USE OF CAR CRASHES RESULTING IN INJURIES TO IDENTIFY SYSTEM WEAKNESSES

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ABSTRACT

The objective was to identify system weaknesses and components (road user, vehicles, and road) where improvements would yield the highest potential for further reductions in car occupant injuries. The study also aimed to evaluate whether it is a difference in type of improvements due to injury severity (fatally injured, Maximum Abbreviated Injury Scale 2+ injury outcomes and injury leading to permanent medical impairment). Three different data sets of real-life car crashes were used; In-depth fatal crash data of the Swedish Transport Administration (n=248), in-depth crash injury data collected by the UK On The Spot (OTS) accident investigation project (n=120) and the Swedish database STRADA including police reported and hospital-registered injuries (n=451). All crashes were classified according to the vehicle's safety rating by Euro NCAP (European New Car Assessment Programme) and whether the vehicle was fitted with ESC (Electronic Stability Control) and had some kind of defined whiplash protection systems. For each crash, the road was also classified according to EuroRAP (European Road Assessment Programme) criteria, and human behavior in terms of speeding, seat belt use, and driving under the influence of alcohol/drugs. Most of the crashes occurred when two or all three components interacted (in 40% of the total number of cases). In total, the noncompliance with the vehicle safety criteria was judged to influence the injury outcome more often in car crashes with serious injury outcomes or where the occupants sustained injuries leading to permanent medical impairment than in crashes including fatally injured only. The road standard was the one of the three components that was most often linked to a fatal outcome. Injury outcomes, irrespective of severity, were mostly related to an interaction between the three components: the road, the vehicle, and the road user. However, the significance of the components differs depending on crash severity. The vehicle's safety is the most important component to reduce serious injury outcomes and injuries leading to permanent medical impairment. In fatal crashes improvements to the road would yield the highest potential for further reductions of car occupant injuries.

INTRODUCTION

Despite improvements in vehicle safety and the vehicle occupants' awareness about benefits associated with safety devices, traffic injuries continue to occur. Road crashes are the leading cause of death among people aged 10–25 (McMahon and Ward, 2006). In total more than 42,000 road users are killed and around 3.5 million are injured each year in the EU (Hobbs et al., 2001). Traffic crashes are one of the leading causes of disability and reduction of productive years in the population (Peden et al., 2004). The Swedish Transport Administration (STA) has therefore broadened the definition of serious injuries and since 2008 the definition also includes injuries leading to permanent medical impairment.

To identify the most important road safety problems, the STA has introduced a model for a safe road transport system that links the properties of an inherently safe road transport system through some safety performance indicators (SPIs) (Linnskog, 2007, OECD, 2008, Peden et al., 2004, Stigson, 2009, Tingvall et al., 2010). The chosen SPIs have been proven to have a potential for reduction in injury risk. All the SPIs have been linked to each other and criteria have been defined. The STA model describes how the 3 components (road, vehicle, and road user) should interact to achieve safe road traffic. In this way, deviation from the fulfillment of these criteria could be seen as noncompliance. The definition of a safe road transport system in the STA model, based on biomechanical limits that human beings can tolerate without sustaining serious injuries, is that the driver uses a seat belt, not exceeding the speed limits and is sober; the vehicle has a 5-star rating by Euro NCAP (European New Car Assessment Programme) and is fitted with ESC (electronic stability control) and have some kind of defined whiplash protection systems; and the road has a 4-star rating by EuroRAP (European Road Assessment Programme); see Figure 1. Based on the Vision Zero philosophy, no one should be

fatally or seriously injured in a car crash under such circumstances (Tingvall, 1995).

