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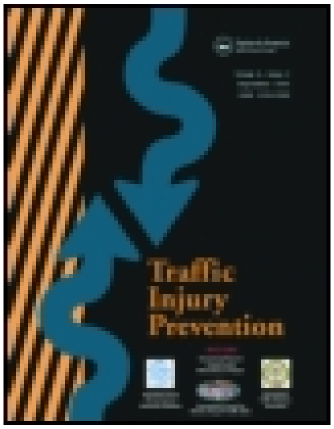

Traffic Injury Prevention
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gcpi20

Use of Fatal Real-Life Crashes to Analyze a Safe Road Transport System Model, Including the Road User, the Vehicle, and the Road

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Published online: 03 Oct 2008.

To cite this article: Helena Stigson , Maria Krafft & Claes Tingvall (2008) Use of Fatal Real-Life Crashes to Analyze a Safe Road Transport System Model, Including the Road User, the Vehicle, and the Road, Traffic Injury Prevention, 9:5, 463-471, DOI: 10.1080/15389580802335240

To link to this article: http://dx.doi.org/10.1080/15389580802335240

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Traffic Injury Prevention, 9:463–471, 2008
Copyright © 2008 Taylor & Francis Group, LLC
ISSN: 1538-9588 print / 1538-957X online
DOI: 10.1080/15389580802335240

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Use of Fatal Real-Life Crashes to Analyze a Safe Road Transport System Model, Including the Road User, the Vehicle, and the Road

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***Objective**. To evaluate if the Swedish Road Administration (SRA) model for a safe road transport system, which includes the interaction between the road user, the vehicle, and the road, could be used to classify fatal car crashes according to some safety indicators. Also, to present a development of the model to better identify system weakness.*

***Methods**. Real-life crashes with a fatal outcome were classified according to the vehicle's safety rating by Euro NCAP (European Road Assessment Programme) and fitment of ESC (Electronic Stability Control). 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. Each crash was compared with the model criteria, to identify components that might have contributed to fatal outcome. All fatal crashes where a car occupant was killed that occurred in Sweden during 2004 were included: in all, 215 crashes with 248 fatalities. The data were collected from the in-depth fatal crash data of the Swedish Road Administration (SRA).*

***Results.** It was possible to classify 93% of the fatal car crashes according to the SRA model. A number of shortcomings in the criteria were identified since the model did not address rear-end or animal collisions or collisions with stationary/parked vehicles or trailers (18 out of 248 cases). Using the further developed model, it was possible to identify that most of the crashes occurred when two or all three components interacted (in 85 of the total 230 cases). Noncompliance with safety criteria for the road user, the vehicle, and the road led to fatal outcome in 43, 27, and 75 cases, respectively.*

***Conclusions.** The SRA model was found to be useful for classifying fatal crashes but needs to be further developed to identify how the components interact and thereby identify weaknesses in the road traffic system. This developed model might be a tool to systematically identify which of the components are linked to fatal outcome. In the presented study, fatal outcomes were mostly related to an interaction between the three components: the road, the vehicle, and the road user. Of the three components, the road was the one that was most often linked to a fatal outcome.*

Keywords Accident Analysis; Fatal Crashes; Road Safety; Vehicle Safety; Human Behavior

INTRODUCTION

Today the road transport system is not a tolerant man-machine system for its users, in that it has the potential to be one of the most significant public health issues in society. Different kinds of legislation directed towards vehicle manufacturers, road users, and road designers have been developed but remain independent of each other, with the road user being the unstable link between the vehicle and the road. Haddon (1980) described most aspects of the prevention of road casualties, but still the components in the system are hardly compatible with each other. Most research based on the Haddon's matrix has been focused on each phase (pre-crash, crash, and post-crash) at one time to examine the causes of traffic crashes and to generate ways of preventing and controlling them.

New techniques erase the dividing line between the phases, which makes it important to study them together in order to optimize occupant protection. By further development of the Haddon's matrix, Zein and Navin (2003) have design a classification model for crashes that explain crashes as a multifactor event that links the road user, the vehicle, and the road together. Treat (1980) and Sabey and Taylor (1980) conducted studies where they tried to identify the main contributing factors and their interactions. The focus of these studies was to identify the cause of the crash: human errors and failings, poor road design or adverse conditions, and vehicle defects. The road user was the sole or a contributory factor in approximately 95% of all

Received 11 January 2008; accepted 16 June 2008.
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crashes. The road and vehicle factors were often linked with a road user factor.

