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VEHICLE MISMATCH – A CASE STUDY

Roman Mikulec, Pavlína Moravcová, Kateřina Bucsuházy, Martina Kostíková, Jakub Motl
Transport Research Centre, Brno, Czech Republic

Abstract

Sport utility vehicles (SUV) gain more popularity and with more manufacturers being involved in their production their accessibility rises as well. This however creates an opportunity for collisions with smaller passenger vehicles. There is obvious mismatch in weight, stiffness and height between SUVs and other, smaller passenger vehicles. Furthermore, the average age of passenger vehicles in Czech Republic is over 15 years. Even when these older vehicles crash even with vehicle of similar weight and build, there is a significant mismatch in stiffness and safety equipment (especially airbags). These kinds of vehicle mismatches thus create risk of more serious injuries in case of crashes. The Czech In-Depth Accident Study project (CzIDAS) collects on-site crash data and injury data for further analysis of traffic accidents in order to present traffic risk factors. Analysis of vehicles' collision speed and damage is carried out and verified using simulation programme calculation, information about passengers' injuries is obtained from contracted hospital facilities. The traffic accidents presented in this case study serve to showcase the risks associated with vehicle mismatch crashes, currently happening on roads of Czech Republic.

Keywords: vehicle; crash; injury; vehicle mismatch; accident analysis

1 Introduction

Sport utility vehicles (SUVs) became more popular and with more vehicle manufacturers incorporating SUVs in their production their accessibility rises, as well as probability of their involvement in road traffic crashes. In the case of vehicles such as SUVs or MPVs, the construction is different from a conventional (compact) passenger vehicle (with a self-supporting body). The body of SUVs consists of a separate chassis, which is composed of several longitudinal elements (beams) and transverse elements (crossbars). The structure is heavier and significantly stiffer, and the distribution of forces changes during the collision. Each vehicle model and its construction have its own structural behaviours (Vangi, 2020).
While driving modern (and heavier) vehicle provides safety benefits to driver and other passengers of said vehicle, at the same time, (in case of crash with other passenger vehicle) it creates a safety issue in form of mismatched crash (i.e. weight, stiffness and safety equipment). Vehicle mismatch drastically influences course of the collision (from extent of vehicle damage to severity of sustained injuries). Important factor is magnitude of force impulse during the collision and subsequently damage to vehicle interior and so called survival space influencing severity of the road traffic crashes (Brewer and Smith, 2008).
As mentioned above, among other things, a mismatch can occur even in form of vehicle safety equipment and stiffness and seemingly matched vehicles can prove otherwise, especially when one of the vehicles is significantly older (the average age of passenger vehicles in Czech Republic is over 15 years) (CIA, 2020).

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The relative effect of stiffness and weight parameters on risk of driver's fatal injury in a head-on collision was explored in (Eyges, 2009). Authors of this study point out, that according to their research, weight of the vehicle has greater influence on collision outcome compared to vehicle weight.
Similar research concerning vehicle mismatch in collisions of passenger vehicles and light truck vehicles (including SUVs), was seen in (Acierno, 2004, Mandell, 2010; Desapriya, 2013). It was concluded that vehicle mismatch was associated with death and serious injuries in vehicle crashes. While passenger vehicles have become safer, many of the safety features have been designed for crashes with other passenger vehicles. Thus, emphasis was put on improving performance of vehicles when struck by a higher barrier and re-designing both passenger vehicles and light truck vehicles to be more compatible in frontal collisions. In (Toy, 2003) vehicle mass was found to be influencing crashworthiness of light truck vehicles relative to passenger vehicles.
Another study (Cobb, 2005) concluded increased risk of spinal injury for passenger vehicle occupants when involved in two vehicle crash with light truck vehicles. Interestingly the study also presented increased risk of spinal injury for occupants of light truck vehicles in general, however this was thought to be a result of lower safety standards for trucks. Chipman (2004) described vehicle size disparity, especially when the struck vehicle is smaller and lighter, as almost a consistent risk factor for occupant injury. Desapriya (2013) stated, that occupants in passenger vehicles that collide with vehicles on truck frames were at twice the risk for injury, because vehicles on truck frames inflict significant body damage to passenger vehicles.
Takubo (2000) also pointed that structural characteristics of larger vehicles (as SUVs) foster human errors. Though the viewpoint of the driver is high, enabling him to observe traffic situation in front of the vehicle, there is a risk that an overconfident driver may grow careless. Also, SUV's centre of gravity is high, which can magnify rolling motion. Study (Ross, 2003) supports these findings and points out that driver's behaviour (human error) and vehicle design (vehicle structural properties) can not be separated when evaluating risk factors.
It is important to note, the topic of vehicle mismatch is a safety issue discussed for more than two decades, but lately seems more pronounced (and relevant) due to aforementioned popularity of SUVs. Vehicle mismatch, however, is not issue exclusive for SUVs, but for all mismatched collision opponents. While mismatch in collision of passenger vehicle with train, tram or truck is obvious, the focus of this article are collisions of two passenger vehicles.