A safe road should be designed to control the crash severity when foreseeable crash scenarios arise, by, for example, removing trees and other objects close to the road or installing a protective barrier between the vehicle and roadside object, to fulfill the criteria of safe road according to EuroRAP and thereby the STA model (Johansson, 2008). Furthermore, two-way single carriageways with traffic traveling in opposite directions could be allowed with a speed limit of up to 70 km/h, based on vehicle safety system limits (Johansson, 2008, Linnskog, 2007, WHO, 2008). To prevent interaction of vehicles with other vehicles and objects at higher speeds, the road should have physical barriers to prevent crossing over and guardrails to protect loss of control into objects in the roadside area (trees, poles, rocks, or rollover tripping mechanisms). The vehicle safety level is an important key factor if the road user is fatally or seriously injured in a crash. The main definition of a safe vehicle in the STA model is that the vehicle should have been awarded a 5-star rating in a Euro NCAP crash test (EuroNCAP 2008) and should be fitted with ESC. The reason for this is that ESC has been shown to effectively reduce the risk of crash involvement (Farmer, 2006) as well as crashes with personal injuries, especially serious and fatal injuries (Erke, 2008, Ferguson, 2007, Krafft et al., 2009, Lie et al., 2006). Investigators have established that the standardized consumer crash tests such as Euro NCAP have led to significant improvements in vehicle crashworthiness (Farmer and Lund, 2006, Kullgren et al., 2010, Kullgren et al., 2002, Lie and Tingvall, 2002). Studies have shown that existing whiplash prevention systems in average reduce the risk of permanent medical impairment with approximately 50 %, see latest published results in Kullgren and Krafft (2010). In the STA model it is assumed that the road user is complying with the road rules. A safe road user is defined in the STA model by the following criteria: wearing a seat belt, complying with the speed limit, and not driving under the influence of alcohol/drugs. These three aspects of driver behavior have been identified as key factors for fatality and injury risk (Farmer and Lund, 2006, Hermans et al., 2009, OECD, 2008, WHO, 2008). However, there are other factors that increase driver fatality risk, but the effects of these 3 factors on injury risk are huge and well documented, as further described below. Seat belt use has been shown to dramatically reduce the fatal outcome (Kullgren et al., 2005). Drivers with a blood alcohol concentration (BAC) somewhat below 0.1% have been shown to expose both themselves and other road users to a very high risk (Zador et al., 2000). Speed has been identified as a key risk factor that has a powerful impact on the risk of sustaining a serious injury (Elvik, 2007, Farmer and Lund, 2006, WHO, 2008).

No study has been evaluating differences in safety improvements with regards to injury severity especially injuries leading to permanent medical impairment. The objective was therefore to identify system weaknesses and components (road user, vehicles, and road) where improvements would yield the highest potential for further reductions in car occupant injuries. The study aimed to evaluate whether it is a difference in type of improvements due to injury severity (fatally injured, Maximum Abbreviated Injury Scale 2+ injury outcomes and injury leading to permanent medical impairment).
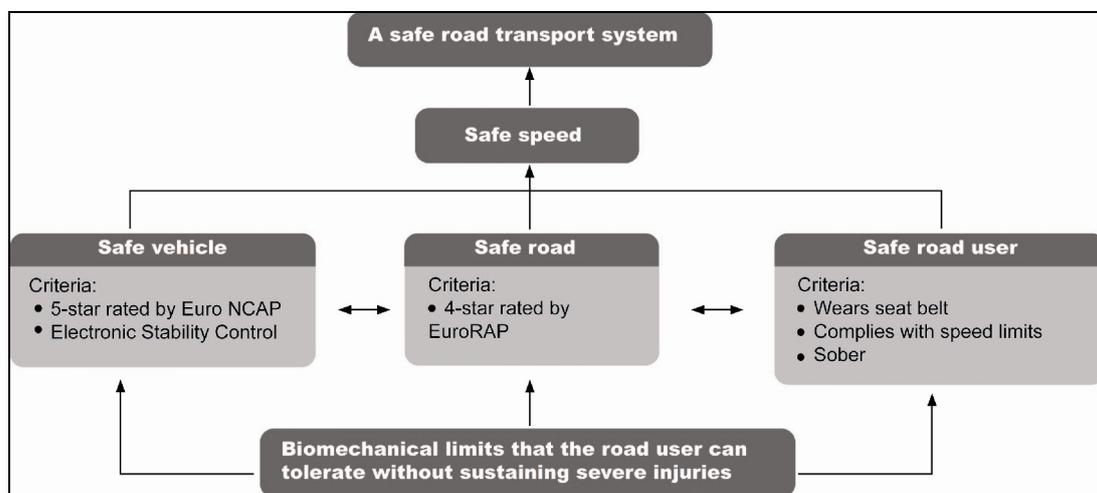

Figure 1. The Swedish Transport Administration model for a safe road transport system.