Traditionally, studies have mostly been focused on factors relating to driver error and crash causation (Bedard et al., 2002) rather than finding the reason for injury outcome. To achieve a safe road transport system that prevents fatal and severe injuries, the system must be seen as a dynamic system consisting of the humans, and the vehicles on the road there some elementary safety requirements must be fulfilled (Tingvall, 1997). By increasing the number of constraints on the occupants, such as wearing seat belts, adhering to speed limits, and driving a safe car, the road environment must be constructed in such a way that it allows drivers to make small mistakes without this leading to fatal or serious injuries. The interaction between the different components of the road transport system, such as vehicles, roads, the roadside area, and road users, is thus important. This does not mean taking responsibility away from drivers, but most crashes are linked to human factors, and a sustainable transport system needs to address this fact in the same way as occupational injury is handled and seen as a system control problem (ISO, 2008). This means that a safe system should be designed to minimize the consequences in unforgiving situations instead of focus elimination of human errors. Most types of accidents are judged to be human error and, according to Rasmussen (1997), to look at accidents in terms of event is not so useful to make improvements of the system. He suggests that task analysis based on human error should be replaced by a model focus on control factors aimed to remove deviation from requirements of a safe system. To achieve improvements in the road traffic system, Rasmussen pointed out that the traffic safety research should focus on interactions between the components and study how they could be controlled in the road transport system rather focus on risk variables.

There is a common understanding of not only important risk variables associated with serious road crashes but also associated safety indicators (Peden et al., 2004). The safety indicators mentioned are related to vehicle, infrastructure, seat belt use, speed, and soberness. The Swedish Road Administration (SRA) has introduced a model for a safe road transport system, where these safety indicators have been linked to each other and criteria have been defined (Linnskog, 2007). 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 model, based on biomechanical limits that human beings can tolerate without sustaining severe injuries, is that the driver uses a seat belt, does not exceed the speed limits, and is sober; the vehicle has a five-star rating by Euro NCAP (European New Car Assessment Programme); and the road has a four-star rating by EuroRAP (European Road Assessment Programme); see Figure 1. Based on the "vision zero" philosophy, no one should be killed or seriously injured in a car crash in such circumstances (Tingvall, 1997). The capacity of the system for injury mitigation is determined by the safety standard of the vehicle and road. The primary role of the road is to assist in the reduction of crash energy and to help the vehicle to maximize its inherent safety

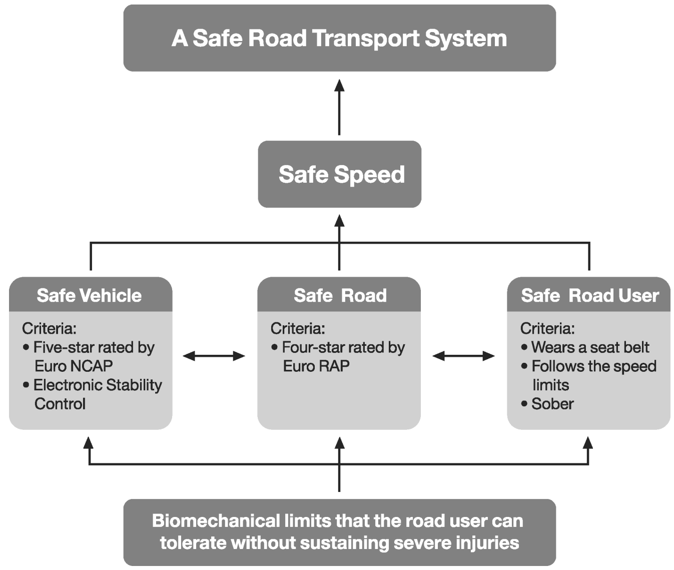

Figure 1 The SRA model for a safe road transport system.

protection design. Speed limits play a fundamental role in the model; e.g., the safety level of the road must increase if the speed limit increases.

In the SRA model, the criteria for the road are based on the EuroRAP Road Protection Score (RPS), a rating score that considers road factors in user protection from fatal or serious injuries (EuroRAP, 2007). The RPS ranges from 1 to 4, where 4 is the rating for a high road safety standard, giving a relatively low risk rating for fatal and serious injuries. The RPS is based on data gathered from real-world crashes and crash tests correlated to survivable limits. Brüde and Björketun (2006) have validated the RPS and found that the star rating corresponded well with real-life data: the higher the star rating, the fewer the car crashes with serious and fatal injuries. Table I describes the requirements for a road to achieve a four-star rating. The criteria for a four-star road are mainly focuses on the road's protection capacity for three different crash types: head-on crashes, run-off-the-road, and crashes at intersections. The total road star rating is summarized by a weighting factor based on the distribution of these three crash types.

