Article citation info:
GONERA J, NAPIÓRKOWSKI J. Model for forecasting the geometry of the floor panel of a passenger car during its operation. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2018; 20 (4): 689–695, http://dx.doi.org/10.17531/ein.2018.4.20.

Jarosław GONERA
Jerzy NAPIÓRKOWSKI

MODEL FOR FORECASTING THE GEOMETRY OF THE FLOOR PANEL OF A PASSENGER CAR DURING ITS OPERATION

MODEL PROGNOZOWANIA STANU GEOMETRII PŁYTY PODŁOGOWEJ SAMOCHODU OSOBOWEGO W TOKU EKSPLOATACJI*

A number of vehicle users pay attention to the impact of changes in the car body geometry during long-term use on the safety level. However, this issue has not been properly dealt with in research studies. The aim of this study was to identify changes in the floor panel, to develop a model to forecast the geometry during the car use and to identify the points which undergo the maximum displacement. The paper presents the effect of the car mileage on the floor panel condition, taking into account variable environmental factors. In the course of the study, the position of points fixing the front suspension, front bench and rear suspension was determined, as was the position of points situated on parts of the load bearing structure of the car body. The results were used to develop a model for forecasting changes of the floor panel geometry during car use. The probability of changes in the floor panel geometry was found to increase with the mileage. The probability of reaching the maximum permissible geometric changes (3 mm) in a floor panel is accurately described by the probabilistic model in the form of the Rayleigh distribution. Diverse models of the floor panel geometry changes were obtained depending on the environmental conditions and type of the base points under analysis.

***Keywords**: passenger car, car body, floor panel, car body geometry, safety.*

Wielu użytkowników samochodów osobowych zwraca uwagę na istotność wpływu na poziom bezpieczeństwa zmian geometrii nadwozia pojazdów podczas ich wieloletniej eksploatacji. Jednak dotychczas zagadnienie to nie znalazło odpowiedniego odzwierciedlenia w literaturze. Celem pracy była identyfikacja zmian geometrii płyty podłogowej, opracowanie modelu prognozującego stan geometrii w toku eksploatacji i zidentyfikowanie punktów ulegającym największym przemieszczeniom. W pracy przedstawiono wpływ przebiegu pojazdu na stan geometrii płyty podłogowej z uwzględnieniem zróżnicowanych warunków środowiskowych. Podczas badań określano położenie punktów mocujących zawieszenie przednie, przednią ławę i zawieszenie tylne oraz położenie punktów znajdujących się na elementach struktury nośnej nadwozia. Na podstawie uzyskanych wyników opracowano model prognozowania zmian geometrii płyty podłogowej w toku eksploatacji. Stwierdzono, że prawdopodobieństwo zmian geometrii płyty podłogowej podczas eksploatacji rośnie w czasie, wraz ze wzrostem przebiegu. Prawdopodobieństwo osiągnięcia stanu dopuszczalnego (3 mm) zmian geometrycznych na płycie podłogowej dobrze opisuje model probabilistyczny w postaci rozkładu Rayleigha. Uzyskano zróżnicowane modele zmiany geometrii płyty podłogowej w zależności od warunków środowiskowych oraz rodzaju analizowanych punktów bazowych.

***Słowa kluczowe**: samochód osobowy, nadwozie, płyta podłogowa, geometria nadwozia, bezpieczeństwo.*

1. Introduction

The issue of an assessment of the condition of a passenger car body geometry is usually considered in the context of repair work [17, 22]. To this end, procedures have been developed for car approval for traffic by car manufacturers, as well as relevant regulations [22]. The issue of the car body technical condition is linked inextricably with the safety of its use [3].

Safety system development in modern cars is oriented mainly towards reducing the risk of a car accident and minimising the injury if such an accident happens [6, 11]. The construction of the car body, aimed at limiting the accident effects by minimising the injuries of the car driver and passengers, is one of the most important elements of passive safety [5, 15, 18, 25]. Active car body-related safety elements mainly include the appropriate deployment of the fixing points for parts of the suspension and the steering system which directly affect the wheel geometry [4, 10, 20, 22, 23].

The car body geometry is understood to denote the appropriate, in line with the manufacturers' requirements, deployment of all the base points on the floor panel and on the upper parts of the car body relative to the three reference planes [1, 8]. There are base points on car bodies which are used for geometry measurements. These points usually include structural holes, which are used to fix subassemblies, and auxiliary holes, used especially for measurements [1, 16]. Manufacturers of passenger cars usually assume that the difference between the required and the actual position of base points should not be greater than 3 mm [12, 16, 17]. When base points in crumple zones are displaced during an accident or a road collision, some unexpected distortions of the body may occur, which absorb virtually no energy [7, 8, 24]. In modern cars, it is not possible to regulate many parameters of the suspension and steering systems. Therefore, for example, the camber angle, the kingpin inclination or the castor angle are not adjustable. A change of the car body geometry will therefore result in a change of these parameters, which may make it difficult to maintain the right kinematics of motion [22, 26].

