ANALYSIS OF A SAFE ROAD TRANSPORT SYSTEM MODEL AND ANALYSIS OF REAL-LIFE CRASHES ON THE INTERACTION BETWEEN HUMAN BEINGS, VEHICLES AND THE INFRASTRUCTURE.

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ABSTRACT

The objective of this study was to evaluate whether a simple model for a safe road transport system, which includes the interaction between human beings, vehicles and the infrastructure could be used to optimise the components of the system.

Real-life crashes with a fatal outcome were classified according to the vehicle's active and passive safety system. For each crash, classification was also made of the infrastructure with EuroRAP, and human behaviour in terms of speeding, seat belt use and driving under the influence of alcohol. The ideal situation was simulated, when all the above factors were altered to what is expected in a safe system.

All fatal crashes where a car occupant was killed that had occurred in Sweden during 2004 were included: in all 215 crashes with 248 fatalities. The data was collected through the in-depth fatal crash data collection from the Swedish Road Administration.

It was possible to show both the model as well as where the highest potential could be found in a systems perspective. The model could handle more than 90% of the crashes. In general, it was found that impact severity was higher than the expected crash protection of a modern and safe vehicle, even when the occupants were belted and not speeding. The most common and weakest part of the system was therefore the road in the form of speed infrastructure relations. The human criteria were fulfilled in 28% of single collisions and in 80% of side impacts. A safe car, according to the given criteria, would have influenced the outcome in 41% of the accidents on 50km/h- and 70km/h-roads, and 32% on 90km/h-roads.

The future road transport system must be more compatible and more effective in limiting the consequences of road crashes. When prioritising preventive measures, the model might be an instrument to support that process.

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. Haddon [1] put forward most of the prevention aspects on road casualties, but still the components in the system are hardly compatible with each other. Different kinds of legislation directed towards vehicle manufacturers, road users and road designers have been developed but remain independent from each other, with the road user being the unstable link between the car and the road.

To achieve a safe road transport system that avoids fatal and severe injuries being sustained, some elementary safety requirements must be fulfilled. By increasing the number of constraints on the occupants, such as the use of 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 the vehicles, the roads, the roadside area and the road users, is thus important.

Since 2001 the European Road Assessment Programme (EuroRAP), a sister programme to EuroNCAP, has focused on actions that are needed to make European roads safer. EuroRAP provides independent safety ratings of roads in Europe [2]. The EuroRAP rating score takes into consideration how well a road protects the user from fatal or serious injuries. The rating focuses on three different crash types: head-on collisions, run-off-the-road and side collisions at intersections. By rating the safety of a road in this way, taking into account all considerations, the rating is summarised by a weighting factor based on the distribution of the crash types. The protection afforded pedestrians and cyclists is the fourth crash-type characteristic under consideration. These four crash types account for about 80% of all fatal and serious accidents on major roads outside urban areas [3]. EuroRAP consists of two test protocols, both designed to evaluate road standard: road protection score (RPS), and risk mapping.

In EuroRAP it has been concluded that the modern car cannot, on its own, provide sufficient protection for its occupants in a two-car crash at speeds above 70 km/h. In order to avoid fatal or serious injuries in crashes at speeds higher than 70 km/h, the road environment must be designed to eliminate frontal two-car crashes at higher speeds, or to lower the severity of single-car crashes into roadside areas. When a crash occurs, the vehicle and the road must work together as a system to provide protection for the vehicle occupants and other road users.

The safety level of the road has a significant correlation to speed limits and therefore plays an important part in the EuroRAP star-rating programme. The Swedish Road Administration uses the definition of safe speed for different road environments (See Table 1) [4,5]. Speeds over 70 km/h place higher demands on the road environment to meet the envisaged safety requirements for a four-star road. In such cases, the road design should be more forgiving.

Table 1. The Swedish Road Administration's definition of safe speed

Road type	Safe speed (km/h)
Roads with potential conflicts between cars and unprotected road users	30
Junctions with potential side impacts between cars	50
Roads with potential head-on collisions between cars	70
Roads where head-on collision/side impacts are impossible	>100

To prevent the three crash types, different measures need to be taken. A joint statement for the crash types is that a road with a four-star rating should produce limited crash energy that a car with a four-star rating is able to absorb by the vehicle's crumple zones and safe restraints systems. To avoid head-on collisions with fatal outcomes this means that the speed limit on the road should be 70 km/h, or in the case of higher speed limits lanes of opposing traffic should be separated with a barrier or a wide central reservation. To prevent run-off-the-road accidents, the road must have a clear safety zone adapted to the speed limit. A safety zone is a recovery area, which the vehicle leaving the roadway needs in order to stop safely, or which helps to reduce the crash energy to an acceptable level so that it will not result in a fatal or serious injury. For side impacts in intersections the speed limit must be 50 km/h, or there must be a roundabout to limit the severity of the crash.