The definition of a safe vehicle in the model is that the vehicle should have been awarded a five-star rating in a Euro NCAP crash test (Euro NCAP, 2007) and should be fitted with

Table I Criteria for the Four-Star Rating of a Road in the Safe Transport Model

Head-on collisions
$\leq$ 70 km/h safe speed limit
>70 km/h separated lanes required
Run-off-the-road collisions
$\leq$ 50 km/h safe speed limit
$\leq$ 70 km/h guard-rail or safety zone >4 m required
>70 km/h guard-rail or safety zone >10 m required
Collisions at intersections
$\leq$ 50 km/h safe speed limit
>50 km/h grade separated or roundabout required

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Electronic Stability Control (ESC), since ESC has been shown to effectively reduce the risk of crash involvement (Ferguson, 2007).

Finally, the safe road user is defined by the following criteria: wearing a seat belt, following the speed limit, and not driving under the influence of alcohol/drugs. The effects of these three factors are well documented. Seat belt use has been shown to dramatically reduce the fatal outcome (Kullgren et al., 2005). Drivers at blood alcohol concentration (BAC), somewhat below 0.1% have been shown to expose both themselves and to other road users for a very high risk (Zador et al., 2000). There is a very strong statistical association between speed and crashes with injuries (Ydenius and Kullgren, 2001; Elvik, 2007). Speed has more powerful impact on crashes and injuries than any other risk factor (Elvik, 2007).

In order to find a tool to more systematically identify system weakness, the criteria in the SRA model were used and further developed in this study. The objective was to evaluate whether the criteria in the SRA model for a safe road transport system could be used to classify fatal car crashes based on in-depth studies and to present a development of the model to better identify system weakness. This study only addresses fatally injured car occupants.

METHODS

For the current study, analyses began at the stage where a crash had occurred and focused on finding the reason for the fatal 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 evaluate whether it is possible to use the SRA model to identify weaknesses in the transport system, real-life crashes with fatal outcomes were classified and adapted to the model criteria (see Figure 1). However, some factors were added to the SRA criteria. Instead of using the EuroRAP RPS for the total road route, as described in the introduction, a crash scene rating was made, based on the spot where the crash occurred. The crashworthiness of the road was classified according to the type of central reservation, roadside area, and intersection, in order to highlight the local risk of the crash and how these three components influenced crash outcome. Regarding the road user criteria, a crash was classified as alcohol related if the driver was under the influence of alcohol, if a passenger riding with a drunk driver was killed, or if the opposite vehicle was driven by a driver under the influence of alcohol (BAC above 0.02% limit).

Classification of Each Crash

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

Step 1) Were the criteria in the SRA model fulfilled or not?
Step 2) In crashes where more than one of the three components is noncompliance with the safety criteria, are all components correlated to the fatal outcome?

In Step 2, the classification of crashes where safety criteria were exceeded in more than one of the three components in the transport system is based on the principles in Figure 2. Take the example of a driver of a car with a three-star rating, who was fatally injured in a head-on collision on a 90-km/h road with a two-star rating. In Step 1 this crash would have been classified as an AB; i.e., not fulfilling the criteria for the road and the vehicle. The car might exhibit massive overloading of the structure, and even if the car had a five-star rating, the estimation of crash severity is far higher than survivable levels. In this case the fatal outcome is primarily linked to noncompliance with the road safety criteria and would therefore be classified as an A in Step 2.

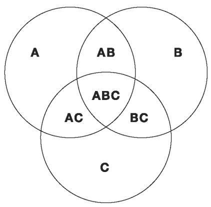
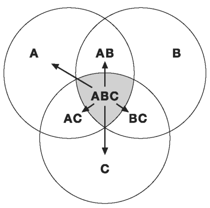
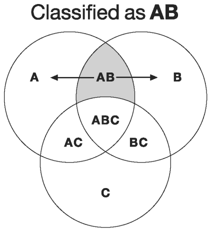
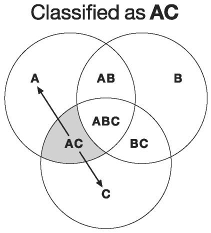
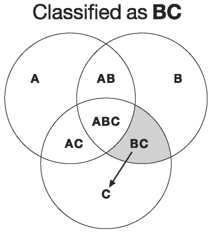
Another example, cases where an unbelted occupant was fatally injured (e.g., in a crash that occurred on a road with a three-star rating, with no compartment intrusion and where a belted car occupant survived), would be classified as a C in Step 2, instead of an AC in Step 1. But in a case where both an unbelted and belted occupant were fatally injured cause of high crash severity, primarily linked to noncompliance with the road safety criteria, it would have been classified as an A in Step 2, instead of an AC in Step 1. Driving under the influence of alcohol or estimated excessive speeding takes the occupant outside the encompassing design of a safe road transport system (Zador et al., 2000; Elvik, 2007), and therefore in crashes due to alcohol/speeding the human component (C) could never be excluded in the Step 2 evaluation. These cases were therefore classified as a C, or, in combination with the road and/or the car, classified as AC, BC or ABC. The classification in Step 1 was retained in cases where it was impossible to identify the components that contributed to the fatal outcome. The analysis in Step 2 is a further development of the criteria in the SRA model.

