Characteristics of future crashes in Sweden – identifying road safety challenges in 2020 and 2030

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Abstract It has been proposed by the European Commission that the number of road fatalities within the European Union should move close to zero by 2050. In response to that, Sweden has set out to revise the national road safety targets of 2020 and 2030.

In order to address future safety challenges, there is a need to consider the characteristics of future crashes. The objective of this study was therefore to quantify and investigate the characteristics of severe crashes in 2020 and 2030. Injury crashes were reduced from a baseline in 2014 to a given time in the future based on the implementation of safety interventions. The material consisted of hospital admission data with AIS diagnoses.

Results show that the actions planned to be taken in Sweden between now and 2020 and 2030 will continue to increase the safety level for car occupants, but are estimated to be insufficient for vulnerable road users. It was concluded that there is a need to define a safety system for vulnerable road users that takes a holistic approach to sustainability by including both injury prevention measures and measures to encourage more health-promoting and fossil-free modes of transport.

Keywords Road safety, vulnerable road users, future crashes, vehicle safety, road safety management

I. INTRODUCTION

It has been proposed by the European Commission (EC) that the number of road fatalities within the European Union (EU) should move close to zero by 2050 [1]. Furthermore, the United Nations (UN) has set up a number of global goals for sustainable development, several of which, for the first time, relate to road safety. Goal number 11 explicitly states that: "By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons" [2].

In response to that realisation of the Vision Zero, Sweden has set out to revise the national road safety targets for 2020, to provide a proposal regarding targets for 2030 and to make a vision statement with regard to 2050. The current national road safety target for Sweden is to halve the number of fatalities and reduce the number of seriously injured by 25% from 2007 to 2020 [3], which corresponds to a maximum of 220 fatalities and 4,000 seriously injured by 2020. Targets have also been set on a number of safety performance indicators in order to facilitate the link between safety countermeasures and final outcomes [4-5]. No interim targets have been set for the period beyond 2020. However, the planning process for actions to be taken in the period 2020–2030 must take into account that road safety development in Sweden should align with the sustainable development goals on a European and global level.

The transport system is evolving as safety improvements in road infrastructure, vehicle fleet and speed management changes the characteristics of the road transport system. As a result of these changes, the crash characteristics are changing, too. As an example, the proportion of fatal head-on crashes in Sweden was reduced from 44% in 2000 to 27% in 2013. This decrease was mostly due to the implementation of median barriers and the introduction of Electronic Stability Control (ESC) [6]. Urbanisation and the shift to more sustainable and health-promoting transport modes, like bicycles, also poses future changes in the road transport system. As an example, the Swedish government have ambitions to increase the level of bicycling and is investing in the bicycle infrastructure to achieve this [7].

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As the road transport system continues to evolve, it is reasonable to assume that the crashes of the future will differ markedly from the crashes of today and the past. This fact can make retrospective analysis of crash data invalid when trying to predict the future impact of new or existing safety measures. Naturally, accident data will always be retrospective in nature, but the validity of the crash data needs to be controlled by taking into account the evolution of the transport system when estimating benefits of future technologies [8].

It is also clear that, depending on data source and injury rating method, problem scenarios will differ. While fatalities are dominated by vehicle occupants in rural areas, hospital-reported injuries with long-term consequences are dominated by vulnerable road users (VRUs) in urban areas [9]. As road safety measures historically have primarily addressed fatalities, this study has focused on injuries with long-term consequences, i.e. medical impairment.

In order to facilitate the short- and long-term prioritisations of road safety measures, the objective of this study was to quantify and investigate the characteristics of crashes and injuries leading to medical impairment in the 2020 and 2030 perspective. Also, the objective was to investigate the usability of a prediction method that takes into account not only retrospective crash data but also implemented and planned safety measures.

II. METHOD

The Swedish Transport Accident Data Acquisition (STRADA) is managed by the Swedish Transport Agency and includes police records that can be merged with hospital data. In Sweden, crashes on public roads resulting in at least one injured person are recorded by the police and included in STRADA, together with trauma hospital admissions. This study used hospital admissions data with AIS-coded injuries, which were matched with police reports containing road characteristics and vehicle information. Reports not containing sufficient information were excluded. All other injury crashes reported in STRADA in 2014, a set of 30,246 injured individuals in total, were included in the analysis (Table I). Out of these, 18,605 originated from road traffic crashes and 11,641 were pedestrians falling in the road transport system without the involvement of a vehicle.

TABLE I
ROAD TRAFFIC CASUALTIES IN 2014 BY ROAD USER CATEGORY

Road user	MAIS2+	MAIS3+	Total (MAIS1+)
Passenger cars	673	179	3,996
Pedestrians-motor vehicles	321	95	762
Pedestrians falling[1]	5,477	426	11,641
Bicyclists	4,148	397	10,736
Powered two-wheelers	718	147	1,913
Heavy Goods Vehicles	36	14	223
Buses	111	22	437
Others	194	53	538
Sum	6,201	907	18,605
Sum incl. pedestrians falling	11,678	1,333	30,246

[1]Injured pedestrians falling in the road transport system without the involvement of a vehicle.