2 Methods and crash reconstruction

2.1 Data collection and analysis

Data used in this study were gained as part of CzIDAS (Czech In-depth Accident Study) project currently implemented by the Transport Research Centre, in Czech Republic. The methods utilised by the CzIDAS project are primarily based on German In-depth Accident Study (GIDAS), however the project uses its own certified methodology, better suited for Czech traffic environment.
The project involves detailed documentation of road traffic crashes and their consequences with aiming to present causes both crashes themselves and of the injuries sustained during these crashes. The analysis of events occurring during crashes was based on objective data gained from the scenes of traffic crashes, i.e. photo documentation of damage to vehicles, the surrounding environment and trace evidence documented by geodetic measurements (i.e. total station, GNSS). Information from medical facilities about the injuries of those involved in traffic crashes is also acquired. The events occurring during crashes are recreated with the aid of computer simulation modelling. The simulation programme Virtual CRASH (version 4.0) was used for the simulations, in which not only the dimensions of the collision partners are considered, but also their weights.

2.2 Overview of passenger vehicles crashes

There were 456 road traffic crashes in CzIDAS database involving collision of two passenger vehicles. The influence on crash severity of two main factors involved in vehicle mismatch (i.e. vehicle age and weight) is shown in following tables.

Table 1 Influence of vehicle age on crash severity

	Uninjured [%]	Minor injury [%]	Severe injury [%]	Fatal injury [%]
Up to 4 years	41	56	2	1
5 to 9 years	36	59	4	1
10 to 14 years	36	56	6	2
Over 15 years	28	63	6	3

Table 2 Influence of vehicle weight on crash severity

	Uninjured [%]	Minor injury [%]	Severe injury [%]	Fatal injury [%]
Up to 1000 kg	14	75	8	3
1000 to 1500 kg	34	59	5	2
Over 1500 kg	46	50	3	1

It is obvious in case of two passenger vehicles collision, with increasing age of the vehicle and decreasing weight the risk of severe or fatal injury increases. Safety features, standards and material used in construction of older vehicles, together with the technical condition of the vehicle and the associated gradual degradation of material (most often seen as corrosion of the vehicle body) could influence the crash consequences significantly. Especially the corrosion of main structural parts could lead to greater extent of vehicle damage possibly leading to intrusion into vehicle interior.

3 Case studies

To present the risk involved in vehicle mismatch, the following road traffic crashes of mismatched vehicles are presented together crashes of similar configuration, but of more compatible vehicles.

Table 3 Summary of incompatible (mismatched) and compatible collisions and involved vehicles

Case / compatibility		Vehicles	Vehicle type	Curb weight [kg]	Make year	Impact type	Injury severity
1	I	Kia Sportage	SUV	1576	2011	Head-on collision	Minor
		Renault Megane	Hatchback	1050	2002		Severe
	C	Škoda Fabia	Hatchback	1139	2001	Head-on collision	Minor
		Škoda Octavia	Combi	1345	2010		Minor
2	I	Ford C-Max	MPV	1450	2005	Sideswipe / Small overlap	Minor
		VW Golf IV	Hatchback	1145	2003		Fatal
	C	Ford Focus II	Combi	1351	2005	Sideswipe / Small overlap	Minor
		Škoda Octavia II	Combi	1426	2009		Minor

3.1 Case no. 1 – head on collision

3.1.1 Incompatible collision

This crash occurred on route with number of curves an elevation changes as driver of vehicle Kia, probably due to microsleep, crossed centreline into opposing lane. Afterwards, vehicle Kia hit head-on vehicle Renault (full frontal collision).

Figure 1 Incompatible collision, left: vehicle Kia; right: vehicle Renault.

Vehicle damage:

- Front side of vehicle Kia was damaged, the deformation was extended up to the front axle of the vehicle. Both driver and passenger airbags were deployed.
- There was damage to the front part of vehicle Renault as well, however the deformation was of greater extent with engine mount damage and engine itself shifting inside the engine compartment. Vehicle passenger compartment was impacted as well. Dashboard was damaged and legroom was intruded, both driver and passenger airbags were deployed.
- Injury severity:
- Driver of vehicle Kia (65 years old) sustained only minor injuries.
- Driver of vehicle Renault (45 years old) sustained severe injuries – comminuted, open fracture of right femur lower part, comminuted fracture of lower end of right tibia, fracture of left femoral neck, sternum fracture, 9^{th} to 10^{th} thoracic vertebra fracture, fracture of 2^{nd} to 4^{th} metatarsus of left leg, overall injury severity expressed by ISS was 13. A passenger in front seat (43 years old) sustained minor injuries and passenger in rear right seat (37 years old) sustained severe injuries.

3.1.2 Compatible collision

This crash occurred on long, straight stretch of the road, as driver of vehicle Skoda Fabia, from unknown reasons, crossed centreline into opposing lane and hit head-on vehicle Skoda Octavia.