METHODS

Three different data sets of real-life car crashes were used; In-depth fatal crash data of the Swedish Transport Administration (n=248), in-depth crash injury data collected by the UK On The Spot (OTS) accident investigation project (n=120) and the Swedish database STRADA including police reported and hospital-registered injuries (n=480).

In-depth Fatal Crash Data of the Swedish Transport Administration

The Swedish Transport Administration (STA) database of in-depth investigations of fatal traffic accidents was used to extract field data for fatal car crashes. All fatal crashes where a car occupant was killed that occurred on public roads in Sweden during 2004 were included: 215 crashes in all, with 248 fatalities. The age distribution ranged from 1 month old to 96 years, and the average age was 45 years. A quarter of the car occupants were over 65 years of age. Seventy-three percent of the occupants were male. The data is further described in an earlier paper by Stigson et al. (2008).

The UK on the Spot (OTS) Data Set

The passenger car crashes in the UK On The Spot (OTS) data set were selected on the basis of occupants with serious injury – in this study serious casualties were defined as car occupants sustaining a Maximum Abbreviated Injury Scale rated greater than or equal to 2 (MAIS 2+) (AAAM, 2005). All crashes in the OTS database occurring between 2000 and 2005 with a car occupant with injury rated MAIS2+ were included, for a total of 101 crashes with 120 occupants. From these crashes, only occupants with MAIS2+ injuries were included. The age distribution ranged from 3 to 93 years, and the average age was 35 years. Only 9 of 120 car occupants were over 65 years of age. Sixty-five percent of the occupants were male. The data is further described in an earlier paper by Stigson and Hill (2009).

The Swedish Database STRADA

The Swedish database STRADA including police reported and hospital-registered injuries (n=451) was used to study car crashes with injury leading to permanent medical impairment. A random number of crashes, involving passenger cars, reported by both the police and by hospitals from year 2008 were selected. The hospitals classification of the injuries (classified according to AIS-2005) was used to evaluate the risk of an injury leading to permanent medical impairment. The risk of

permanent medical impairment (RPMI) was estimated using risk matrices, based on AIS injury level and body region, developed by Malm et al (2008), Table 1. This was performed for the level of 1% permanent medical impairment. The scale of permanent medical impairment is based on judgments made by physicians following a nationally applied Swedish model (SverigesFöräkringsförbund, 2004). To be included in the study the combined risk (RPMI) for a car occupant' injuries had to be at least 8 %. The combined RPMI was calculated based on a product of the risks of not being injured, described by Gustavsson et al. (1990), Eq. 1.

The combined RPMI $= 1 - (1-p_i)(1-p_{i+1})(1-p_{i+2})\dots$ (1).

The age distribution ranged from 2 to 91 years, and the average age was 35 years. Only 6% of the car occupants were over 65 years of age. Fifty-four percent of the occupants were male.

Table 1. Risk of Permanent Medical Impairment (RPMI) on 1%+ level (i.e. 1-99%). Numbers in percent.

	AIS1	AIS2	AIS3	AIS4	AIS5
Head	8.0	15	50	80	100
Cervical Spine	16.7	61	80	100	100
Face	5.8	28	80	80	n.a.
Upper Extremity	17.4	35	85	100	n.a.
Lower Extremity and Pelvis	17.6	50	60	60	100
Thorax	2.6	4.0	4	30	30
Thoracic Spine	4.9	45	90	100	100
Abdomen	0.0	2.4	10	20	20
Lumbar Spine	5.7	55	70	100	100
External (Skin) and Thermal Injuries	1.7	20	50	50	100

All three databases contain detailed information on the road design where the crash occurred, such as road type, speed limits, visibility and roadside area. It also contains information on the involved vehicles (make, model year, status of restraint systems and residual intrusion), occupant information (age, gender, blood alcohol level (BAC), medical and autopsy reports) and police reports from the crashes.