To date, few authors have dealt with changes of the technical condition of accident-free car bodies during their use. The issue is also omitted in regular vehicle technical inspections. The main causes of changes in the technical condition of a car body include road ac-

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl*** cidents or collisions, weather conditions and prolonged use of a car on low quality roads [2, 12, 19, 27]. The issue of the car body wear during its use has been mentioned by the authors of [2, 3, 12, 19]. These are usually general remarks, stating that the manner of a car use affects the car body condition [14]. Nevertheless, the authors of [9] have analysed the effect of the passenger car mileage on changes in the floor panel geometry. According to their findings, the maximum permissible changes of the body geometry (3 mm) at some base points occur after 150,000 km [9]

2. A system approach to changes in the car body geometry

During car use, responses to the road pavement are transmitted through the suspension system [27]. When driving, a passenger car is subjected to continuous kinematic and forced excitations of a broad range of values [14]. During car use, its body is subjected to static and dynamic loads. The static loads result from the torque originating from forces from the pavement, transmitted through the suspension system. They are also a result of bending loads, being a consequence of the mass of the car, passengers and cargo. On the other hand, the dynamic loads are associated with speed and acceleration of a vehicle; they originate while taking bends, driving along a bumpy road, braking and gaining speed [13, 27]. During vehicle use, its body is exposed to such factors as corrosion and fatigue, etc., which contribute to progressive degradation [15].

Compared to those in Western Europe, roads in Poland are in a worse technical condition [21]. According to data received from GDDKiA, up to 38.3% of the trunk roads in Poland require repair work. The condition of regional, county and commune roads is even worse.

During car use, wear processes take place which include changes in the geometry of the floor panel and upper parts of the body (Fig. 1). The geometry of a car body is characterised by a set of characteristics C. A body during car use is subjected to a variety of excitations W, which bring about changes of geometry, which in these cases are responses to the wear process Z.

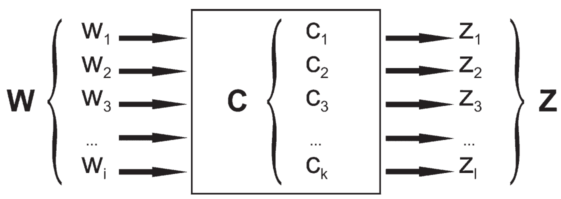

Fig. 1. A graphic illustration of the process of a car body wear during its use: C – a set of characteristics of an object, W – a set of excitations, Z – a set of responses of the object

$\mathbf{C = \{c_1, c_2, c_3, \ldots, c_k\}}$ $\mathbf{k} = \overline{1, \boldsymbol{K}}$, where: c_k is a representation of the actual characteristics of the body geometry, k = 1, 2, 3, …K;

- c_1 – position of base points which characterise the active safety on the right side of the floor panel;
- c_2 – position of base points which characterise the active safety on the left side of the floor panel;
- c_3 – position of base points which characterise the passive safety on the right side of the floor panel;
- c_4 – position of base points which characterise the passive safety on the left side of the floor panel;
- c_k – k-th characteristic of the car body geometry.

$\mathbf{W = \{w_1, w_2, w_3, \ldots, w_i\}}$ $\mathbf{i} = \overline{1, \boldsymbol{I}}$, where: w_i is a representation of the real excitations acting on the car body during its use, i = 1, 2, 3, …I;

- w_1 – total mileage of a vehicle;
- w_2 – environmental conditions in which a car is used, associated to the country in which it is used;
- w_3 – age of the car;
- w_4 – characteristics of the car use so far;
- w_5 – road incidents in which the car may have participated;
- w_6 – factors exceeding standard use;
- w_7 – environmental conditions of use;
- w_i – i-th excitations acting on the car.

$\mathbf{Z = \{z_1, z_2, z_3, \ldots, z_l\}}$ $\mathbf{l} = \overline{1, \boldsymbol{L}}$, where: z_l is a representation of actual responses, l = 1, 2, 3, …L;

- z_1 – change of position of points which characterise the active safety on the right side of the floor panel;
- z_2 – change of position of points which characterise the active safety on the left side of the floor panel;
- z_3 – change of position of points which characterise the passive safety on the right side of the floor panel;
- z_4 – change of position of points which characterise the passive safety on the left side of the floor panel;
- z_l – l-th characteristic of changes of the car body geometry.