Aim

Integrated crash studies that focus on illustrating the interaction between human beings, vehicles and the infrastructure are rare. The objective of this study was to evaluate whether a simple model for a safe road transport system, based on EuroRAP classification and including human beings, vehicles and the infrastructure, could be used to optimise the components of the system.

METHODS AND MATERIAL

The EuroRAP classification model was used to design a simple model for a safe road transport system [2]. In an ideal situation: the driver uses a seat belt, follows the speed limits and is sober; the vehicle has a four- or five-star rating by EuroNCAP; and the

road has a four-star rating by EuroRAP. In such circumstances no one should be killed or seriously injured in a car crash. To evaluate whether it is possible to use this model, real-life crashes with fatal outcomes were classified, adapted to the model criteria. 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 SUVs and 5 MPVs, were included in this study. Crashes where there was a suspicion of suicide were excluded. The data was collected through the in-depth fatal crash data collection from the Swedish Road Administration.

Both two-vehicle and single-vehicle crashes, as well as both belted and unbelted occupants, are included in this study. The material was divided into four different groups: run-off-the-road crashes, head-on collisions, accidents at intersections and "other" including vehicle–animal collisions, rear-end collisions and multiple collisions.

In-depth studies

Investigators at the Swedish Road Administration's seven regions carry out the in-depth studies soon after a fatal crash has occurred [6]. Information is compiled to provide a complete picture of the crash. The investigators collect evidence about what has happened before, during and after the crash. Information such as brake marks, direction of the impact forces on the vehicle and time when the ambulance arrives is collected. The investigation also includes information about road design, vehicles and human beings. No analysis is made by the investigators at the scene of the accident. The analyses carried out in this study are based on the SRA's data.

The road All information is collected about 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. Photos of the road are taken in both directions and degree of slopes is also measured.

Photos and information of the road quality from the crash were used to classify the infrastructure based on the EuroRAP Road Protection Score (RPS). The RPS ranges from 1 to 4, where 4 is the rating for a high road-safety standard, giving a relative risk rating for fatal and serious injuries. The RPS rating is based on data gathered from real-world crashes and crash tests. The score is based on well-known facts from real-life crashes and crash tests. Underlying these limits are the biomechanical criteria for how much a human being can be exposed to during a crash without sustaining severe injuries.

Point RPS - Instead of using the EuroRAP RPS for the total road route, the classification 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 influence the crash outcome. The road's potential to protect the road user from serious injury has in all cases been defined. Both the individual scores for one of the three crash types and also the combination of them were calculated. Table 2 describes the requirements for a road to achieve a four-star rating. The material was classified depending on collision type.

Table 2. Criteria for the four-star rating of a road in the safe transport model.

The Road	EuroRAP ★★★★
To prevent:	
Head-on collisions	70 km/h >70 km/h separated lanes
Run-off-the-road accidents	50 km/h 70 km/h guard-rail or Safety zone >4 m 90 km/h h guard-rail or Safety zone >10m 110 km/h guard-rail or Safety zone >10m
Accidents at intersections	Roundabout or 50 km/h >50 km/h grade separated

The vehicle The investigators compile information on the age of the vehicle, the condition of the vehicle, which safety system the vehicle is equipped with and whether this was activated or not, and use of the seat belt. They also determine 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 is also documented.

Crashes with fatal outcome were classified according to the vehicle passive safety system using EuroNCAP. For crashes where the outcome was more difficult to estimate, a consensus group with significance experience from both real-life crashes and crash tests was used to estimate the crash safety properties of the vehicle.

The model used also requires that the vehicle, apart from being at least four-star rated by EuroNCAP, should be fitted with a side airbag, head-protection airbags and Electronic Stability Control. This is due to the fact that these systems have been shown to effectively reduce fatalities [7,8]. Table 3 shows the requirements for a safe car in the model.

Table 3. Criteria for the vehicle in the safe transport model.

The vehicle
EuroNCAP ★★★★
ESC
Side airbag
Head-protection airbag

Driving conditions All crashes are followed up using police reports, medical journals and a post-mortem report. This includes information about the age of the occupants, gender, seat belt use and fatal injuries. For each crash, human behaviour was classified in terms of speeding, seat belt use and driving under the influence of alcohol, or whether there was a suspicion of suicide. Only excessive speed could be detected from this material. Table 4 shows the criteria which the occupants are required to meet in the safe transport model.