Classification of Each Crash

For the current study, analyses began at the stage where a crash had occurred and focused on finding the reason for the injury outcome, not the reason why the crash occurred. This could be due to one component or a combination of all three components of the system: the road, the vehicle, and/or the road user. To identify weaknesses in the

transport system, real-life crashes with different injury severity outcomes were classified and adapted to the STA model criteria (Figure 1). All crashes were classified according to the vehicle's safety rating by Euro NCAP (European New Car Assessment Programme) and whether the vehicle was fitted with ESC (Electronic Stability Control) and proved to have some kind of defined whiplash protection systems. The road was classified according to EuroRAP (European Road Assessment Programme) criteria. Since the EuroRAP classification does not address rear-end crashes the classification was extended, Appendix. For each crash human behavior in terms of speeding, seat belt use, and driving under the influence of alcohol/drugs were classified.

The classification was made in two steps, based on the following questions:

1. Did the crash involve noncompliance with the road criteria, vehicle criteria, and/or road user criteria?

2. For crashes where more than one of the three components does not comply with the safety criteria, are all of the components correlated to the injury outcome? This is achieved through a detailed case-by-case review.

The classification based on the criteria of the STA model provides a picture of the safety standard of the three components in crashes. Step 2 is a further analysis of the crashes to ascertain which of the failed criteria correlates to the injury outcome. The method is further described in earlier papers by Stigson et. al (2008) and Stigson and Hill (2009).

RESULTS

Most of the crashes occurred when two or all three components interacted (in 40% of the total number of cases, in 36% crashes with RPMI, in 68% crashes with serious injured and 37% in crashes with fatally injured car occupants). In total, the noncompliance with the vehicle safety criteria was judged to influence the injury outcome more often in car crashes with serious injury outcomes (51%) or where the occupants sustained injuries leading to permanent medical impairment (69%) than in crashes including fatally injured only (43%). The road was the one of the three components that was most often linked to a fatal outcome (63%). The corresponding data crashes with injuries with a RPMI and crashes with serious injured was 53%.

Road

The number of roads that met the criteria of a safe road differs depending on injury severity. A lower safety standard on the road will lead to higher crash severity. Fifty-five percent of the crashes with injuries with a RPMI occurred on roads that complied with the safety criteria. The corresponding data for crashes with serious or fatal injuries was 41% and 24% respectively. Forty-one percent of the crashes with injuries with a RPMI occurred on roads with a speed limit of 50 km/h. The corresponding data for crashes with serious or fatal injuries was 37% and 9% respectively.

Car

Only a small number of passenger cars in the three different data sets met the criteria for a five-star rating by Euro NCAP. (In 7% of crashes with injuries with a RPMI. In all crashes with AIS2+ injuries the safety standard of the vehicle did not comply with the criteria of being 5-star rated by Euro NCAP or fitted with ESC. One percent of the cars in fatal crashes comply with the criteria of safe vehicle.) The potential of ESC could be high, since large number of crashes started with loss of control. ESC might have had an effect in 30% of the fatal crashes, 40% of crashes with serious injuries and 23% of crashes with injuries with a RPMI. Rear-end crashes account for a one third of all the crashes with RPMI. In total cars were judged to have the potential to be the main contributor for injury reduction in 36% of all rear-end crashes if they were fitted with whiplash preventive systems. In the remaining 64% of the crashes the car and road together were judged to contribute to whiplash injury reduction. These crashes occurred on roads with high speed limit (70-110 km/h) on which the effect of whiplash protection systems was judged to be lower.