In Sweden, a serious injury is defined as an injury leading to a permanent medical impairment of 1% or more. Injury severity was therefore derived from AIS to risk for permanent medical impairment (RPMI) to reflect long-term consequences. RPMI has been developed to estimate the risk for a patient of suffering from a medical impairment on a specific level, based on the location and severity of the injury. The criteria of determining the extent of the medical impairment are related to the loss of function, pain and/or mental dysfunction [10]. Risk matrixes for deriving a minimum of 1% risk for permanent medical impairment (RPMI1%+) and 10% risk (RPMI10%+) are included in Appendix A.

The individual RPMI, based on several injuries could be calculated as:

$$RPMI = 1 - \prod_{i=1}^{n}(1 - risk_i), \tag{1}$$

Where *i* is the number of injuries.

The artificial number of permanent medical impaired individuals (PMI1%+ and PMI10%+) in a population is the sum of RPMI [11]. The distribution of injured individuals in Table I could therefore be expressed as impaired individuals on the 1% and 10% level, as in Table II.

TABLE II

ESTIMATED NUMBER OF PERMANENT MEDICAL IMPAIRMENTS IN 2014 BY ROAD USER CATEGORY

Road user	PMI1%+	PMI10%+
Passenger cars	1 664	273
Pedestrians	283, 2,645[1]	55, 248[1]
Bicyclists	2 145	257
Powered two-wheelers	608	86
Heave Goods Vehicles	54	12
Busses	71	10
Others	114	21
Sum	4,937, 7,582[1]	714, 962[1]

In this study, injury crashes were reduced from a baseline in 2014 to projected figures for 2020 and 2030 based on the future implementation of safety interventions, such as road improvements and vehicle safety systems. The safety interventions were attributed individual target populations, risk-reducing factors and penetration level in time. In addition, traffic volume increase was taken into account. This method has been previously used to address fatalities [8], but in a case-by-case analysis. In this study, a statistical approach to calculating the reduced RPMI was taken.

The first step in the analytical approach was to take the effect of traffic volume increase into account by multiplying the $RPMI_{2014}$ by the changed probability for a crash in the future. The relationship between crash frequency and traffic volume was based on established relationship from literature (Appendix C). A yearly increase of motor vehicle traffic of 1% was assumed in the baseline scenario, in line with other traffic volume prognosis by the Swedish Transport Administration [12].

The next step was to make assumptions regarding the implementation of road safety interventions that would influence the safety level of the road transport system to 2020 and 2030. All interventions included in the analysis are shown in Table III. The probability for a specific vehicle safety system to be implemented in a specific year is shown in Appendix E. Regarding technologies already existing on the Swedish market, the implementation rate was acquired through the take-up rate on new vehicles. Other assumptions on implementation rates were based on future legislation already decided by the EC. Regarding non-existing or non-regulated vehicle safety systems, conservative assumptions were made in consultation with industry experts and based on road maps of new car assessment programs (NCAP). In order to investigate the sensitivity of the results based on the assumptions of implementation levels, best-case and worst-case scenarios were developed. The best case was scenario defined by a five-year earlier implementation of not-yet-implemented systems compared to the baseline scenario, with effect estimates increased by 50%. The worst-case scenario was defined as a five-year later implementation than the baseline scenario, with the effect estimates reduced by 50%.

Information on the infrastructural development in Table III was obtained from the infrastructural plan of the Swedish Government for the period 2018–2029 [13], together with consultation with experts at the Swedish Transport Administration.

The third step was to define target population and risk-reducing factors (RR) for each of the interventions, as shown in Table III. Established relationships from the literature were used as far as possible. Both target groups and effect estimations were gathered from literature or from descriptions on system functionality given by manufacturers. If multiple interventions were applicable in the same crash they were treated as independent events, If not stated otherwise in literature. For example, risk reducing factors from pedestrian protection have been found to vary with speed limit. Regarding interventions with a not-yet-proven risk-reducing effect, assumptions were made based on the system functionality which could be explained as when, how and where a vehicle safety system is active and functional. Typically, system functionality was defined by taken into account type of crash scenario, sensor range and other factors defining the limits of the system performance. For further explanation and references regarding the effectiveness of interventions, see Appendix D.

TABLE III
TARGET POPULATION AND RISK-REDUCING FACTORS

Intervention	Target population	RR
Heavy Goods Vehicles		
Seat Belt Reminder	Unbelted occupants	0.368-0.48
Autonomous Emergency Braking - high speed	Rear-end crashes involving HGV, dry and wet roads	0.5
Electronic Stability Control	Loss of control crashes on roads without median barriers	1
Lane Keeping Assist	Lane departure crashes on roads without median barriers	1
Passenger cars		
Seat Belt Reminder	Unbelted occupants	0.368-0.48
Electronic Stability Control	Road state ice and snow	0.3
Electronic Stability Control	Road state dry and wet	0.06
Crashworthiness	All passenger car occupants	0.01/year to 2020
Lane Keeping Assist	Head-on and single vehicle crashes, road state dry and wet, speed limit ≥70 km/h	0.5
Autonomous Emergency Steering	Rear-end and VRU crashes	0.5
Autonomous Emergency Braking		
- low speed	Rear-end crashes involving passenger cars, speed limit ≤50 km/h	0.2
- high speed incl. wild life	Rear-end and wild life crashes involving passenger cars, speed limit >50 km/h	0.25
- intersection	Intersection crashes involving motor vehicles	0.25
- reversing	Reversing crashes involving VRU	0.5
- VRU	VRU to passenger car crashes, speed limit <=50 km/h	0.5
Pedestrian protection (21 p)	Pedestrian to passenger car crashes, speed limit >50 km/h	0.005/point
Pedestrian protection (21 p)	Pedestrian to passenger car crashes, speed limit 30-50 km/h	0.02/point
Powered Two-wheelers		
Traction Control	Rear-wheel spin	1
Anti-lock Brake System	All motorcycle crashes	0.55-0.65
Infrastructure		
Median barriers	Head-on and single vehicle crashes, rural, speed limit ≥90 km/h, ≥2000 AADT	0.75
Milled Centre Rumble Strips	Head-on and single vehicle crashes, rural, speed limit 80 km/h, ≥2000 AADT, road width >7.5	0.15
Speed cameras	All passenger car occupants	-
Speed limit changes	All passenger car occupants	-
Speed management	Passenger car and VRU crashes, urban areas	0.5-0.8