The literature analysis has shown that there have been no studies aimed at determining the effect on the changes of the car body geometry of: w1 – total mileage of a vehicle and w2 – environmental conditions of use. The quantitative effect of these parameters on changes in the body condition has not been identified so far. Therefore, the effect of these characteristics has been examined.

The aim of this study was to identify changes in the floor panel and to develop a model to forecast its geometry during car use. As an auxiliary objective, characteristic points of the body with the greatest displacement were identified.

3. Study methodology

A total of 120 passenger cars with diverse mileage from 10,000 to 360,000 km were included in the study. The vehicles were divided into two categories. The first category, marked PL, included cars used on domestic roads. The other, marked EU, included cars used on the roads of Western Europe. Each of the two categories included the same number of cars – 60. The cars had the same construction parameters (i.e. hatchback type body, spark-ignition engine and the front-wheel drive). None of them had been in an accident or a collision, in none of them had any events been identified which would go beyond normal use (e.g. exceeding the maximum allowed capacity).

The floor panel geometry was measured with an accuracy of 1 mm with a Gysmeter device manufactured by Gys (Fig. 2). The measurement range of the Gysmeter device was between 400 and 2650 mm. The measurement device was equipped with a dedicated set of measurement tips, fitted to the base points under analysis. Owing to the set, measurements could be conducted without dismounting parts of the suspension and steering system. The actual position of the characteristic base points was measured and compared to the position required by the vehicle manufacturers. The measurements were made relative to the reference points, situated at the back part of the car, in the rear of the passenger compartment. No changes in geometry, including deformations, were identified at the reference points in the cars under study. The data on the position of the base points on the floor panel were taken from the database in the Allvis Light programme. This provides the required distance (in mm) between individual base points.

A total of 12 characteristic base points were selected, which could be found in each of the passenger cars under study. Six of them were on the right and six on the left side of a car. Three of the points were associated with active safety and three with passive safety.

Fig. 2. Measurements of the floor panel geometry with a GYSMETER device manufactured by GYS

An analysis was conducted of the characteristics associated with (Fig. 3):

- geometry of the suspension and the steering systems (active safety) - the front suspension fixing points, the rear points fixing the front bench and the rear suspension fixing points;
- passive safety - points situated near the bulkhead, at the beginning of front longitudinals and at the end of the rear longitudinals.

During the measurements, each car was placed on a 2-column lift and fixed as recommended by the manufacturer. Dedicated magnetic tips on a permanent external pole and suitable measurement tips on a moveable pole were used with the Gysmeter device.

Changes in geometry for the given points of the floor panel Pzg were determined from the formula:

$$\mathbf{P_{zg}} = \left|\mathbf{WOPB} - \mathbf{ROPB}\right|\left[\mathrm{mm}\right], \tag{1}$$

where:

WOPB– required distance between the base points [mm];
ROPB – actual distance between the base points [mm].

The uncertainty for measurements of the actual distance between the base points (ROPB) was 1 mm. In consequence, uncertainty for P_{zg}, i.e. change of the geometry for the given points of the floor panel, was also 1 mm.

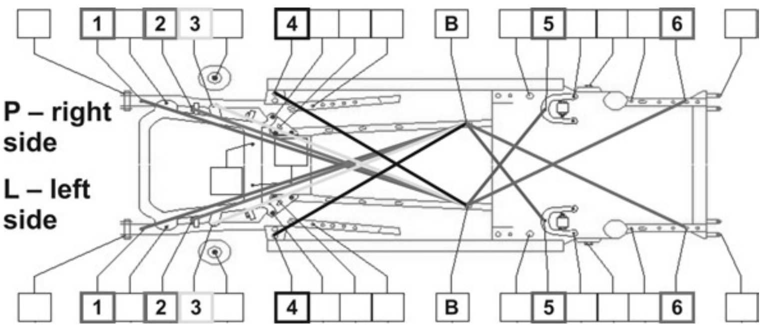

Fig. 3. Deployment of points at which measurements of the floor panel geometry was conducted, where: B – reference points, initial during the measurements; 1 – points situated at the beginning of the front longitudinals; 2 – front suspension fixing points; 3 – rear points fixing the front bench; 4 – points situated near the bulkhead; 5 – rear suspension fixing points; 6 – points situated at the end of the rear longitudinals

4. Analysis of the floor panel geometry changes

The size of the changes of the base points position (Table 1) was related to their deployment on the floor panel. The smallest changes in the floor panel geometry were observed near the bulkhead. Particularly large changes were observed at the base points of fixing the front suspension, rear suspension and at the front bench fixing point. The average displacement in the cars under study in these areas exceeded 6 mm. The point position changes exceeding 10 mm were also identified.