In order to secure the reliability of the classification, the authors classified the data separately. In some cases where a disagreement occurred or where the outcome was more difficult to estimate (Step 2), a consensus group with significant experience of both real-life crashes and crash tests was assembled. Approximately 25% of the crashes were discussed in the consensus group. The group was used to estimating the crash safety properties of vehicles, the surroundings of roads, and their effectiveness in preventing overall injury. The principles in Figure 2 were followed in Step 2. Folksam real-life crash recorder database was used to evaluate and compare measured crash severity and estimated crash severity for the crashes included in the study.

Data

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. In total, 205 passenger cars, 5 sports utility vehicles (SUV), and 5 multi-purpose vehicles (MPV) were included in this study. Crashes suspected to be suicide were excluded.

Both multiple-vehicle crashes and single-vehicle crashes, as well as both belted and unbelted occupants, were included in this study. The material was divided into four different groups: single-vehicle crashes (116 fatalities), head-on crashes

Classification, Step1	**New classification based on analysis of the car's deformation, Step 2**
	A = non-compliance with road criteria B = non-compliance with vehicle criteria C = non-compliance with road user criteria
Classified as ABC 	Reclassified as ***A*** if the crash severity was above the limit required for a safe* car to protect a safe* occupant.
	B not applicable since human behaviour and the safety level of the road override the performance of a safe* car.
	Reclassified as ***C***. A safe* occupant would probably have survived.
	Reclassified as ***AB*** if the criteria for the occupant are considered to be irrelevant for the outcome.
	Reclassified as ***AC*** if the criteria for the car are considered to be irrelevant for the outcome.
	Reclassified as ***BC*** if the criteria for the road are considered to be irrelevant for the outcome.
	ABC, the classification in Step 1 was retained in cases where it was impossible to identify the components that contribute crash severity above survivable limits.
Classified as **AB** 	Reclassified as ***A***.
	Reclassified as ***B***. A safe* occupant would probably have survived in a safe* car.
	AB, the classification in Step 1 was retained.
Classified as **AC** 	Reclassified as ***A***.
	Reclassified as ***C***.
	AC, the classification in Step 1 was retained.
Classified as **BC** 	B not applicable since human behaviour overrides the performance of a safe* car.
	Reclassified as ***C***.
	BC, the classification in Step 1 was retained.

* Definition of safe means criteria of the model are fulfilled.

Figure 2 Governing principles used to determine the reason for fatal injury in Step 2.

(80 fatalities), crashes at intersections (34 fatalities) and "other" (18 fatalities), including vehicle–animal crashes, rear-end crashes, and multiple crashes.

In-depth studies. The data were collected from the in-depth fatal crash data collection of the Swedish Road Administration (SRA, 2005). Investigators from the seven regions of the SRA carried out the studies within a week after a fatal crash occurred. Information was compiled to provide a complete picture of the crash. The investigators collected information such as brake marks, direction of the impact forces on the vehicle, and time when the ambulance arrives. The investigation also included information about road design, vehicles, and road users involved. No analysis was made by the investigators at the scene of the crash.

All information was collected on the design of the road such as road type, road width, surface, speed limits, roadside area, distance to, e.g., trees or rocks, and visibility. Along with photos of the road, this information was used to classify the infrastructure based on the EuroRAP Road Protection Score (RPS). The potential of the road to protect the road user from serious injury was in all cases been defined. The material was classified depending on collision type.

The investigators compiled information on make, model, and age of the vehicle, the condition of the vehicle, the safety systems the vehicle was equipped with and whether these were activated or not, and the wearing of seat belts. They also determined how the collision forces were loaded on the vehicle and how the collision object influenced the crash. Impact deformations and degree of intrusion in the vehicle were also documented. The authors and the consensus group used this information to estimate crash severity. Excessive speeding was based on evidence from witness and/or estimations by the SRA investigators. All crashes in the in-depth studies included police reports and medical and autopsy records. This included information on the age of the occupants, their gender, seat belt use, and medical diagnoses. For each crash, human behavior was classified in terms of estimated speeding, use of seat belt, and driving under the influence of alcohol (BAC, above 0.02%), or whether there was a suspicion of suicide (based on SRA documentation). BAC and toxicology for occupants killed were collected from the autopsy reports. Information on alcohol in surviving drivers was collected from police reports.

RESULTS

With the help of the SRA model for a safe road transport system it was possible to classify 93% of the in-depth fatal car crashes. Figure 3 (Step 1, as described in the Methods section) shows the number of fatally injured occupants, where each of the components (the road user, the vehicle, and the road) were in noncompliance with the safety criteria. There was no crash where all three components were fulfilled. Most of the occupants (203 of 230) were fatally injured when two or all of the three components did not meet the criteria for a safe road transport system.