Table 4. Criteria for the car occupants in the safe transport model

Driving conditions
Use of the seat belt
Speed limits followed
Driver not under the influence of alcohol

Analyses begin at the stage where a crash has occurred, and focus on finding the reason for the fatal outcome, not the reason why a crash has occurred. This could be due to one or a combination of all the three parts of the system. For all crashes, the ideal situation was simulated, when all the above factors were changed to the expected outcome in a safe system.

RESULTS

It was possible to use the model for a safe road transport system to classify the in-depth fatal crash data collection from the Swedish Road Administration. The model could handle 91% of the crashes. When only crash types specified in EuroRAP (run-off-the-road crashes, head-on collisions and accidents at intersections) were included, the model could handle 96%.

In Table 5 and Table 6, it is shown that of the three components, the human being, the vehicle and the road, the last one was the most common and weakest part, causing non-surviving crash severity (180 cases out of 248). Eight crashes resulted in fatal outcome despite all safety criteria in the model being fulfilled. According to the criteria, the human being fulfilled the requirements in 106 cases and the vehicle was rated by EuroNCAP as four- or five-star in 45 cases. In seven crashes, there was no specified evidence about whether the occupants were using their seat belts.

Table 5. Classification of the crash using the criteria for a safe road system (except for the vehicle, where only EuroNCAP classification was used).

Human	Vehicle	Road	N
not safe	not safe	not safe	89
not safe	not safe	OK	29
not safe	OK	not safe	9
not safe	OK	OK	8
not declared	not safe	not safe	4
not declared	not safe	OK	2
not declared	OK	OK	1
OK	not safe	not safe	59
OK	not safe	OK	20
OK	OK	not safe	19
OK	OK	OK	8
			248

Table 6. The number of occupants who could be saved by reducing crash severity to sustainable levels by changing at least one component in each crash: the road, the vehicle and/ or the human behaviour.

All crashes	Fatalities		n=248
By changing:	Human	Vehicle	Road
	59	81	120
In combination	40	42	53
Total	99	123	173

Roads

Almost half of all fatal crashes (47%) during the study period involved a vehicle running off the road. Head-on collisions and accidents at intersections also constitute a major problem since they accounted for respectively 32 and 13% of the total number of fatalities. The remaining eight percent of the fatal crashes were classified as the collision type defined as "other". Seventy-seven percent of the crashes occurred on standard two-lane, single-carriageway roads with one lane in each direction, and eight percent occurred on roads less than sex metres wide. Only 15% occurred on motorways or roads with a 2+1 configuration.

Twenty-six percent of the crashes occurred on four-star roads, and of these, 35% of the fatal injuries were caused by the road alone or in combination with a low standard of car safety and/or failure in human behaviour such as not wearing a seat belt. In 16 of the total number of fatalities on the four-star roads, the main problem was the road, even if it was rated as the highest safety level (See Table 7). Five of these were collisions with heavy vehicles on roads where the speed limit was 70 km/h. Crashes with animals, moose and deer, account for three of these accidents. The others were run-off-the-road crashes. Three were caused by failure of the guard-rail and one occurred on a motorway with a safety zone, but in this case the vehicle safety level was low. Two of the crashes occurred on roads where the speed limit was 50 km/h, and in these two cases the speed probably exceeded the limit.

In total, 45% of the crashes occurred on roads with a two-star rating (See Table 8). Of these, 91% of the fatalities were caused by the road alone, or in combination with the vehicle and/or a human being.

Table 7. The number of occupants who could be saved on four-star roads by reducing crash severity to sustainable levels by changing at least one component in each crash: the road, the vehicle and/ or the human being.

All crashes at	★★★★	**EuroRAP** roads	
	Fatalities		n=66
By changing:	**Human**	**Vehicle**	**Road**
	25	27	16
Possible	2	3	2
In combination	6	6	4
Total	33	36	22

Table 8. The number of occupants who could be saved on two-star roads by reducing crash severity to sustainable levels by changing at least one component in each crash: the road, the vehicle and/ or the human being.

All crashes at	★★	**EuroRAP** roads	
	Fatalities		n=112
By changing:	**Human**	**Vehicle**	**Road**
	16	39	78
Possible	1	1	3
In combination	17	15	19
Total	34	55	100

Vehicles

The safety standard of the vehicle was insufficient in 75% of the total number of crashes. Side airbags and head-protection airbags could have had an effect in 17 out of 23 of the crashes at intersections. The potential of Electronic Stability Control, ESC was also high, since more than a quarter of the total number of crashes started with loss of control. Airbags were missing in 63% of all frontal impacts and in 80% of all side impacts. Improvement in the vehicle safety level would have had more effect on the crashes occurring on roads with speed limits of 50- and 70-km/h than on 90- and 110-km/h roads (See Appendix Tables A-E).

