as declared by PEUGEOT, where 346 707 vehicles were called, but the probability of detecting errors was 0.999269888. The optimal period for detecting an error in vehicles is at the level of 3 - 11 years.

5 Conclusion

The recalls of products in the automotive industry represent an area of poor quality, which is reflected in the poor quality of components in automobiles, in the software, electrical, and electronic areas, in environmental quality, in management, and diagnostics. Based on the established hypotheses, the consequences and causes of the emergence of recall actions in automotive companies. The most common cause of recalls was found to be electrical engineering, electronics, and brake systems. At the same time, the risks associated with vehicle errors were identified. In terms of errors, these were design errors, material and software errors. The most called vehicles were Citroen, and the error rate was 3.74%. The greatest risk of the components in the supplier structure was represented by the car bodywork, electrical systems, and accessories. The biggest problem in the structure of suppliers was supply companies specializing in brakes, fuel systems, fasteners, lighting, and wheels. The error rate was used to monitor the relation between risk and error rate, and the results show the lowest error rate at KIA with the lowest number of called vehicles. The quality of selected suppliers does not affect the quality of manufactured products - vehicles. It is clear from the research results that the detectability of the error is not related to the number of called vehicles and the risk of components is not related to the structure and quality of suppliers to the automotive industry. Call-to-action is an effective tool for automotive companies to take corrective action and ensure the safety of customers who have purchased vehicles with potential, later identified errors. The error rate in the production process is a basic strategic goal of automotive companies, which is focused on reducing the error rate on the part of suppliers, reducing the error rate in the production process, and, ultimately, reducing the costs associated with call-to-actions.

Acknowledgement

This paper was developed within the project implementation VEGA 1/0340/21 “The impact of a pandemic and the subsequent economic crisis on the development of digitization of enterprises and society in Slovakia.”

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