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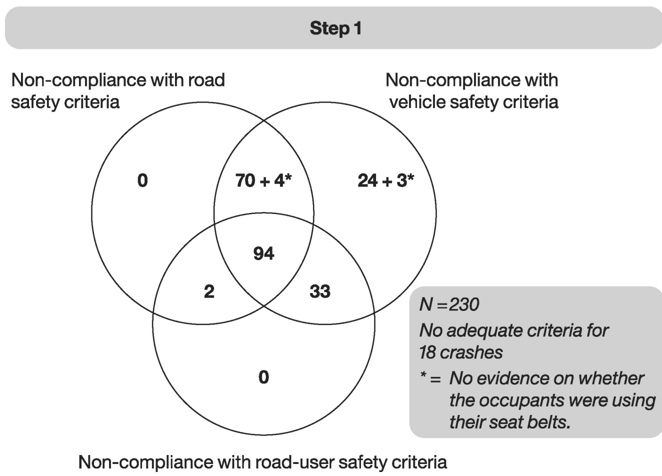

Figure 3 The number of fatalities where the road, vehicle, and/or road user did not comply with the criteria of the model (Step 1).

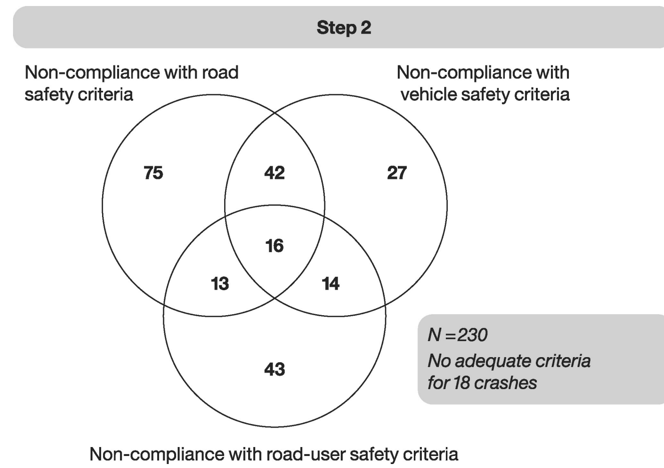

Figure 4 Reasons for fatal outcomes divided into noncompliance with safety criteria for the road, the vehicle, and/or the road user (Step 2).

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Roads

Twenty-four percent of the crashes occurred on roads with a four-star rating, 19% occurred on three-star roads, 48% on two-star roads, and 9% on one-star roads. Even in the case of four-star roads, 60 occupants were fatally injured. Twenty-eight occupants were fatally injured in single-vehicle crashes, 26 in head-on crashes, and 6 in intersection crashes. Collisions with heavy goods vehicles (HGVs) accounted for 53% (17 of 32) of all collisions with another vehicle on four-star roads. In all head-on collisions on roads with a four-star rating, the vehicles' safety standard was too low, and in 10 crashes the occupants did not fulfill the requirements. All six fatally injured occupants in intersection collisions collided with an HGV or an LGV (light goods vehicle). Only 4 of the 28 fatally injured occupants in single-vehicle collisions fulfilled the occupant requirements.

Vehicles

In two of the total number of crashes, the safety standard of the vehicle met the criteria for a five-star rating by Euro NCAP and the vehicle was fitted with Electronic Stability Control (ESC). Eighteen percent of the vehicles had a four-star rating, 7% were three-star rated, 2% were two-star rated by Euro NCAP, and the remaining 72% of the vehicles were not crash-tested by Euro NCAP, mostly because they were pre-1996 year models. The potential of ESC could be high, since more than a quarter of the total number of crashes started with loss of control. ESC might have had an effect in 45% (52 of 116) of single-vehicle crashes and 28% (22 of 80) of head-on crashes.

Road Users

The road users fulfilled the requirements of the criteria in 94 of the 230 cases. Forty percent of the vehicle occupants who were killed were not wearing seat belts, and more than a quarter of the total occupants (66 of 230) 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. In seven cases there were no evidence on whether the occupants were using their seat belt, but the consensus group considered the seat belt use to be irrelevant for the outcome.

In 58 of 230 cases it was judged that the driver exceeded the posted speed limit. In most of these cases (43 of 58), the driver/passenger was also not wearing a seat belt and/or was driving under the influence of alcohol. The average BAC value was 0.16%. The behavior of the occupants was most critical in single-vehicle collisions. Only 25% of the occupants had fulfilled the requirements, compared with 51% and 74% in head-on and intersection crashes, respectively.