If all the cars that were rated by EuroNCAP as four- and five-star had been equipped with ESC and head-protection airbags, 20 lives could probably have been saved (See Figure 1-3). The potential for reducing the number of fatalities was highest in single-vehicle collisions. In the case of side impact at intersections, changes in both the road and the vehicle are required.

Figure 1. Single-vehicle crashes - The number of occupants in cars with a four- or five-star rating by EuroNCAP who could be saved by changing at least one component in each crash: the road, the vehicle and/ or the human behaviour. The effect of

ESC and airbag has been taken into consideration of the outcome.

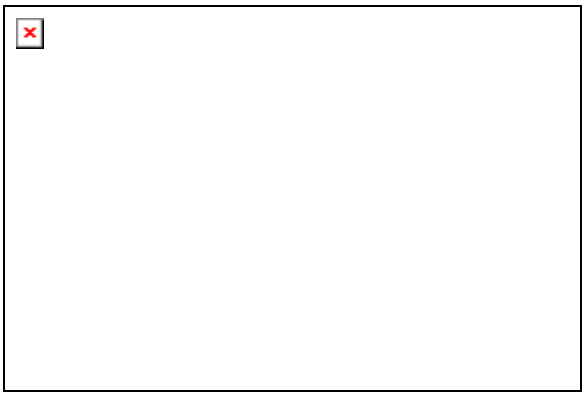

Figure 2. Head-on collisions - The number of occupants in cars with a four- or five-star rating by EuroNCAP who could be saved by reducing crash severity to sustainable levels by changing at least one component in each crash: the road, the vehicle and/ or the human behaviour. The effect of ESC and airbag has been taken into consideration of the outcome.

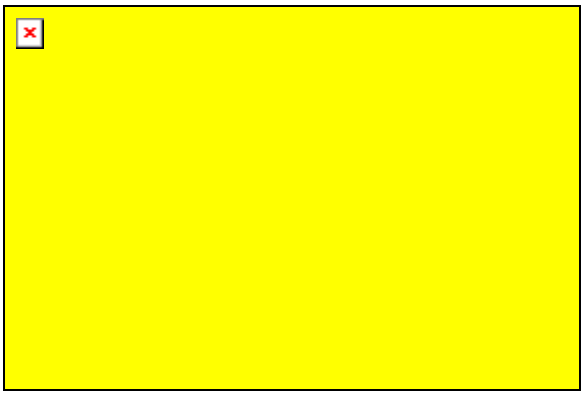

Figure 3. Intersection collisions involving cars rated by EuroNCAP as four- or five-star. In order to save the occupants' lives, changes in both the vehicle and the road are necessary. None of these vehicles was fitted with a head-protection airbag.

Human beings

Forty percent of the occupants who were killed were not wearing seat belts, and more than a quarter of them were driving under the influence of alcohol or other drugs.

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 mainly correlated to a lower biomechanical tolerance level than the model criteria. Both were run-off-the-road crashes.

When the human criteria were fulfilled, the standard of the vehicles was more often of a good safety level compared with the accidents where the human requirements were not fulfilled (See Appendix Figure 1-2). The behaviour of the occupants was most critical in single-vehicle collisions. With a change in human behaviour, almost half of the occupants in single-vehicle collisions that did not fulfil the criteria would have survived (See Appendix Table F-G).

A sustainable transport system

In the crashes where at least one component was not fulfilled according to the criteria in the model, an estimation was made regarding which of the components would change the crash conditions so as not to exceed human tolerance (See Table 6). Given the standard of the car and the human behaviour for 120 occupants, a four-star road would have reduced the severity of the crashes to survivable levels. In 81 cases, a four-star car with ESC and side collision protection would have made it possible to survive the collision, and the human being would have changed the outcome in 59 cases by using a seat belt and/or not speeding and/or being sober. For the rest of the crashes, change is required in several components. In Table 7 and 8, the same analysis is made as in Table 6, but for four respective two-star roads. There was a large difference in the number of crashes with a non-survival outcome, depending on the standard of road safety: 16 out of 66 on four-star roads compared with 78 cases out of 112 on two-star roads.