Road Users

The road user met the criteria more often in a crash with RPMI than in crashes with serious or fatal injuries. Number of road users that met the criteria was 84% in crash with RPMI than, 44% in crashes with serious injuries and 41% in fatal crashes. Almost 90% of the road-users in crashes with injuries with a RPMI were wearing seat belt. The corresponding number for car occupants in crashes with serious or fatal injuries was 73% respectively 60%. More than a quarter of the total fatally injured occupants included cases with drivers under the influence of alcohol/drugs, with a passenger riding with a drunk driver, or cases where the opposite vehicle was driven by a drunk driver. The frequency of alcohol/drugs was much lower in crashes with serious injuries or crashes with injuries with a RPMI (12% respectively 4%). In 25-35% it was judged that the driver exceeded the speed limit.

Crash Type Distribution

The crash type distribution differs depending on injury severity, table 2. Single-vehicle crashes account for the main part of all casualties regardless of injury severity. Head-on crashes account for almost a third of all crashes resulting in fatal or serious injuries. However, in crashes with injuries with RPMI, this crash type account for less than one tenth of all crashes. Both crashes at intersections and rear-end crashes account for significant higher proportion of these crashes leading to injuries with a risk of permanent medical impairment.

Table 2. Crash type distribution for different injury outcomes.

Crash Type Distribution	RPMI (%)	MAIS 2+ injuries (%)	Fatalities (%)
Single-vehicle crashes	35	38	46.5
Head-on crashes	7	31	32
Crashes at intersection	26	20	13.5
Rear-end	23	2	0.5
Other	9	9	7.5

A slightly higher proportion of noncompliance of the vehicle and the road user safety criteria was judged to be linked to the MAIS2+ injury outcome compared with fatally injured car occupants. The differences between these two are clearer if the crashes are divided into crash types. A higher proportion of the single-vehicle crashes was judged to be related to noncompliance with the road user safety criteria in crashes with MAIS2+ injury outcome (48 compared with 28%). Both these data sets show that noncompliance with the road and the vehicle safety criteria were most often linked to the injury outcome in head-on crashes. Injury outcomes in head-on crashes were mostly related to an interaction between the road and the vehicle rather than the components separately. In total, the noncompliance with the vehicle safety criteria was judged to influence the injury outcome more often in crashes with MAIS2+ injury outcome than in crashes including fatally injured only.

The circumstances in crashes leading to injuries with a RPMI differ from crashes with MAIS2+ injuries and fatal crashes. In very few cases noncompliance of the road user was judged to be linked to the injury outcome except from single-vehicle crashes (there 18% was judged to be linked to the injury outcome). In all crashes irrespective of crash type the vehicle safety criteria was most often linked to the injury outcome. However, injury outcomes in crashes were most often related to an interaction between two or all three components rather than each component separately. The highest interaction between the components was in single-vehicle crashes followed by intersection and rear-end crashes. In head-on crashes the vehicle safety criteria was doubtless the most important component.

DISCUSSION

In this study, crashes have been analyzed, based on the STA model, to study the interaction between the components (road, vehicle and road-user) and thereby identify criteria and actions that are needed to achieve a safe system in which severe injuries can be avoided. It has been shown that depending on injury severity, different weaknesses in the system were identified. This will lead to different actions for injury reduction. Improvements of the safety level of the three components will have different possibilities in crashes with different crash severity. Furthermore, the study shows that it is important to study how the components interact and make actions that favor all the three components. The reason for this is that most crashes are caused by more than just one factor. Weaknesses in the road transport system could be identified successfully by a multifunction analysis such as the one presented in this study. The classification based on the criteria of the STA model provides a picture of the safety standard of the three components in car crashes. To prevent fatal car crashes it is primarily the road safety standard that has to be improved. For crashes with seriously injured and crashes with injuries with a RPMI it is manly the vehicle's safety standard that has to be improved.

The study shows that the crash type distribution differs between the three data sets. Single-vehicle crashes, head-on crashes and crashes at intersections account for more than 90% of all the crashes with serious and fatally injured car occupants. In crashes with injuries with a RPMI these crash types only account for 67%. Rear-end crashes account for 23%. The complexity with rear-end crashes is that this crash type often cause whiplash injuries and whiplash injuries account for a major part of injuries leading to permanent medical impairment (Malm et al., 2008). There are two reasons for the fact that rear-end crashes do not account for a high proportion in the two other data set; the crash type occur in general in road environment such as intersections or at zebra crossings and that whiplash injuries mostly occur in low impact crashes. Another factor that differs between the three data sets is the posted speed limit at the roads where the crashes occurred. In the data set with only fatally injured occupants, the crashes more often occurred at roads with a higher posted speed limit than in the two other data set.