Much greater displacements of the base points were observed in the cars used in Poland compared to those used in Western Europe (Table 1). This applied to all the areas of the floor panel. Regardless of the place, the displacements of characteristic points of the floor panel in the cars used in Poland were greater than in the cars used in Western Europe. The displacements near the bulkhead (4P and 4L) were slightly greater in cars used in Poland. The differences between the cars used in Poland and those used in Western Europe were the smallest in this area (up to 0.3 mm). Similarly, relatively small differences between the two categories were observed at the points situated at the beginning of the front longitudinals (1P and 1 L) and at the end of the rear longitudinals (6P and 6L). The differences reached approx. 0.5 mm. Greater differences in the geometry changes between cars used in Poland and in Western Europe were observed at the base points connected with fixing the front suspension (2P and 2L), the front bench (3P and 3L) and the rear suspension (5P and 5L). The differences in these areas exceeded 1.5 mm. And the greatest base point displacements were observed at the rear suspension fixing points situated on the right side of the car body. Differences exceeding 3 mm were observed at these points in cars used in Poland and in Western Europe.

The analysis of variance has shown that changes in the floor panel geometry in cars used in Poland and in Western Europe differed significantly (Fig. 4).

Table 1. A list of mean changes of the geometry at the base points depending on where a car is used

The geometry changes at the base points			
Place of car use		**PL [mm]**	**EU [mm]**
1P	Front longitudinal	2,13	1,83
1L		2,13	1,67
2P	Fixing of front suspension	6,25	4,67
2L		5	3,5
3P	Fixing of front bench	4,88	3,33
3L		4	2,67
4P	Near the bulkhead	1,5	1,33
4L		1,63	1,33
5P	Fixing the rear suspension	6,5	3,33
5L		4,88	3
6P	Rear longitudinal	2,63	2
6L		2,13	1,67

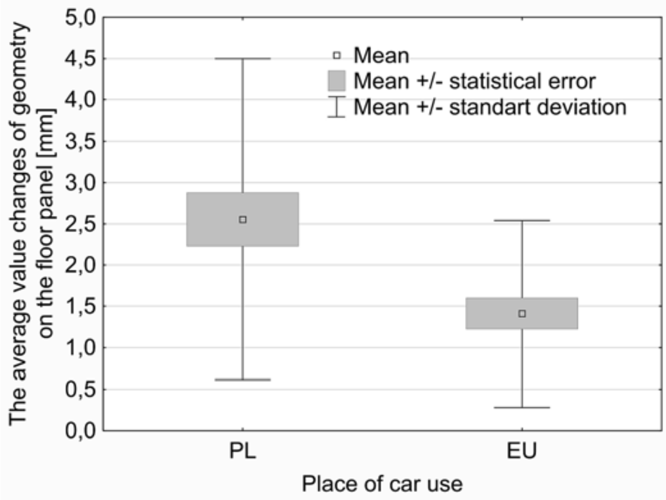

Fig. 4. A comparison between the base points displacement in cars depending on the country of use

a)

