Estimated Lives Saved by Recently Implemented Vehicle Safety Standards in India: Implications and Future Safety Needs

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Estimated Lives Saved by Recently Implemented Vehicle Safety Standards in India: Implications and Future Safety Needs

Pradeep Puthan Pisharam, Nils Lubbe, Johan Davidsson

Abstract India recently mandated several vehicle safety standards. The objective of this study was to estimate the share of lives saved in different types of road users that will be saved by these standards when they take full effect and to identify and analyse India's future road traffic fatalities. We followed the residual crash analysis approach. Explicit deterministic rules were created for each standard, providing two estimates (one conservative, one optimistic) about which types of crashes would no longer lead to fatalities. The rules were applied to the historical in-depth crash database Road Accident Sampling System India (RASSI). While the recently introduced safety standards will undoubtedly save lives in India, we estimated that they are not sufficient to ensure the 50% reduction in road traffic fatalities that India has committed to by 2030. Our estimates of future crashes call for increased attention to fatal crashes involving PTW riders and pedestrians, either through safety standards or other means.

Keywords: Accidents, assessment, benefit prediction, safe system, vision zero.

I. INTRODUCTION

Despite global efforts such as the Brasilia and Stockholm declarations [1–2] and the United Nations Sustainable Development Goal (SDG) 3.6 aimed at halving road fatalities [3], many countries' progress has been discouraging. Over the last decade, India's road crashes have continued to show an increasing trend, although it has flattened in the last three years. India lost 150,000 lives in 450,000 road crashes in 2019, accounting for 11% of world road fatalities [4]. Further, estimations from the World Health Organization (WHO) and Global Burden of Diseases indicate that India's road crashes are likely underreported by at least 45% [5–6]. The economic burden of road crashes on Indian society amounts to nearly 3% of the GDP [7]. India's population, vehicle registrations, and total road length are increasing; unless drastic steps are taken, fatalities will continue to rise. Having committed to the Stockholm declaration, India now has a target of halving the road traffic fatalities by 2030.

Several high-income countries have demonstrated that the number of road crashes can be reduced using various countermeasures through road safety policies. The safe system approach is a proven framework that incorporates safer vehicles, safer roads, and safer speeds. Safer vehicles that prevent the crash or absorb its energy, thus offering protection for occupants (self-protection), are an essential part of this approach [8]. A safer vehicle design should also protect other road users outside the cars (like pedestrians or cyclists) when there is a critical situation (partner-protection). Along with safer vehicles, roads that are safer for all road users are the second aspect of the safe system approach [8]. Finally, safer speeds, the third aspect, are the speeds which do not exceed biomechanical thresholds for injury causation, given the state of safe vehicles and roads [8–9].

Several policies aiming to facilitate a faster adoption of safer vehicles in India are in place, implemented either through safety standards amended in 2019 or new ones. Table I lists the recently introduced vehicle safety standards and applicable vehicle classes. The vehicle classes are defined as follows: M (motor vehicle with at least four wheels used for carrying passengers), M1 (vehicle used for carrying passengers, comprising not more than eight seats in addition to the driver's seat), N (vehicle with at least four wheels used for carrying goods), L1

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(Moped) ,and L3 (Motorcycle) [10].

The WHO has recommended that frontal crash, side crash, and Antilock Braking System (ABS) for Powered Two-Wheelers (PTW) be part of the minimum vehicle standards [11]. Electronic stability control (ESC) is a technology that is recommended by the WHO, as ESC has been proven effective in preventing loss-of-control crashes. Although it is included in safety regulations in many countries [12–14], it is yet to be mandated in India.

TABLE I
IMPLEMENTED VEHICLE SAFETY STANDARDS IN INDIA IN 2019

Standard	Applicable vehicle class
Offset frontal crash	M1
Side crash (Moving deformable barrier)	M1
Pedestrian protection	M1
Seat belt reminder	M1 Driver and front passenger
Overspeed alert	M1
Reverse parking alert	M and N (Except tractors)
ABS or Combined Braking System (CBS) for Powered Two-wheelers (PTW)	L1 and L3

The real-world effectiveness of newly implemented standards cannot be immediately measured; it takes several years to affect a substantial part of the country's vehicle fleet. Analysing crashes after 100% of the vehicle fleet meets the safety standards would be too late to guide future policies, especially in countries where motorisation is rapidly increasing and the influence of other factors such as improved infrastructure would confound the analyses.