The reduction in RPMI for an injured individual from 2014 to 2020 was based on the relevant intervention and risk-reducing factor in Table III and could be expressed as:

$$RPMI_{2020} = RPMI_{2014} \times \prod_{j} (1 - (P_j(I) \times RR_j)) \tag{2}$$

Where RPMI2014 = the risk for an individual to sustain a PMI based on an injury sustained in 2014.
P (I) = the probability for an intervention to be implemented in 2020
RR = the risk-reducing factor of the intervention given the circumstances of the crash and injury level.

As an example, a belted passenger car occupant in a car model year (MY) 2004 was involved in a single vehicle crash on a road covered with ice or snow. The occupant sustained injuries equivalent to a RPMI1% of 0.112. The RPMI1%+$_{2020}$ was calculated as:

$$RPMI_{2020} = RPMI_{2014} \times (1 - P(I) \times RR) \quad (3)$$

$$RPMI_{2020} = 0.112 \times 0.661 = 0.074$$

where P (I) = 1, since a car with MY 2004 would be MY 2010 in 2020 and consequently have ESC as standard 2020. RR = 0.661, based on the RR of ESC and crashworthiness, which are assumed to be independent variables.

The residual PMI, PMI$_{2020}$ and PMI$_{2030}$, were grouped by road user, crash type and injury severity in order to investigate the characteristics of future crashes.

III. Results

The estimated number of seriously (PMI1%+) and very seriously (PMI10%+) injured traffic participants in 2020 and 2030 are shown in Figs 1 and 2. The national target in Sweden is a maximum of 4,000 seriously injured in 2020, but the estimated number is 4,690 in 2020 and 4,160 in 2030. Hence, the implemented and/or planned road safety actions were not estimated to have enough impact to reach the target set for 2020 with regards to seriously injured. The total reduction of seriously injured from the starting year of 2007 was estimated at 14% instead of the targeted 25%. The estimated reduction of very seriously injured was similar to seriously injured, but on a lower level.

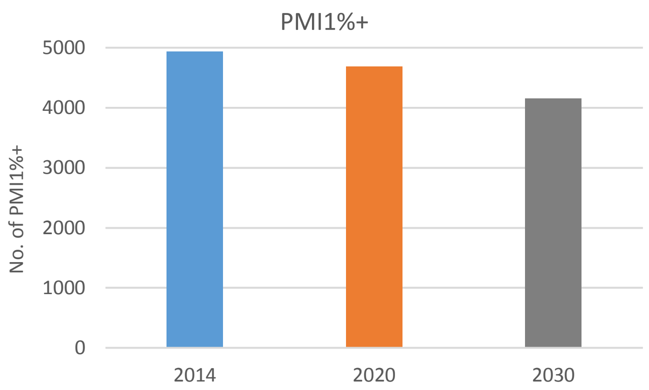

Fig. 1. Estimated number of seriously injured in 2020 and 2030.

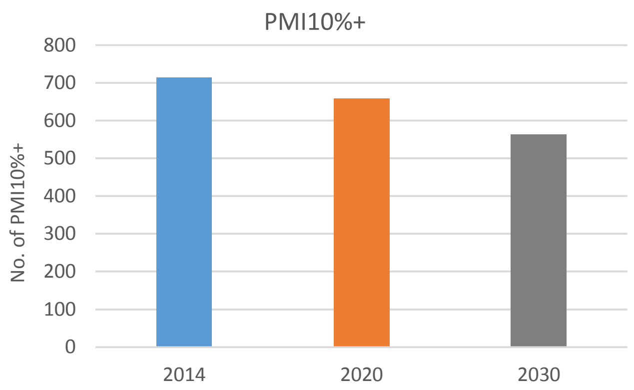

Fig. 2. Estimated number of very seriously injured in 2020 and 2030.

In Figs 3 and 4, the estimated numbers of seriously and very seriously injured in 2030 are grouped by road user category. Almost half of all long-term impairments from road traffic crashes are due to bicycle crashes, where single bicycle crashes account for 80%. In this category, the reduction to 2030 was estimated to be only 4%, while it is 28% for passenger car occupants. The distribution of very seriously injured was different because passenger car occupants were the most frequently injured in 2014 (Fig. 4). However, the estimated distribution in 2030 shows injured bicyclists as the most frequently injured due to the unequal reduction to 2030.