Figure 2 Compatible collision, left: vehicle Skoda Fabia; right: vehicle Skoda Octavia.

Vehicle damage:

- Vehicle Skoda Fabia had damage of front right corner, the deformation was reaching right front wheel, which was shifted backwards, right front fender was destroyed, and right front rail was also damaged, the cross beam was shifted backwards. Both passenger and driver airbags were deployed.
- Front side of vehicle Skoda Octavia was damaged, the deformation was extended up to the cross bar. Both driver and passenger airbags were deployed.
- Injury severity:
- Driver of vehicle Skoda Fabia (84 years old) sustained only minor injuries.
- Driver of vehicle Skoda Octavia (37 years old) and two passengers (2 and 31 years old) sustained only minor injuries.

3.2 Case no. 2 – sideswipe collision

3.2.1 Incompatible collision

This crash occurred as driver of vehicle Ford, from unknown reasons, crossed centreline into opposing lane and hit head-on vehicle Volkswagen (small overlap / sideswipe collision).


Figure 3 Incompatible collision, left: vehicle Ford; right: vehicle Volkswagen.

Vehicle damage:

- Left and front side of vehicle Ford were damaged. The impact was pointed towards driver, which is the reason not only front side and engine compartment were damaged, but also A-pillar, left sill and left front door. Dashboard and driver seat mounting were damaged. Both driver and passenger front airbags were deployed.
- Left and front side of vehicle Volkswagen were damaged. In this case the impact was pointed towards driver as well, engine mount and left side were damaged. Leg room was intruded, and dashboard shifted inside the vehicle. Both driver and passenger front airbags were deployed.

• Injury severity:
• Driver of vehicle Ford (29 years old) sustained only minor injuries (chest bruises)
• Driver of vehicle Volkswagen (20 years old) was fatally injured. Front seat passenger sustained severe injuries.

3.2.2 Compatible collision

This crash occurred as driver of vehicle Skoda crossed centreline into opposing lane and hit head-on vehicle Ford (small overlap / sideswipe collision).


Figure 4 Compatible collision, left: vehicle Škoda; right: vehicle Ford.

Vehicle damage:
• Front side of vehicle Škoda was damaged, the deformation was of mostly the left side of the vehicle and extended up to the front axle of the vehicle. The left front rail was not deformed, however left front wheel was ripped off and there was severe deformation of left A-pillar, left sill and left front door. Both driver and passenger airbags were deployed.
• Vehicle Ford had damage was focused to left corner, the deformation reached up to left front wheel, which was shifted backwards, left front fender was destroyed, left A-pillar was damaged and left door panel was ripped off. Left front rail was not damaged Only left curtain airbag was deployed.
• Injury severity:
• Driver of vehicle Skoda (32 years old) was not injured, a front seat passenger (35 years old) sustained only minor injuries.
• Driver of vehicle Ford (48 years old), front seat passenger (44 years old) and baby (2 years old), seated in the left rear seat sustained only minor injuries.

4 Discussion and conclusion

Vehicle crash compatibility as health protection policy was discussed in number of previous studies (e.g. Jenefeldt, 2004). This complex issue, however, requires reconciliation of structural interaction, stiffness, and weight of vehicles. In case of mismatched collision, there is a risk of increased vehicle deformation and passenger compartment intrusion, leading to sever or fatal injuries (Faerber, 2001; Jenefeldt, 2004).
Just like aforementioned studies (e.g. Desapriya; 2005, Chipman, 2004), CzIDAS data suggest both vehicle weight and age affect severity of injuries documented in passenger vehicle collision. This safety issue is presented using cases of both incompatible (mismatched) and compatible passenger vehicle collisions.
The presented cases of incompability were present in form of significant weight, construction (i.e. age or materials used) and shape differences of involved vehicles, which led to severe injuries of disadvantaged vehicles' occupants. In the compatible cases, the vehicles involved were better matched in weights and the platforms on which the vehicles were built were of similar technology, making the vehicles more crash compatible.
It is obvious, vehicle mismatch poses a safety concern, which will need to be addressed by vehicle manufacturers. Euro NCAP implemented new moving barrier to moving vehicle frontal

crash test, replacing the regulation-based moderate offset-deformable barrier test, used by Euro NCAP for the last 23 years. This new crash test not only evaluates the protection of occupants inside the passenger vehicle, but also assesses how the vehicles' front-end structurers contribute to injuries in the collision partner. (EuroNCAP, 2020)
An emphasis is put on making new (larger) vehicles, such as SUVs more compatible in collisions with smaller vehicles. However, as was mentioned above, vehicle weight is only one factor, leading to vehicle mismatch, the other significant factor being vehicle age. Besides fewer safety features, old vehicles are also often associated with poor condition (most noticeable in form of corrosion) further influencing crash injury severity (mainly due to more significant deformation of vehicle). Thus, an emphasis should be placed on periodic vehicle inspection, vehicles failing requirements to pass these inspections should not be permitted to be operated in traffic to ensure safety of passengers.
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