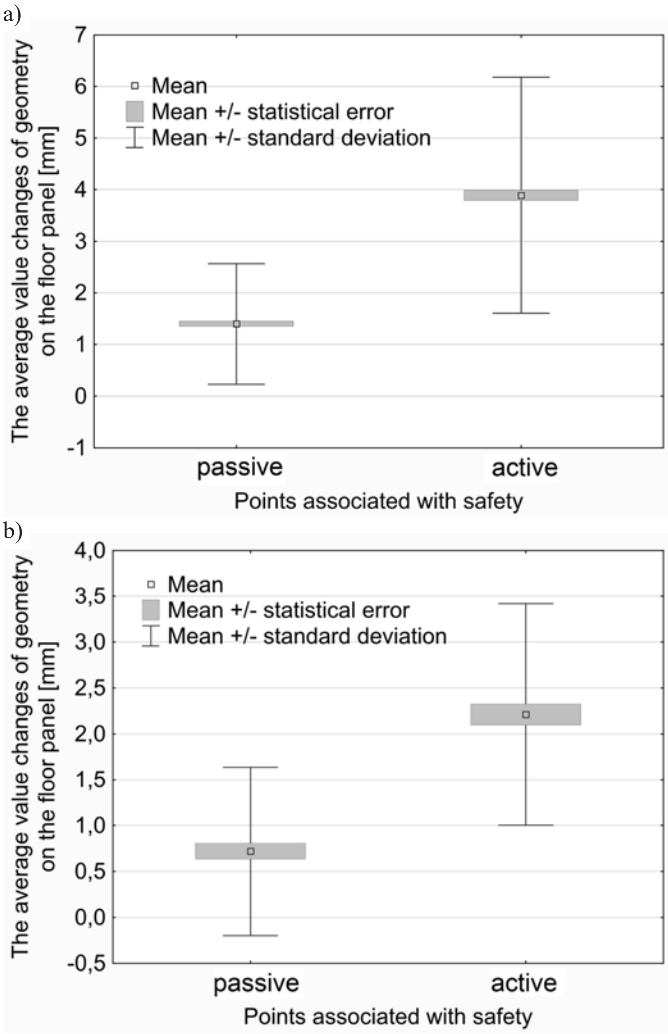

Fig. 5. A comparison between the base point displacements in cars used on roads: a. in Poland. b. in Western Europe. depending on the type of safety for which they are responsible

This study also employed an analysis of variance. whose aim was to determine the effect on the geometry changes in the type of safety for which the given base points are responsible (Fig. 5) and the side of the car where they are situated (Fig. 6).

a)

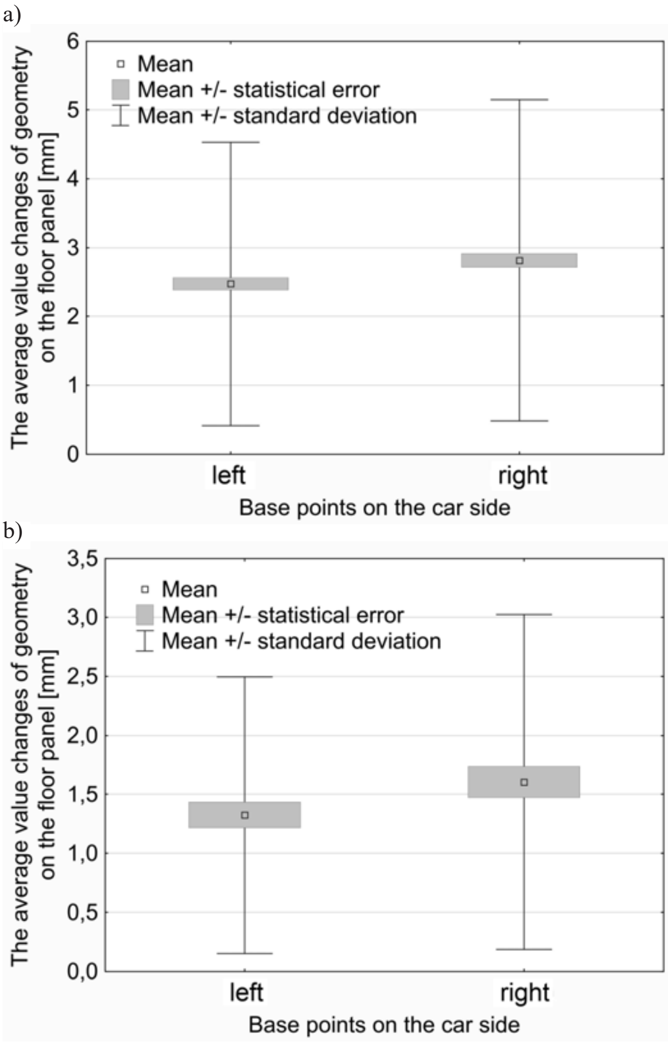

Fig. 6. A comparison between the base point displacements in cars used on roads: a. in Poland. b. in Western Europe. depending on the side of a car where the points were situated

Significant changes were found between the base points related to passive and active safety. Such differences were observed both in cars used in Poland and in those used in Western Europe. Greater geometry changes were observed at the base points related to active safety. Moreover. greater changes in the floor panel geometry - both in the cars used in Poland and in those used in Western Europe - were observed at the points situated on the right than on the left side of the car body.

The intensity of the floor panel geometry changes was constant. regardless of the car mileage (Fig. 7). However. an increase in the total geometry changes was observed with increasing mileage. The intensity of the geometry changes depended on the country in which a car was used. the type of safety for which the base points were responsible and the side on which they were situated. Tables 2 and 3 show the intensity of the floor panel geometry changes observed in this study.

Greater changes of the floor panel geometry changes in regard to the mileage were observed in the cars used in Poland. They were twice greater in virtually all cases. Moreover. several times greater changes were observed at points responsible for active than those responsible for passive safety of a car. The differences between the geometry changes on the right and left side of a car were not significant.