DISCUSSION

Road traffic crashes are a considerable public health problem and in order to achieve the target for road casualty reductions in Europe it is important to analyse cause of death in road crashes. The future road transport system, taking into consideration the infrastructure, vehicles and human beings, must be more compatible and more effective in limiting the consequences of road crashes when the crashes cannot be avoided. In order to achieve a more sustainable system, a preventive philosophy is necessary, where the infrastructure is based on the capabilities and limitations of human beings through good planning and road design. The Swedish Road Administration uses the model in their work to identify weaknesses in the road transport system. Integrated crash studies are rare and the model has never previously been evaluated. The model might be one way of evaluating the importance of the different components, to enable better prioritisation in the prevention work.

Limitations of the study
The data was limited to fatal crashes. If the model is to be a useful tool in traffic safety work, it is necessary to include serious injuries.
The estimation of crash severity in the cars was based on the Swedish Road Administration's data. There is a risk that the photos showing the deformation zone of the cars might be misleading (3D to 2D). However, in most cases written text was included that elucidated the data.

The analyses of the crashes were partly subjective, especially when it came to large deformations of the vehicle. The ideal situation was simulated, when all factors were altered to what is expected in a safe system. The ideal situation was simulated using factors that might have provided a safe outcome, if they were applicable to this particular case, in order to assess the probability of preventability and adaptation to the safe road transport system. To minimise errors of classification, a consensus group with significant experience from both real-life crashes and crash tests went through part of the material to estimate vehicle crash safety properties and the possibility of survival in another car or with other restraint systems.

Only excessive speed could be detected from this material. Probably more of the crashes than could be detected occurred at speeds over the speed limit. It is known that many drivers drive faster than the posted speed limit [9]. The speed limit has a major influence on the speed of impact.

Infrastructure in Sweden
In 1997 the Swedish government decided upon a road transport safety strategy called "Vision Zero", the aim of which is that no fatal or serious injuries should occur in the road transport system [10,11]. Therefore there have been major efforts on Swedish roads to create a safe road environment, e.g. central barriers to separate the traffic and minimise head-on collisions; guard-rails to prevent collisions with dangerous roadside areas, such as rocks, trees and poles; or the removal of roadside objects. However, one important step in creating a more sustainable road system is that the speed limits should be based on the safety level of the road. The concept of safe speed, one of the principles in this model, has been proposed to the Swedish government as the criterion for creating a new speed limit system.

The traffic situation in Sweden differs from other parts of Europe. The flow on the Swedish roads is much lower and the proportion of traffic on motorways is relatively low compared with for instance the UK or the Netherlands [5]. The network in Sweden consists of three main roads: motorways, two-lane roads 9-13 m wide, and two-lane roads 6-8 m wide. During recent years there has been a rapid growth of 2+1 roads with a central barrier in Sweden. This has been shown to be very effective in reducing the number of fatalities and serious injuries. Only two cases of fatalities on this type of road were represented in this study.

Safety model
The safety model used in this paper describes the simple interaction between a few components of the road transport system. 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 user, the vehicle and the road/speed, it is still a valuable attempt to both analyse as well as predict improvements in the system. Any further factors added to the model would have to contribute substantially in order to constitute any contribution to the model. While the model in the above sense seems simple, the NCAP and RAP rating systems are quite complex. It is also understood that the model does not give any guidance as to which method should be applied in order to generate contributions to fulfil the factors in the model. While it is clear that drivers should be sober, the model does not indicate at all how this could be achieved.

The safety criteria used in the model, to achieve a safe road transport system, cover more than 90% of the crashes. Only a few fatal crashes occurred despite the fact that all criteria were fulfilled. In these cases the criteria for safety road system does not work. Such examples are compatibility with passenger cars and heavy vehicles and small overlap collisions.

The road and the vehicle
In small overlap collisions the intrusion is the most critical parameter. Lindquist et al [12] have shown that the injury mechanisms are different in these crashes compared with full frontal collisions, and therefore a restraint system other than frontal airbags is needed to protect car occupants. The restraint system as well as front design of the vehicle should be constructed to manage this type of crash.

To improve the potential for injury prevention in head-on collisions with trucks, the truck could either be fitted with frontal underrun protection or enforced adoption of a lower speed limit on two-lane roads. More efforts are needed to solve the problem of head-

on collisions on roads where the speed limit is 70 km/h.

Vehicle–animal crashes with both moose and deer are also 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. Modern cars have been shown to manage a collision with animals such as moose at 70 km/h [13]. Further studies are needed to evaluate the survivor potential in a collision at 90 km/h.