Cause of Fatal Outcome

Even if several of the criteria were in noncompliance with the safety criteria in the model, the reason for a fatal outcome might not be linked to all these failed criteria. For instance, the safety standard of a car is more or less irrelevant in a frontal collision with an HGV at 90 km/h. Based on levels of crash severity that human beings can survive, each crash was analyzed to identify the components contributing to crash severity exceeding survivable limits, and thus constituting the reason for a fatal outcome (Step 2, as described in the Methods section); see Figure 4. Two or all three components were seen to interact in 85 of the total 230 cases. Noncompliance with safety criteria for the road user, the vehicle, and the road led to fatal outcomes in 43, 27, and 75 cases, respectively. Two or all three components were interacting in 53% of all the fatal injuries in single-vehicle crashes, in 26% of head-on crashes, and in 9% of the intersection crashes.

DISCUSSION

The future road transport system, taking into consideration roads, vehicles, and road users, must be more compatible and more effective in limiting the consequences of road crashes when crashes cannot be avoided. In order to achieve a more sustainable system, a preventive philosophy is necessary, where the road infrastructure is based on the capabilities and limitations of human beings through good planning and road design. Current safety

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policies are moving towards defining safety criteria (Peden et al., 2004) rather than identifying risk factors.

In most crashes there are multiple causes of injury outcome. In this study, instead of focusing on risk factors, some safe indicators for what could be expected in a safe road transport system were presented. 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 SRA model provides a picture of the safety standard of the three components in fatal car crashes. The further developed classification gave a more adequate picture of the efforts needed to create a safer road transport system. By using the SRA model alone it is difficult to ascertain which failed criteria are important for the fatal outcome. Step 2 is one way of approaching the analysis of cause correlations between unsurvivable crash severity and noncompliance criteria, in order to identify system weaknesses. The model does not propose solutions but rather qualities of a safe road transport system.

The SRA model is mainly directed towards crashworthiness of the road transport system and describes the simple interaction between a few components. While road crashes and crash outcome are complex and dependent on a large number of factors, the model only reflects a few of them. If, on the other hand, the model can capture the majority of serious crashes in relation to outcome, by integrating the road user, the vehicle, and the road/speed, it is still a valuable attempt to both analyze as well as predict improvements in the system. The philosophy of the model is that any further factors added to the model would have to contribute substantially in order to constitute any improvement to the model. While the model in the above sense seems simple, the Euro NCAP and EuroRAP rating systems are quite complex.

The safety criteria used in the model address most of the crashes. However, a number of shortcomings in the criteria were identified. The model did not address rear-end crashes, vehicle-animal crashes, or hitting stationary/parked vehicles or trailers. The criteria of the model are not adequate to classify the safety level of the road and the vehicle in these crashes. The criteria of road and vehicle only address single-vehicle crashes, head-on crashes, and intersection crashes. Vehicle-animal crashes with both moose and deer are a problem on Swedish roads. Fatal crashes with animals occurred on roads with speed limits of 70, 90, and 110 km/h. In most cases the animal went through the windscreen and/or the roof collapsed. It has been shown that modern cars withstand a collision with animals such as moose at 70 km/h (Matstoms, 2003).

Further studies are needed to evaluate the survivable potential in animal collisions at 90 km/h. Collisions with HGVs account for a significant proportion of all fatal car crashes on roads with a four-star rating. The definition of a safe road for intersection and head-on collisions is based on survivability in collisions between passenger cars. This is an unsatisfactory condition, and as many previous studies have suggested (Mackay et al., 1992; Krusper and Thomson, 2008), one that requires attention, in order to solve compatibility problems with passenger cars and heavy vehicles. One way of reducing crash severity in crashes with heavy vehicles would be to fit HGVs with deformable frontal protection in combination with new smart systems that reduce impact speed by automatic braking before impact. Otherwise, the enforced adoption of a lower speed limit on two-lane roads is necessary for HGVs.

Previous studies have shown that it is hard to protect occupants from serious injuries in collision with narrow objects such as poles and trees at impact speeds above 30–50 km/h (Kloeden et al., 1999; Delaney et al., 2003). In Victoria, Australia, the guidelines for widths of safety zones specify that they should be 3 m wide on single-carriageway roads in built-up areas (Parliament of Victoria Road, 2005). This is not included in the classification system of the SRA model. Based on this study it was not possible to evaluate whether there is a need of a safety zone at 50 km/h. Half of the single-vehicle crashes on four-star rated roads occurred on roads with speed limit of 50 km/h. In all these cases both the vehicle and the road user did not comply with the criteria of the model. Further studies are necessary to evaluate whether a safety zone at 50 km/h is needed in the SRA model.

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 the restrained occupant. Not using seat belts is therefore a behavior that takes the occupant outside the encompassing design of the road transport system. In the future, smart seat belt reminders should probably be one of the criteria for a safe vehicle, since smart seat belt reminders have been shown to increase the use of seat belts to nearly 99% (Krafft et al., 2006; Kullgren et al., 2007). This shows that 100% usage is a natural target to make sure that other systems are used to their maximum potential.