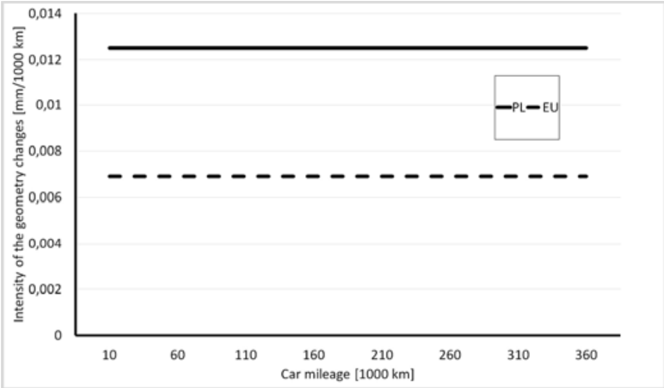

Fig. 7. Intensity of the floor panel geometry changes in cars used in Poland and in those used in Western Europe

Table 2. Intensity of the geometry changes in cars used in Poland

Cars used in Poland					
Type of safety	Passive		Active		At all the floor panel points under study
Side of a car	Right	Left	Right	Left	
Intensity of the geometry changes [mm/1000 km]	0,0060	0,0059	0,0214	0,0168	0,0125

Table 3. Intensity of the geometry changes in cars used in the EU

Cars used in Western Europe					
Type of safety	Passive		Active		At all the floor panel points under study
Side of a car	Right	Left	Right	Left	
Intensity of the geometry changes [mm/1000 km]	0,0026	0,0025	0,0128	0,0099	0,0069

5. A model of the floor panel geometry changes during car use

The following assumptions were adopted to develop a model of the floor panel geometry changes during the car use;

- the critical displacement size of the characteristic points is 3 mm;
- changes of the base point positions are linear for the analysed operational excitations.

Therefore. a model of the floor panel geometry changes in the deterministic approach will have the following form:

$$Z_{pp} = P_p \cdot I_{zg}, \text{ where} \tag{2}$$

Z_{pp} – change of the base points position;
P_p – car mileage;
I_{zg} – intensity of the floor panel geometry changes.

The probability of reaching the maximum allowable displacement of 3 mm grows linearly with increasing car mileage. After the geometry changes reach the critical value. a car must be withdrawn from use or transferred to a garage for repair. The model was verified based on the cumulative distribution function for the Weibull distribution:

$$F(X) = 1 - e^{-(x/\gamma)^k}\text{, where:} \tag{3}$$

F(x) – probability of reaching the critical values (3 mm) of the geometry changes;
k > 1 – parameter of the distribution shape;
$\gamma > 0$ – parameter of the distribution scale.

The probability of changes in the floor panel geometry was found to increase with the mileage. which corresponds to the distribution shape parameter of 2. In consequence. the model adopted a specific form of the Weibull distribution (shape parameter k=2). called the Rayleigh distribution. It applied both to cars used in Poland and in those used in Western Europe. The probability of the floor panel geometry changes was described with the following relationship:

$$F(Z_{pp}) = 1 - e^{-(Z_{pp}/\gamma)^2}\text{, where:} \tag{4}$$

Z_{pp} – change of the floor panel geometry at a given base point.

Based on the measurement results. the scale parameter was taken as two (γ=2). Therefore. the probability of floor panel changes during use had the following form:

$$F(Z_{pp}) = 1 - e^{-(Z_{pp}/2)^2} \tag{5}$$

The formula describing changes of the floor panel geometry at a given base point was transformed and supplemented with the statistics (w) determined in the Statistica software. The following relationship was obtained:

$$P_p = \frac{Z_{pp}}{w \cdot I_{zg}} \tag{6}$$

Tables 4 and 5 present the probability of changes of the floor panel geometry depending on the country in which the car was used. the side where the given base point is situated and the type of safety for which it is responsible.

Data presented in Tables 4 and 5 show that there are considerable differences in the mileage at which 3 mm displacements of the points appear. The differences depend on the condition of roads associated with the country in which a car is used. type of safety for which the given base points are responsible and the side of a car on which they are situated. For example. a geometry change of 3 mm will appear at the base points on the right side of a car. responsible for active safety. with a probability of p=0.05 at a mileage of 41 thousand km in cars used in Poland and at a mileage of 68 thousand km in cars used in Western Europe. On the other hand. the mileage for the left side will be 52 thousand km and 88 thousand km. respectively. For the base points associated with passive safety. a geometry change of 3 mm will appear at a mileage of 143 thousand km in cars used in Poland and at a mileage of 328 thousand km in cars used in Western Europe. It will also be 147 thousand km and 341 thousand km. respectively. on the left side of the car body.