Furthermore, crash severity is high in a collision with narrow objects such as poles and trees, since the load is often concentrated to a small part of the car, and only a minor part of the energy absorption structure will be involved [14]. In such crashes it is hard to protect occupants from serious injuries in impact speeds above 30-50 km/h [15,16]. Therefore there is a shortcoming in the EuroRAP classification system, since there are no demands for a clear zone at 50 km/h. In Victoria, Australia, the guidelines for safety zone widths on single-carriageway roads in built-up areas state that they should be a minimum of three metres wide [17]. This needs to be evaluated. Speed should be in accordance with the type of road and compatible with the road environment. To stimulate development of safer vehicles, similar criteria to those for two-vehicle crashes tested in EuroNCAP should be used to develop a protection system for crashes between cars and roadside objects.

In addition to the criteria in EuroRAP for a safe car (at least four stars), this model has included equipment demands for side head-protection airbags and electronic stability control (ESC), since this provides a high preventive effect. McCartt and Kyrychenko [7] found that fatal injuries were reduced by 37% for head-protection airbags, and by 26% for torso-only side airbags, in side impacts. In our study this could probably have had an effect on the outcome in 17 out of 23 side impacts. In addition, more than a quarter of the crashes started with loss of control, and none of these cars were equipped with ESC.

Human beings

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 behaviour that takes the occupant outside the encompassing design of the road transport system. Smart seat belt reminders have been shown to increase seat belt use to nearly 99% [18,19], which shows that 100% usage is a natural target to make sure that other systems are used to their maximal 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 party, but also because the risk of incorrect behaviour increases, such as driving in the wrong direction on a motorway and other violations of traffic laws.

In two cases, the fatal outcome was probably correlated to a lower biomechanical tolerance level than the criteria in the model. Age and fatal risk are strongly correlated with each other [20]. It might be impossible to have a 100% preventive effect for persons above 70-80 years of age with the criteria in question.

The most effective and efficient way of constructing a safe road transport system is to see how the three components can and must integrate together to minimise crash severity. Speed limits in relation to the infrastructure will be central in the design of such a system. Since the model is based on biomechanical human tolerances, there are several ways of reducing crash severity to improve survival, or better still, of reducing the probability of crash events occurring. This study indicates that the most effective approach to reduce the number of fatalities in Sweden is to make adjustments to roads or speed limits. If a crash takes place, in too many cases the safety level of the car or correct occupant behaviour would not have changed the fatal outcome. The analyses found that the crash severity far exceeded the limitations of human survival and the crashworthiness of the vehicle. The influence of the different components changed depending on the speed limit and type of collision. The occupants' behaviour contributed to a fatal outcome in 72% of all single-vehicle crashes compared with 54% of the total. All the three components of the transport system were weakest in single-vehicle collisions. A good safety level of the car was more crucial on roads with 50- and 70-km/h speed limits than on 90- and 110-km/h roads. This study indicates that many lives could have been saved if the vehicles with a lower standard of safety had been replaced. A modern car is designed to provide the occupants with necessary protection to ensure survival in collisions at up to 70 km/h. The primary role of the infrastructure is to assist in the reduction of the crash energy and to help the vehicle to maximise its inherent safety protection design. This study shows that in 40% of the accidents that

occurred on roads with acceptable speed limits, the vehicle is the component that can contribute most to the reduction of fatalities.

To create a safe road transport system, there must be close cooperation between road designers and car manufacturers. Data on different crash severity depending on collision partner are needed in order to form a future road transport system that does not produce higher crash severity than the vehicle is able handle. The vehicle's crashworthiness must work in interaction with the road infrastructure. A safe road transport system also needs to be safe for all users, even the unprotected road users. This has not been taken into consideration in this study. However, further studies, with more 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

Both the model as well as where the highest potential could be found in a systems perspective, could be shown. In general, it was found that impact severity was higher than the expected crash protection of a modern and safe vehicle, even with a belted driver who was not speeding.

By applying an integrated model of a safe system, both the model and the possible potential are evaluated.

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REFERENCES

[1] Haddon, W., Jr. 1980. "Advances in the epidemiology of injuries as a basis for public policy." Public Health Rep 95, 411-21.

[2] EuroRAP 2007. URL: www.eurorap.org 2007-02-27.

[3] Lynam, D., Sutch, T., Broughton, J. and Lawson, S.D. 2003. "European Road Assessment Programme Pilot Phase Thechnical Report." EuroRAP.

[4] SRA. 2005. "Regeringsuppdrag om hastighetsgränserna på vägarna" (Speed limits on roads - commissioned by the Government), Publikation 2005:100. In Swedish

[5] Koornstra, M., Lynam, D., Nilsson, G., Noordzij, P., Pettersson, H.-E., Wegman, F. and Wouters, P. 2002. "SUNflower: A comparative study of the development of road safety in Sweden, the United Kingdom, and the Netherlands" SWOV, Leidschendam.