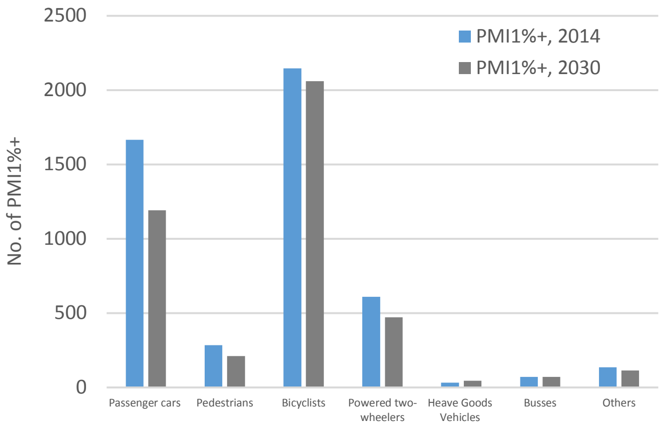

Fig. 3. Estimated number of seriously injured 2030 grouped by road user.

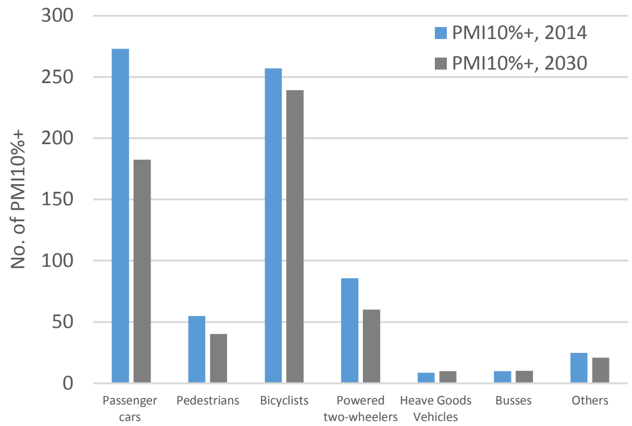

Fig. 4. Estimated number of very seriously injured 2030 grouped by road user.

The two most frequently injured road user categories, passenger car occupants and bicyclists, were further grouped by crash type (Figs 5 and 6). Regarding passenger car occupants, the most common crash type were single-vehicle and rear-end crashes, which were estimated to be reduced to 2030 by 27% and 36%, respectively. Severe bicycle injuries are totally dominated by single crashes (79%), which were not at all estimated to be reduced to 2030. The most severe crash type for bicyclists was being impacted by motor vehicles, which was estimated to be reduced by 37% to 2030.

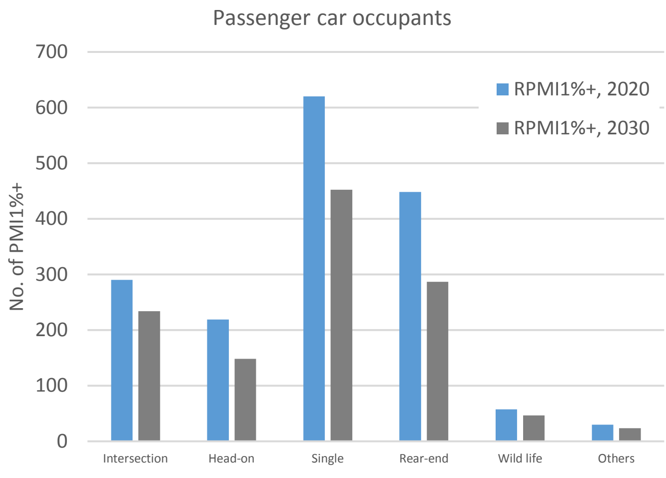

Fig. 5. Estimated number of seriously injured passenger car occupants 2030, grouped by road user.

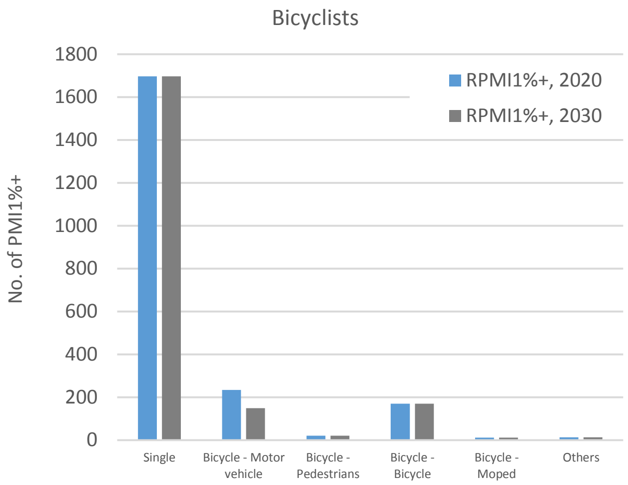

Fig. 6. Estimated number of very seriously injured bicyclists 2030, grouped by road user.

If pedestrians injured without the involvement of a vehicle were included, the estimated number of seriously injured would be distributed as in Fig. 7. It is clear that the number of long-term impairments are higher in this road user category than for all other road users. Since there were no assumed planned road safety interventions targeting this group, no reductions for this group were estimated.