6. Summary

With the mileage of a passenger car exceeding 120.000 km. changes of its floor panel geometry take place which have an impact on its safety. Changes in the floor panel geometry with the growing mileage are especially apparent at points important from the active safety perspective. These changes include displacements of points of fixing the front suspension. the front bench and the rear suspension. An average displacement of these points ranged from 6 mm to 10 mm.

Table 4. The probabilistic model of the floor panel geometry changes for points responsible for active safety on the right side in cars used in Poland

			Points associated with passive safety				Points associated with active safety			
			Left side		Right side		Left side		Right side	
p	w	Z_{gn} [mm]	I_{zg} [mm/1000km]	P [1000km]	I_{zg} [mm/1000km]	P [1000km]	I_{zg} [mm/1000km]	P [1000km]	I_{zg} [mm/1000km]	P [1000km]
0,95	0,45296	3	0,005898	1123	0,006049	1095	0,016771	395	0,021379	310
0,9	0,649186			784		764		276		216
0,8	0,944761			538		525		189		149
0,7	1,194445			426		415		150		117
0,6	1,429441			356		347		125		98
0,5	1,665109			305		298		107		84
0,4	1,914462			266		259		93		73
0,3	2,194514			232		226		82		64
0,2	2,537272			200		195		71		55
0,1	3,034854			168		163		59		46
0,05	3,461637			147		143		52		41
0,01	4,291932			119		116		42		33

Table 5. The probabilistic model of the floor panel geometry changes for points responsible for active safety on the right side in cars used in Western Europe

			Points associated with passive safety				Points associated with active safety			
			Left side		Right side		Left side		Right side	
p	w	Z_{gn} [mm]	I_{zg} [mm/1000km]	P [1000km]	I_{zg} [mm/1000km]	P [1000km]	I_{zg} [mm/1000km]	P [1000km]	I_{zg} [mm/1000km]	P [1000km]
0,95	0,45296	3	0,002544	2603	0,002641	2508	0,009793	676	0,012812	517
0,9	0,649186			1816		1750		472		361
0,8	0,944761			1248		1202		324		248
0,7	1,194445			987		951		256		196
0,6	1,429441			825		795		214		164
0,5	1,665109			708		682		184		141
0,4	1,914462			616		593		160		122
0,3	2,194514			537		518		140		107
0,2	2,537272			465		448		121		92
0,1	3,034854			389		374		101		77
0,05	3,461637			341		328		88		68
0,01	4,291932			275		265		71		55

Displacements of points associated with passive safety were smaller. Moreover. smaller geometry changes were observed in the cars used in Western Europe. The intensity of the changes depended on the position of the points under analysis on the floor panel. For example. displacements of points on the right were as much as 33% bigger than those on the left.

The probability of reaching the maximum permissible (3 mm) geometric changes on a floor panel is accurately described by the probabilistic model in the form of the Rayleigh distribution. Its mathematical form was developed for cars used in various environmental conditions. A 3 mm displacement of a base point associated with active safety on the right side will be reached with the probability of 0.9 at a mileage of 216.000 km in cars used in Poland and at a mileage of 361.000 km in cars used in Western Europe.

The study results presented in this paper are of utilitarian importance. There is a need for introducing compulsory floor panel measurements in cars with mileages exceeding 120.000 km. The legal requirements in this regard will contribute to an improvement in road traffic safety.