Driving under the influence of alcohol is a cause of the crash on most occasions, but in this study, driving under the influence of alcohol has also been classified as a risk factor for fatal outcome not only since the risk of a crash increases dramatically, both for the occupant and the opposite part, but also because the risk of incorrect behavior increases. One of the crashes included in this study was caused by a drunk driver who was driving in the wrong direction on a motorway. In this case the road and the vehicle safety standard are irrelevant. Several studies have shown that fatality risk increases rapidly with BAC (Evans, 1991; Zador et al., 2000; Bedard et al., 2002; Preusser, 2002; Peden et al., 2004). The average BAC value in this study was 0.16%, which correlates with a 30 times higher relative fatality risk compared with a sober driver (Zador et al., 2000).

Limitations of the Study

To secure the reliability of classification, the authors classified the data separately, and disagreements as well as complex cases (Step 2) were handled in the consensus group with significant experience from both real-life crashes and crash tests. Even if the cases in the consensus group were handled in a systematic way, there is a risk of estimations being arbitrary. However, in order to minimize this risk in Step 2, the classification based on

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Step 1 was retained if the outcome was not clear to all in the consensus group.

Since there is a strong correlation between change of velocity and risk of injury (Kullgren, 1998; Ydenius and Kullgren, 2001), the fact that only estimated excessive speed could be detected constitutes a limitation as it is known that also minor changes in speed have large effects on injury outcome (Elvik, 2007). Crash severity was based on ocular assessment from external and internal deformations of the car. Other measurements might change the pattern.

It is known from previous studies conducted on wider datasets that both age and gender influence the risk of being fatally injured in a car crash (Bedard et al., 2002). In particular, age and fatality risk are strongly correlated with each other (Braver and Trempel, 2004). This has not been taken into consideration in the present study. Twenty-five percent of the occupants were over 65 years of age. In two cases, where both were over 80 years old, the fatal outcomes were probably correlated to a lower biomechanical tolerance level than defined in the criteria for the model. To date it might be impossible to achieve a 100% preventive effect for all road users with the criteria in question.

A safe road transport system also needs to be safe for all users, even unprotected road users. This has not been taken into consideration in our study, since the data were limited to fatal car occupants. Further studies, also including data on crashes that cause severe injuries and injuries leading to disability, are needed to evaluate the model and to better understand relationships in the road transport system.

CONCLUSIONS

It was possible to classify 93% of the in-depth fatal crashes according to the SRA model, and no fatalities occurred when all criteria were fulfilled. The model did not address rear-end or animal collisions or collisions with stationary/parked vehicles or trailers (18 out of 248 cases). In order to identify weaknesses in the road traffic system, a method was developed as a complement to the SRA model, for mapping the cause of fatal outcome. In the presented study, fatal outcomes were mostly related to an interaction between the three components: the road, the vehicle, and the road user. Of the three components, the road was the one that was most often linked to a fatal outcome.

ACKNOWLEDGMENTS

The authors wish to thank the consensus group: Ola Boström at Autoliv AB, Mats Lindqvist at Saab Automobile AB, and Anders Kullgren and Anders Ydenius at Folksam Research. We also express our appreciation to Carina Teneberg and Kenneth Svensson at the Swedish Road Administration, for important help with data from the SRA in-depth fatal crash investigations.