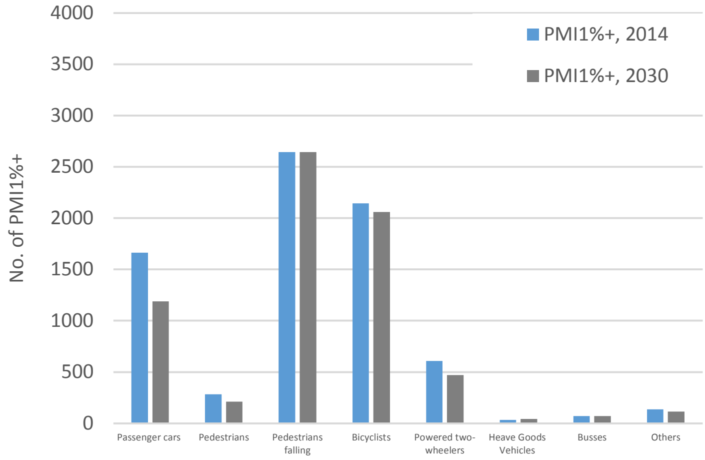

Fig. 7. Estimated number of seriously injured 2030 grouped by road user, including pedestrians falling without the involvement of a vehicle.

The sensitivity analysis showed in total a ±5–6% difference between the baseline estimates of seriously injured to 2030 compared to the best- and the worst-case scenarios (Fig. 8). The largest differences were found among passenger car occupants, at ±18%.

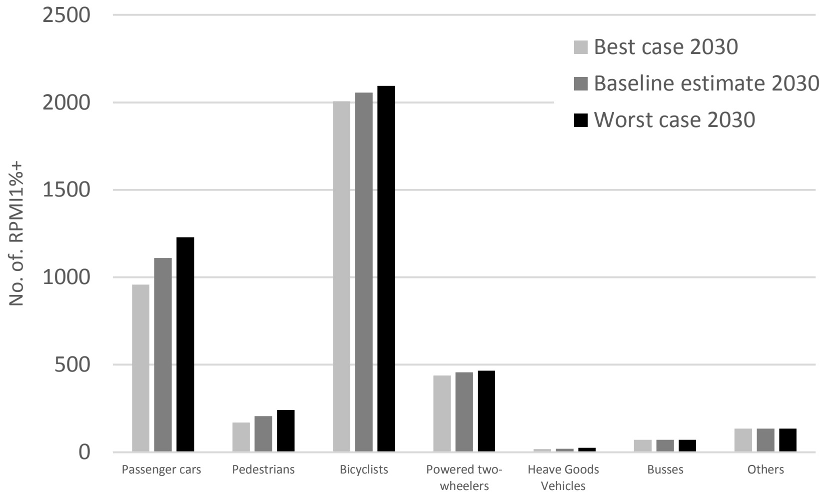

Fig. 8. Estimated number of seriously injured 2030, grouped by road user. Sensitivity analysis with best- and worst-case scenario.

IV. Discussion

The road safety problem will differ depending on how health loss is defined and what type of data sources are used. Historically, police data have been used to measure the development of road safety, which has resulted in interventions addressing passenger car crashes on rural roads [9]. The safety level for vehicle occupants has, as a result of that, increased tremendously. In Sweden, passenger car fatalities have been reduced by more than 50% since 2000, while seriously injured has reduced by one-third since 2006. The result of this study suggests that the positive trend for passenger car occupants will continue to 2020 and 2030, but perhaps not to the same extent. The nature of severe car crashes changes from being primarily constituted of head-on and single crashes in police data, to being constituted of single-vehicle and rear-end crashes when using hospital data (Fig. 5). However, the planned road investments, speed limit revisions and vehicle safety systems currently being implemented (mostly low-speed AEB) were estimated to have a future reduction of injuries from single and rear-end crashes. It should be noted, though, that the estimated reduction in RPMI1%+ from 2020 to 2030 amongst passenger car occupants was 21%. Hence, it will take additional effort to halve the number of severe car occupant injuries during this period.

When it comes to vulnerable road users and, more specifically, their injuries with long-term consequences, traditional road safety interventions have not been equally successful as vehicle occupant fatalities. Impairing injuries amongst VRUs originate mostly from single bicycle crashes in urban areas, which is an area not addressed by already-implemented or planned interventions. The result of this study shows that these injuries will become one of the major safety challenges in the 2030 perspective. Even though Fig. 6 shows an estimated 37% reduction of bicycle-to-motor vehicle crashes, the total bicycle injury reduction is only 4%. When promoting increased bicycling, this is something to take into account. It has been proven that increased physical activity is very beneficial for the individual's health [14]. Therefore, to redesign urban environments and shift some of the travelling to more environmentally friendly and health-promoting transport modes will be beneficial both for the environment and for public health. However, it is essential to not trade off benefits and losses against each other. The journey to a sustainable transport system in 2030 must have a holistic approach and must include injury prevention measures as well as measures to increase bicycling in order to include VRUs in the Vision Zero without losing mobility or freedom.

In addition to bicycle injuries, pedestrian falling in the road transport system without the involvement of a vehicle will be another major safety challenge. Due to a high number of elderly pedestrians, a considerable amount of such cases lead to death during the first 12 months after the fall [15]. Furthermore, the demographic is shifting against a more elderly population, which might increase the need for more effective injury prevention. Even though it is not considered as a road traffic crash today, it is clearly an issue to take into account when planning how to build and maintain sustainable and liveable cities.