[6] SRA. 2005. "In-depth studies of fatal accidents save lives." Swedish Road Administration.

[7] McCartt, A.T. and Kyrychenko, S.Y. 2006. "Efficacy of Side Airbags in Reducing Driver Deaths in Driver-Side Car and SUV Collisions." Traffic Inj Prev, (submitted 2007)

[8] Lie, A., Tingvall, C., Krafft, M. and Kullgren, A. 2006. "The effectiveness of electronic stability control (ESC) in reducing real life crashes and injuries." Traffic Inj Prev 7, 38-43.

[9] ERSO. 2006. "Speeding – web text of the European Road Safety Observatory." In: Safety Net.

[10] Tingvall, C. 1995. "The Zero Vision - A road transport system free from serious health losses" In: Transportation, traffic safety and health, 37-57.

[11] Tingvall, C. and Lie, A. 1996. "The implications of the Vision Zero on biomechanical research." In Proceeding of the IRCOBI Conf Pp11-18., Dublin

[12] Lindquist, M.O., Hall, A.R. and Bjornstig, U.L. 2006. "Kinematics of belted fatalities in frontal collisions: A new approach in deep studies of injury mechanisms." J Trauma 61, 1506-16.

[13] Matstoms, Y. 2003. "Utvärdering av älgatrappen Mooses II med sikte på konsumentprovning" (Evaluation of the moose dummy Mooses II with a view to consumer guidance). VTI meddelande 955, VTI.

[14] Durisek, N.J., Tanner, C.B., Chen, H.F. and Guenther, D.A. 2004. Vehicle characterization through pole impact testing, part I: Vehicle response in terms of acceleration pulses. SAE technical report 2005-04-01-1210.

[15] Kloeden, C.N., McLean, A.J., Baldock, M.R.J. and Cockington, A.J.T. 1999. "Severe and Fatal Car

Crashes Due to Roadside Hazards." NHMRC Road Accident Research Unit The University of Adelaide.

[16] Delaney, A., Langford, J., Corben, B., Newstead, S. and Jacques, N. 2003. "Roadside Environment Safety, Report to RACV." Monash University Accident Research Center.

[17] Parliament of Victoria Road, S.C. 2005. "Inquiry into Crashes Involving Roadside Objects." Parliamentary Paper No 119 Session 2003-5., Parliament of Victoria Road Safety Committee.

[18] Krafft, M., Kullgren, A., Lie, A. and Tingvall, C. 2006. "The use of seat belts in cars with smart seat belt reminders-results of an observational study." Traffic Inj Prev 7, 125-9.

[19] Kullgren, A., Lie, A., Krafft, M. and Tingvall, C. 2007. "Intelligent Seat Belt Reminders - Do They Change Driver Seat Belt Use in Europe." In Proceeding of the 20th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Lyon, France.

[20] Braver, E.R. and Trempel, R.E. 2004. "Are older drivers actually at higher risk of involvement in collisions resulting in deaths or non-fatal injuries among their passengers and other road users?" Inj Prev 10, 27-32.

APPENDIX

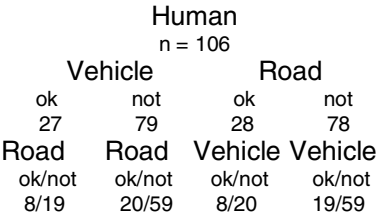

Figure 1. The accidents there the human <u>has fulfilled</u> the requirements. The number of crashes divided into groups of acceptable/not acceptable road/vehicle.

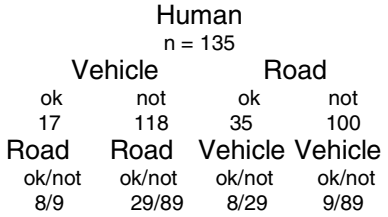

Figure 2. The accidents there the human <u>has not fulfilled</u> the requirements. The number of crashes divided into groups of acceptable/not acceptable road/vehicle.

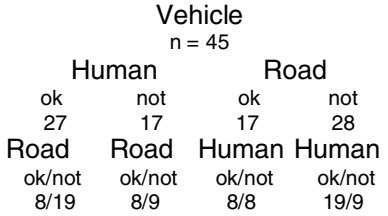

Figure 3. The accidents there the vehicle <u>has fulfilled</u> the requirements of four star rating by Euro NCAP. The number of crashes divided into groups of acceptable/not acceptable road/human behaviour.