This study shows that an improvement of the car safety standard will be crucial for the reduction of road casualties in the future. Only a small part of the included cars fulfilled the criteria of a safe vehicle. In more than two thirds of the cases a safer car would have reduced the injury outcome. The car safety standard was judged to have the highest potential in crashes with injuries with a RPMI. However, the potential of ESC would be highest in fatal and severe crashes, since a higher number of crashes started with loss of control in these data sets. Furthermore, in crashes with RPMI it was judged that cars with whiplash protection systems would have a positive effect in 10% of the total crashes. It is likely to believe that the car safety standard will have an even greater potential to prevent injuries in the future. Systems like automatic emergency braking and lane departure warning will make cars even more important for the reduction of road casualties. In future cars will solve many of the problems around crashes that in this study were linked to the road safety standard or road-user.

The use of seat belts is fundamental in creating a safe road transport system. All other vehicle-related systems, speed limits, road design, etc., are based on a restrained occupant. Not using seat belts is therefore a behavior that takes the occupant outside the encompassing design of the road transport system. Approximately 10% of the occupants in crashes with RPMI, 27% of the occupants in crashes with MAIS2+ injury and 40% of the fatally injured car occupants were not wearing seat belts. The proportion of belted car occupants would probably have been much higher if they had been sitting in a 5-star-rated car because these are fitted with a seat belt reminder. Lie et al. (2008) showed that seat belt reminders increased the seat belt use rate from 85.8 to 97.5% based on measurements in eleven European large cities. In the future, the inherent vehicle safety systems should also encourage the road user to follow the speed limit and prevent the driver from driving under influence of alcohol to minimize the injury outcome in road crashes.

Limitations

It is known from previous studies conducted on wider datasets that both age and gender influence the risk of being injured in a car crash. In particular, age and fatality risk are strongly correlated with each other. This has not been taken into consideration in the present study. Only car occupants were included in this study. It is also necessary to include other road users such as motorcyclists, cyclists, and pedestrians to identify system weaknesses.

In the current study, excessive speeding was considered from the available police investigation data. Only crashes with an import speed of approximately 15 km/h above the speed limit were classified as speeding. It should also be noted that it is a standard and accepted procedure for crash investigators to take a somewhat conservative appraisal of speeds during crash reconstruction. This factor may lead to an overestimation of the potential of a safe vehicle and a safe road.

CONCLUSION

Injury outcomes, irrespective of severity, were mostly related to an interaction between the three components: the road, the vehicle, and the road user. However, the significance of the components differs depending on crash severity. The vehicle's safety standard is the most important component to reduce serious injury outcomes and injuries leading to permanent medical impairment. In fatal crashes improvements to the road would yield the highest potential for further reductions of car occupant injuries.

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APPENDIX

Table I Basic criteria for a safe journey in the SRA model.

Criteria for a safe journey - four-star rated road, five star rated vehicle and a road user that fulfilling the criteria		
Head-on crashes	≤ 70 km./h	a safe vehicle is expected to protect a road user
	> 70 km./h	a safe vehicle and separated lanes are required
Run-off-the-road crashes	≤ 50 km./h	a safe vehicle is expected to protect a road user
	≤ 70 km./h	a safe vehicle and guardrail/safety zone > 4 m are required
	> 70 km./h	a safe vehicle and guardrail/safety zone >10 m are required
Crashes at intersections	≤ 50 km./h	a safe vehicle is expected to protect a road user
	> 50 km./h	a safe vehicle and grade separated/ roundabout required
Rear-end crashes	≤ 50 km./h	a safe vehicle is expected to protect a road user
	≤ 70 km./h	a safe vehicle and T-junction; with right/left turn lanes are required
	> 70 km./h	Manly a safe road, but also a safe vehicle are expected to protect a road user