Estimating the numbers and characteristics of future crashes is a serious task as a prediction interval does, in contrast to a confidence interval, account for the variability of a random variable yet to be observed. By bootstrapping or in any other way using the estimation uncertainty from a statistical model, a prediction interval can be constructed. In contrast, the method used in this study is not truly a statistical prediction of a future outcome. It is more a deterministic method to stepwise reduce a population of crashes by applying probability of implementation and risk-reducing factors. Accordingly, the prediction error in the future estimates is concentrated on the assumptions of the interventions. To tackle this issue, sensitivity analysis was performed (Fig. 8). The sensitivity was largest for the road user category addressed by the most interventions, which is logical. Even though the sensitivity analysis shows that the estimated number of passenger car crashes could differ by ±18%, there are no reasons to believe that this would influence the characteristics of the estimate in 2030 in a way that would affect the result significantly. However, the baseline year is one element that is subject to random variation. In order to minimise the influence of random variation, a representative baseline year should be chosen with regards to the distribution of crashes by road user. In Appendix B, Fig. 9 shows that 2014 could be considered as representative compared to previous years.

Another limitation is the fact that unexpected events affecting road safety could happen to 2030. Changes in infrastructural investments, new regulations, new types of vehicles, economic fluctuation etc. are all things that are hard to predict. This study assumes a business-as-usual scenario, whereby all things except the interventions and traffic volume are excluded from the model. Therefore, when unexpected things occur, the model could be adjusted according to new knowledge as it arises. The introduction of automation and autonomous driving is also worth mentioning since for example the European Road Transport Research Advisory Council (ERTRAC) predict a substantial introduction of automated vehicles to 2030 [29]. However, the advanced driver assistance systems considered in the ERTRAC road map for automated driving are the same as those considered in this paper. Hence, the additional effect of automation compared to what is included in the calculations in this study with foremost address normal driving and not safety critical events.

A factor not included in the estimations of future injuries was the possibility of improved health care and emergency services which could decrease the risk for impairment given an injury. However, these improvements are likely to affect all injuries for all road user groups and will thereby probably not skew the results of this study.

Some of the crashes from the initial dataset from STRADA had to be excluded due to insufficient information in the crash data which could potentially lead to a biased result. However, the analysed material showed no indication to differ in any substantial way with national statistics.

For the first time the transport system is on the agenda of the UN, concerning a sustainable development plan [2] that was adopted in September 2015. The global goals replaces Millennium Development Goals and should be fulfilled in year 2030. Under the concept of sustainability, it includes a number of fundamental measures and rights that citizens should expect of the transport system and its effects.

Among those rights are listed clean air, noise-free and healthy mobility, which are affordable goals that can be achieved for all, including children, elderly and disabled people. The UN sustainable goal formulations do not, for instance, separate fossil-free, road safety and available, but all should be fulfilled and be on the same level and are absolute concepts.

It is clear that we are heading in the direction of a comprehensive approach, where different health-related areas linked to transport are no longer considered in isolation but rather as part of a wider social, technological and ethical development of society, in which traffic safety is a valuable subset. To improve road safety and, ultimately, achieve a safe transport system that is almost free from fatality and severe injury will require a linked approach in which road safety is one dimension. This means we must look at the whole transport system, and its development, in order to prioritise future actions.

V. Conclusions

This study has found that the actions planned to be taken in Sweden until 2030 will continue to increase the safety level for car occupants, but are insufficient for reducing injuries sustained by vulnerable road users. Single bicycle crashes, pedestrians falling without the involvement of a vehicle and rear-end and single-vehicle crashes were identified as major road safety challenges into the future. However, while interventions addressing the challenges connected to car occupants are already being implemented, interventions addressing VRUs are absent. Innovation thinking and problem-solving are needed to find new solutions, and action needs to be taken to step up the implementation of solutions with proven safety benefits.

This study shows that there is a need to identity a safe transport system for vulnerable road users, one that takes a holistic approach to sustainability by including both injury prevention measures and measures to encourage and prioritise health-promoting and fossil-free transport modes.

VI. Acknowledgement

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VIII. APPENDIX A-E

APPENDIX A

TABLE IV

RISK OF 1% OR MORE PERMANENT MEDICAL IMPAIRMENT

Body region	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	17.6%	50%	60%	60%	100%
Thorax	2.6%	4.0%	4%	30%	20%
Thoracic spine	4.9%	45%	90%	100%	100%
Abdomen	0%	2.4%	10%	20%	20%
Lumbar spine	5.7%	55%	70%	100%	100%
External (skin)	1.7%	20%	50%	50%	100%

TABLE V

RISK OF 10% OR MORE PERMANENT MEDICAL IMPAIRMENT

Body region	AIS1	AIS2	AIS3	AIS4	AIS5
Head	2,5%	8%	35%	75%	100%
Cervical spine	2,5%	10%	30%	100%	100%
Face	0,4%	6%	60%	60%	n.a.
Upper extremity	0,3%	3%	15%	100%	n.a.
Lower extremity	0,0%	3%	10%	40%	100%
Thorax	0,0%	0%	0%	15%	15%
Thoracic spine	0,0%	7%	20%	100%	100%
Abdomen	0,0%	0%	5%	5%	5%
Lumbar spine	0,1%	6%	6%	100%	100%
External (skin)	0%	0%	50%	50%	100%