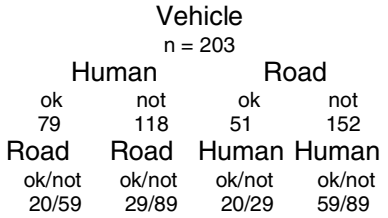

Figure 4. The accidents there the vehicle <u>has not fulfilled</u> the requirements of four star rating by Euro NCAP. The number of crashes divided into groups of acceptable/not acceptable road/human behaviour.

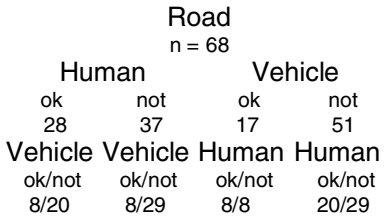

Figure 5. The accidents there the road <u>has fulfilled</u> the requirements of four star rating by Euro RAP. The number of crashes divided into groups of acceptable/not acceptable vehicle/human behaviour.

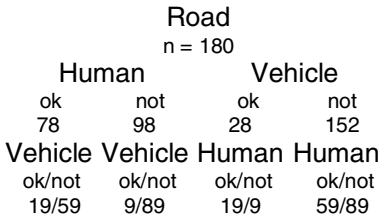

Figure 6. The accidents there the road <u>has not fulfilled</u> the requirements of four star rating by Euro RAP. The number of crashes divided into groups of acceptable/not acceptable vehicle/human behaviour.

Table A. The number of incidences where the factors did not meeting safety characteristics at various speed limits.

Factors	**50 km/h**	**70 km/h**	**90 km/h**	**110 km/h**
Human	16	36	62	21
Vehicle	18	64	97	24
Road	0	52	111	17

Table B. The number of occupants whose lives could have been saved on roads with the speed limitation of 50 km/h.

50 km/h	Fatalities		n= 22
By changing:	**Human**	**Vehicle**	**Road**
	10	9	3
Possible	1	1	1
in combination	1	1	1
Total	12	11	5

Table C. The number of occupants whose lives could have been saved on roads with the speed limitation of 70 km/h.

70 km/h	Fatalities		n=78
By changing:	**Human**	**Vehicle**	**Road**
	21	30	24
in combination	12	16	22
Total	33	46	46

Table D. The number of occupants whose lives could have been saved on roads with the speed limitation of 90 km/h.

90 km/h	Fatalities		n= 113
By changing:	**Human**	**Vehicle**	**Road**
	12	36	78
Possible	4	1	1
in combination	18	17	20
Total	34	54	99

Table E. The number of occupants whose lives could have been saved on roads with the speed limitation of 110 km/h.

110 km/h	Fatalities		n= 35
By changing:	**Human**	**Vehicle**	**Road**
	16	6	15
Possible		4	
in combination		3	3
Total	16	13	18

Table F. Single-vehicle collisions classified by the criteria for a safe road system.

Human	Vehicle	Road	N
not safe	not safe	not safe	59
not safe	not safe	OK	18
not safe	OK	not safe	4
not safe	OK	OK	3
OK	not safe	not safe	20
OK	not safe	OK	2
OK	OK	not safe	5
OK	OK	OK	2
not declare	not safe	not safe	2
not declare	not safe	OK	2
			117

Table G. The number of occupants that could be saved in single-vehicle collisions

Single-vehicle	Fatalities		n= 117
By changing:	**Human**	**Vehicle**	**Road**
	43	51	54
Possible	4	3	1
in combination	23	7	20
Total	70	61	75

Table H. Head-on collisions classified by the criteria for a safe road system.

Human	Vehicle	Road	N
not safe	not safe	not safe	24
not safe	not safe	OK	5
not safe	OK	not safe	5
not safe	OK	OK	5
OK	not safe	not safe	18
OK	not safe	OK	12
OK	OK	not safe	6
OK	OK	OK	4
not declare	not safe	not safe	1
			80

Table I. The number of occupants that could be saved in head-on collisions

Head-on Collision	Fatalities		n= 80
By changing:	**Human**	**Vehicle**	**Road**
	11	27	57
Possible	1	3	2
in combination	5	5	0
Total	17	35	59

Table J. Intersections collisions classified by use the criteria for a safe road system

Human	Vehicle	Road	N
not safe	not safe	not safe	6
not safe	not safe	OK	1
OK	not safe	not safe	14
OK	not safe	OK	3
OK	OK	not safe	7
OK	OK	OK	1
not declare	not safe	not safe	1
not declare	OK	OK	1
			34

Table K. The number of occupants that could be saved in side impacts at intersection

Intersection	Fatalities		n= 34
By changing:	**Human**	**Vehicle**	**Road**
	2	0	1
in combination	7	30	29
Total	9	30	30