References

1. Aguilar J J, Sanz M, Guillomía D, Lope M, Bueno I. Analysis, characterization and accuracy improvement of optical coordinate measurement systems for car body assembly quality control. International Journal Advanced Manufacturing Technology 2006; 30: 1174–1190,https://doi.org/10.1007/s00170-005-0143-5.
2. Ahrens G, Dellmann T, Gies S, Hecht M, Hefazi H, Henke R, Pischinger S, Schaufele R, Tegel O. Applications in Mechanical Engineering. Transport Systems, Würzburg: Springer Science Media, 2009.
3. Anderson R. Numerical and experimental evaluation of spring back in a front side member. Division of Production and Materials Engineering. Lund 2007.
4. Bera T K, Bhattacharya K, Samantaray A K. Evaluation of antilock braking system with an integrated model of full vehicle system dynamics. Simulation Modelling Practice and Theory 2011; 19: 2131–2150, https://doi.org/10.1016/j.simpat.2011.07.002.
5. Boruta G, Piętak A. Mechatronika samochodu. Układy bezpieczeństwa czynnego i biernego. Olsztyn: Wydawnictwo Uniwersytetu Warmińsko-Mazurskiego,2012.
6. Chen H, Gong X, Hu Y F, Liu Q F, Gao B Z, Guo H Y. Automotive Control: the State of the Art and Perspective. Acta Automatica Sinica 2013: 39.
7. Duffy J E. I-Car Professional Automotive Collision Repair. New York: Delmar a division of Thomson Learning 2001.
8. Duffy J. E. Auto Body Repair Technology. Boston: Delmar Cengage Learning 2009.
9. Gonera J, Napiórkowski J. Effect of the mileage of a passenger car on changes in its body geometry. Seoul: Conference 2nd Annual International Symposium on Material Science and Engineering (ISMSE), 2018, https://doi.org/10.1063/1.5030315.
10. Guoye W, Juanli Z, Yanli F, Yanru Z. Study on ESP Control Principle of Light Off-road Vehicle Based on Brake / Drive Integrated Control. Physics Procedia 2012; 25: 834–841, https://doi.org/10.1016/j.phpro.2012.03.165.
11. Habibovic A, Davidsson J. Causation mechanisms in car-to-vulnerable road user crashes: Implications for active safety systems. Accident Analysis and Prevention 2012; 49: 493– 500, https://doi.org/10.1016/j.aap.2012.03.022.
12. Heißing B, Ersoy M. Introduction and Fundamentals, Chassis Handbook: Fundamentals, Driving Dynamics, Components, Mechatronics, Perspectives. Wiesbaden GmbH: Vieweg + Teubner Verlag – Springer Fachmedien 2011.
13. Jackowski J, Łęgiewicz J, Wieczorek M. Samochody osobowe i pochodne. Warszawa: WKiŁ 2011.
14. Konieczny Ł. Wykorzystanie metod drganiowych w ocenie stanu technicznego mechanicznych i hydropneumatycznych zawieszeń pojazdów samochodowych. Gliwice: Wyd. Politechniki Śląskiej 2015.
15. Liss M, Żółtowski B. Analiza modalna jako metoda diagnozowania stanu nadwozi samochodów osobowych. Postępy w inżynierii mechanicznej Developments in mechanical engineering 2014; 3: 21–28.
16. Livesey W A, Robinson A. The repair of vehicle bodies. Oxford 2006.
17. Michalski R, Gonera J. Kompleksowa ocena stanu technicznego nadwozia samochodu. Studia i materiały polskiego stowarzyszenia zarządzania wiedzą; Bydgoszcz: Polskie Stowarzyszenie Zarządzania Wiedzą 2011; 47: 169–183.
18. Milanés V, González C, Naranjo J E, Onieva E, Pedro T D. Electro-hydraulic braking system for autonomous vehicles. International Journal of Automotive Technology 2010; 11: 89‒95, https://doi.org/10.1007/s12239-010-0012-6.
19. Mizuno D, Suzuki S, Fujita S, Hara N. Corrosion monitoring and materials selection for automotive environments by using Atmospheric Corrosion Monitor (ACM) sensor. Corrosion Science 2014; 83: 217–225, https://doi.org/10.1016/j.corsci.2014.02.020.
20. Ozdalyan B. Development of a slip control anti-lock braking system model. International Journal of Automotive Technology 2008; 9: 71–80, https://doi.org/10.1007/s12239-008-0009-6.
21. Przybyłowski A. Stan infrastruktury transportu drogowego w Polsce z uwzględnieniem aspektów bezpieczeństwa. Research papers of Wrocław University of Economics 2014; 367: 261–271, https://doi.org/10.15611/pn.2014.367.29.
22. Raatz B. Nowoczesne technologie pomiarów i napraw karoserii powypadkowych. Ząbrowo: Oficyna Wydawnicza Troton 2005.
23. Reński A. Bezpieczeństwo czynne samochodu. Zawieszenia oraz układy hamulcowe i kierownicze. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej 2011.
24. Stack M. Trade of vehicle body repair – Vehicle Measuring. Dublin: SOLAS 2014.
25. Straky H, Kochem M, Schmitt J, Isermann R. Influences of braking system faults on vehicle dynamics. Control Engineering Practice 2003; 11: 337–343, https://doi.org/10.1016/S0967-0661(02)00301-5.
26. Tobota A. Naprawy powypadkowe nadwozi, a bezpieczeństwo. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej 1997.
27. Wallentowitz H. Virtuelle Fahrzeugentwicklung–Netzwerkeals Voraussetzungenzur Problemlosung. Berlin: Erfolg in Netzwerken; Springer – Verlag Berlin Heidelberg 2002.

Jarosław GONERA
Jerzy NAPIÓRKOWSKI
Department of Vehicle and Machinery Construction and Operation
Faculty of Technical Sciences
University of Warmia and Mazury in Olsztyn
Oczapowskiego str. 11, 10-716 Olsztyn, Poland

E-mails: jaroslaw.gonera@uwm.edu.pl, jerzy.napiorkowski@uwm.edu.pl