APPENDIX B

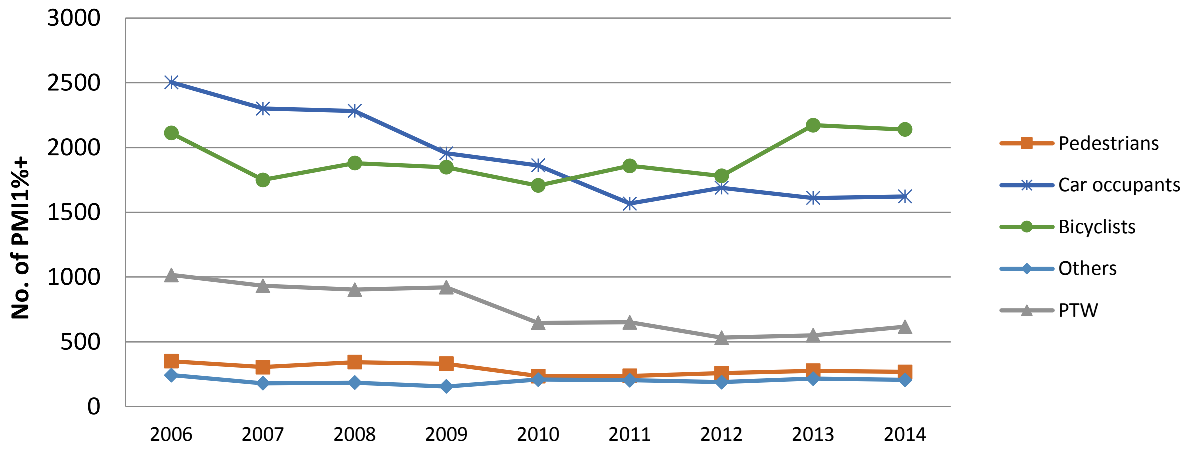

Fig. 9. Seriously injured grouped by road user 2006-2014.

APPENDIX C

A change in traffic volume affects the number of injury crashes, resulting in a change in accumulated RPMI. By scaling the RPMI of each crash injury with a growth factor, the impact of additional injury crashes due to a change in traffic volume is taken into account. As an example, an injury crash with a growth factor of 1 is interpreted as a crash indifferent to traffic volume change, while a growth factor equal to the change in traffic volume indicates that the crash risk is proportional to the traffic volume increase.

Growth factors have been empirically derived for each road user category based on the road environment [16]. The road users are segmented as motorised vehicles (MW) (passenger cars, powered two-wheelers and heavy goods vehicles), bicyclists/mopeds and pedestrians (BC). The road environments of interest are straight roads and intersections. For injury crashes at intersections involving motorised accident, information regarding road authority and the type of intersection are required in order to insert the correct constants listed in Table VII and Table VIII. Growth factors are listed below where $G = Growth\ factor$ and $Q = Traffic\ Volume\ Growth$. Different G were applied depending on crash type were MW,MW = motor vehicle to motor vehicle crash, MW,single = single motor vehicle crash, MW,BC = motor vehicle to BC crash and BC,Single = single vehicle crash with bicyclists or mopeds. As can be observed in the equations below, the risk of MW,MW crashes as well as MW single crashes and BC single crashes is proportional to the Traffic Volume Growth.

Growth factors on straight roads:

$$G_{MW,MW} = Q_{PW}$$

$$G_{MW,Single} = Q_{PW}$$

$$G_{MW,BC} = Q_{BC}^{0.334} * Q_{MW}^{0.389}$$

$$G_{BC,single} = Q_{BC}$$

Growth factors on intersections:

$$G_{MW,MW} = Q_{MW}^{a+b}$$

$$G_{MW,single} = Q_{MW}^{a+b}$$

$$G_{MW,BC} = Q_{MW}^{0.52} * Q_{BC}^{0.65}$$

$$G_{BC,Single} = Q_{BC}$$

Where the coefficient of a, b are found in Table VI and VII below:

TABLE VI
M MOTOR VEHICLE-TO-MOTOR VEHICLE AND SINGLE-VEHICLE CRASHES, URBAN AREAS

	a		b	
Speed limit	-50	60-	-50	60-
Intersection	1,45	1,25	0,6	0,55
Roundabout	1,2	1,2	0	0
Interchange	1,45	1,25	0,5	0,45

TABLE VII
MOTOR VEHICLE-TO-MOTOR VEHICLE AND SINGLE-VEHICLE CRASHES, STATE ROADS

	a	b
Intersection	1,25	0,55
Roundabout	1,2	0
Interchange	1,25	0,45

APPENDIX D

Risk-reducing factors for all intervention included in the analysis are listen in Table VIII below. For the majority of interventions, the effectiveness has been validated in real-life studies, which are referred to in the right-hand column. For other interventions, assumptions have been made based on the performance of similar systems or system design. The basic principle was that with a system design addressing a very specific target group, the effectiveness is very close to 100% with an RR = 1, as suggested by [17]. A risk-reducing factor of 1 was assumed for Electronic Stability Control and Lane Keeping Assist on heavy goods vehicles, as well as Traction Control on motorcycles. Targets groups for those systems are listed in Table III. All versions of Autonomous Emergency Braking were assumed to have the same effect as AEB low speed, which have been evaluated in real-life crashes. It should be noted, though, that RR in AEB low speed and intersection was reduced by 50% on crash level as the risk reduction is relevant only for the struck vehicle in a rear-end crash. AEB high speed for wild-life crashes was assumed to have a lower effectiveness in order to have a conservative approach.

As mentioned in the Methods section, sensitivity analysis was performed with a best-case scenario where RR for all vehicle safety systems was increased by 50% and a worst-case scenario where RR was reduced by 50%.

For speed cameras and speed limit changes, general effects on all passenger car occupants were applied as it was problematic to apply average travelling speed changes to specific crashes.