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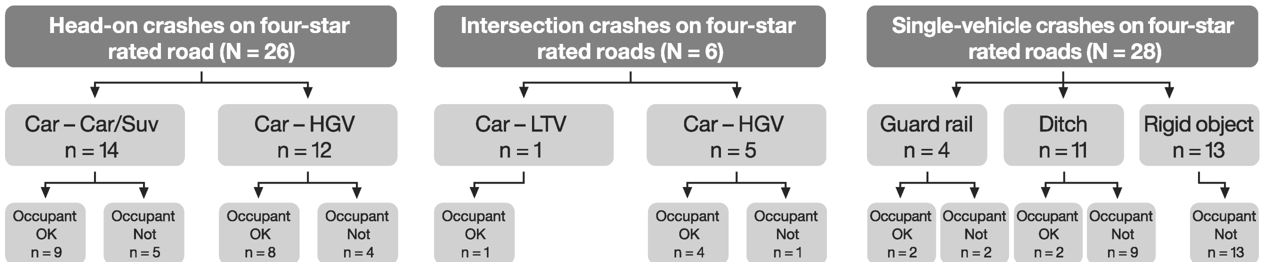
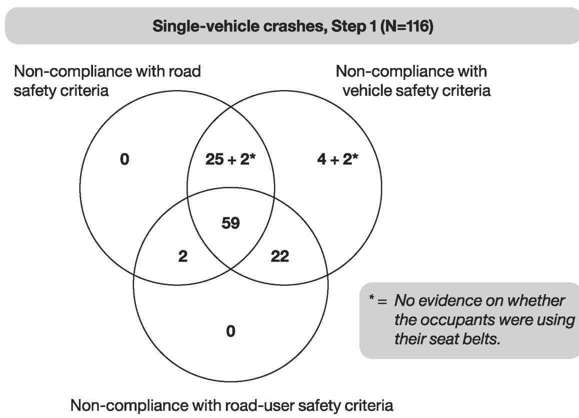
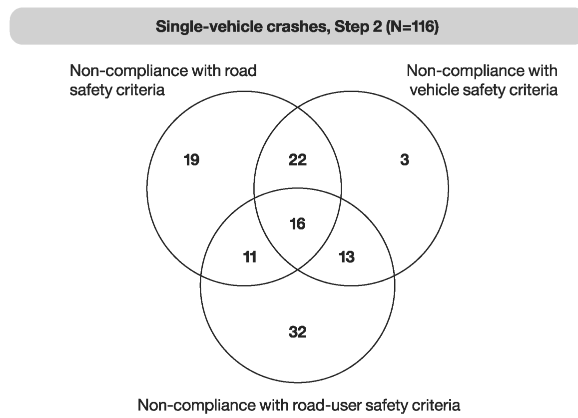
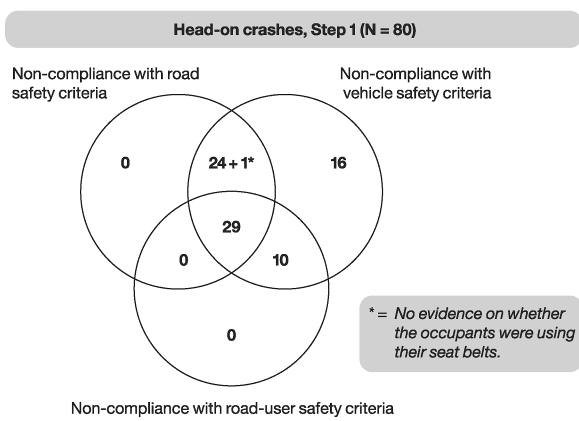
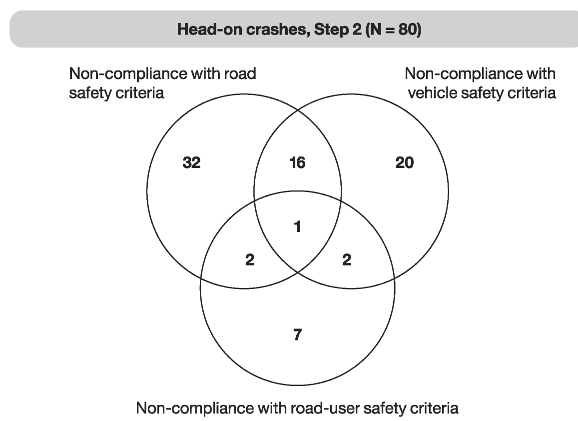
APPENDIX

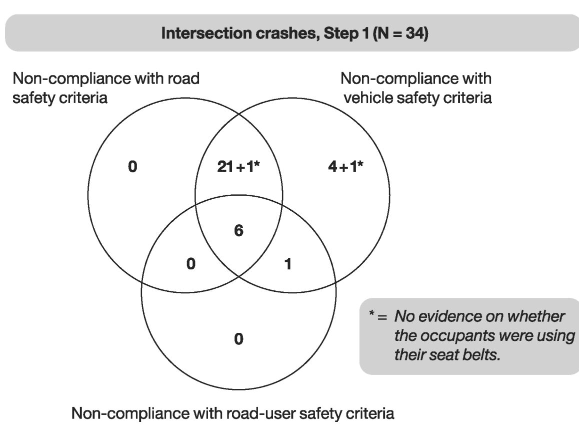


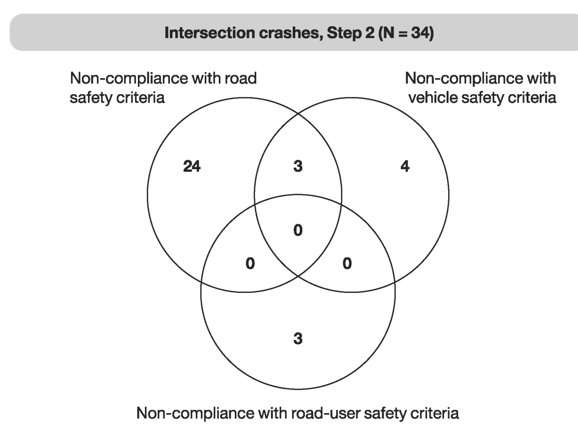












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