TABLE VIII
TARGET POPULATION AND RISK REDUCING FACTORS

Intervention	**RR, RPMI1%**	**RR, RPMI10%**	**Reference**
Heavy Goods Vehicles			
Seat Belt Reminders	0.368	0.48	[18]
Autonomous Emergency Braking			-
- high speed	0.5	0.5	
Electronic Stability Control	1	1	-
Lane Keeping Assist	1	1	-
Passenger cars			
Seat Belt Reminders	0.368	0.48	[18]
Electronic Stability Control	0.3	0.3	[19]
Electronic Stability Control	0.06	0.06	[19]
Crashworthiness	0.99 per year to 2020	0.9875 per year to 2020	[20]
Lane Keeping Assist	0.5	0.5	[21]
Autonomous Emergency Steering	0.5	0.5	-
Autonomous Emergency Braking			[22]
- low speed	0.2	0.2	
- high speed incl. wild life	0.25	0.25	-
- intersection	0.25	0.25	-
- reversing	0.5	0.5	-
- VRU	0.5	0.5	-
Pedestrian protection (21 p)	0.005 per point	0.043 per point	[23]
Pedestrian protection (21 p)	0.02 per point	0.04 per point	[23]
Powered Two-wheelers			
Traction Control	1	1	-
Anti-lock Brake System	0.55	0.65	[24]
Infrastructure			
Median barriers	0.75	0.75	[25]
Milled Centre Rumble Strips	0.15	0.15	[26]
Speed cameras	-	-	[27]
Speed limit changes	-	-	[27]
Speed management	0.5	0.8	[28]

APPENDIX E

	Heavy Goods Vehicles				Passenger Cars										PTW	
	ESC	SBR	AEB	LKA	ESC	SBR	LKA	AES	AEB low speed	AEB high speed	AEB crossing	AEB rear	AEB VRU	pedestrain protection	ABS	TC
1999	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2000	0%	0%	0%	0%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%
2001	0%	0%	0%	0%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%
2002	0%	0%	0%	0%	12%	15%	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%
2003	0%	0%	0%	0%	15%	36%	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%
2004	0%	0%	0%	0%	69%	58%	0%	0%	0%	0%	0%	0%	0%	10%	10%	0%
2005	0%	0%	0%	0%	85%	80%	0%	0%	0%	0%	0%	0%	0%	13%	15%	3%
2006	0%	0%	0%	0%	91%	78%	2%	0%	0%	0%	0%	0%	0%	15%	15%	5%
2007	0%	0%	0%	0%	96%	79%	3%	0%	1%	0%	0%	0%	0%	19%	15%	10%
2008	0%	0%	0%	0%	98%	84%	4%	0%	2%	0%	0%	0%	0%	25%	15%	15%
2009	0%	0%	0%	0%	99%	96%	5%	0%	5%	0%	0%	0%	2%	30%	30%	20%
2010	0%	5%	5%	0%	99%	95%	6%	0%	7%	0%	0%	0%	4%	40%	60%	25%
2011	0%	10%	10%	0%	99%	94%	7%	0%	10%	0%	0%	0%	6%	75%	62%	30%
2012	20%	20%	20%	0%	99%	98%	8%	0%	20%	0%	0%	0%	8%	85%	70%	35%
2013	50%	30%	35%	5%	99%	99%	9%	0%	30%	0%	0%	0%	10%	91%	78%	40%
2014	75%	40%	50%	10%	100%	99%	10%	0%	40%	0%	0%	0%	15%	95%	84%	45%
2015	100%	50%	75%	20%	100%	100%	12%	0%	50%	0%	0%	0%	20%	100%	90%	50%
2016	100%	60%	100%	100%	100%	100%	14%	0%	60%	3%	0%	0%	25%	100%	90%	55%
2017	100%	70%	100%	100%	100%	100%	16%	0%	70%	5%	0%	0%	30%	100%	100%	60%
2018	100%	80%	100%	100%	100%	100%	18%	0%	80%	7%	0%	0%	35%	100%	100%	65%
2019	100%	90%	100%	100%	100%	100%	20%	0%	90%	10%	0%	0%	40%	100%	100%	70%
2020	100%	100%	100%	100%	100%	100%	24%	5%	100%	10%	5%	5%	45%	100%	100%	75%
2021	100%	100%	100%	100%	100%	100%	28%	10%	100%	10%	10%	10%	50%	100%	100%	80%
2022	100%	100%	100%	100%	100%	100%	32%	20%	100%	20%	20%	20%	55%	100%	100%	85%
2023	100%	100%	100%	100%	100%	100%	36%	30%	100%	30%	30%	30%	60%	100%	100%	90%
2024	100%	100%	100%	100%	100%	100%	40%	40%	100%	40%	40%	40%	65%	100%	100%	95%
2025	100%	100%	100%	100%	100%	100%	50%	50%	100%	50%	50%	50%	70%	100%	100%	100%
2026	100%	100%	100%	100%	100%	100%	60%	60%	100%	60%	60%	60%	75%	100%	100%	100%
2027	100%	100%	100%	100%	100%	100%	70%	70%	100%	70%	70%	70%	80%	100%	100%	100%
2028	100%	100%	100%	100%	100%	100%	80%	80%	100%	80%	80%	80%	85%	100%	100%	100%
2029	100%	100%	100%	100%	100%	100%	90%	90%	100%	90%	90%	90%	90%	100%	100%	100%
2030	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%