Several studies worldwide have investigated the effectiveness of road safety countermeasures based on vehicle safety standards and technologies. Reference [15] proposed a method of residual crash analysis to estimate the probable future effect of countermeasures like vehicle safety technologies, infrastructure improvements, and crashworthiness on future crashes in Sweden [15]. The method was subsequently validated [16] and applied to predict future crash scenarios in Europe and the USA [17–18]. A study on the effectiveness of basic United Nations Regulations No. 14, 16 (seat belts and anchorages), 94 (occupant protection in frontal crash) and 95 (occupant protection in side or lateral crash) estimated that the regulations saved about 40,000 lives in Latin America [19]. For India, a case study estimated the effectiveness of prevailing road safety countermeasures and found that it might be possible to achieve SDG target 3.6, but only with great additional efforts in many areas and improved compliance with regulations [20]. Although the study used data from four scenarios in six cities to predict future road safety scenarios, generalising to the national level in a country as large and diverse as India remains difficult. Reference [18] estimated the potential number of lives saved on Indian roads through the use of various commercially available pre-crash and in-crash safety technologies [18]. However, the study targeted only technologies for M1 vehicles and did not consider the likelihood of their implementation or regulation in India.

Even though some of the standards implemented in India have proven to save lives in other parts of the world for decades, their effect in India may differ, as there are differences in driving behaviour, infrastructure, and types of vehicles sharing the roads. To the authors' knowledge, no publicly available document explains the efficacy of, or the rationale for, prioritising recently implemented safety standards in India, separately or in combination. It is essential to quantify the expected lives saved to determine whether the standards are sufficient to meet the road safety goal of halving fatalities by 2030. It is also important to understand the characteristics of the crashes that will remain after the standards are implemented, to put further strategies in place to reduce road traffic fatalities from those crashes. A deep understanding of future road crashes is required for planning and prioritising the next set of policies targeting crash reductions. Therefore, this study first aims to estimate the share of lives saved in different types of road users that will be saved by the recently implemented Indian vehicle safety standards when they take full effect and compare it to the national target. Second, the study aims to identify, analyse, and describe India's future road traffic fatalities to facilitate setting informed priorities for future road safety strategies and policies.

II. METHODS

This study consists of two main steps: first, we prepared the data for analysis; second, we identified and modelled the recently implemented vehicle safety standards.

Data

We used the Indian in-depth accident database Road Accident Sampling System India (RASSI) to estimate the vehicle safety standards' effectiveness. RASSI is an in-depth crash database like NASS CDS or German In Depth Accident Study (GIDAS), but with parameters to reflect configurations and conditions (e.g., contributing factors, body types, and road types) specific to India. RASSI has the following inclusion criteria [21]

- The crash must take place on a public road within one of the sampling locations (Coimbatore, Pune, Ahmedabad, Kolkata, and Jaipur), and it must involve at least one motorized vehicle.
- The crash spot must be recognizable by final vehicle resting positions (photographs, etc.), vehicle trajectories (skid or brake marks, etc.), or any other evidence (damaged fixed objects, debris, eyewitness, etc.).
- Road, skid marks and other marks must be possible to measure.
- Vehicles must be available for inspection, to enable data collection such as direct damage details, crush profile, intrusions, contacts, and safety system use.
- Make and model of each vehicle involved in the crash must be known.

The database contains crash-related information about the vehicle, the person, and the injury levels. We examined 1,692 fatal crashes from the available 3,721 crashes occurring from 2014 to 2019. We used the weighting factors provided in the database to make data representative of the whole country and to compensate for the underreporting of national data [22].

Modelling of Safety Standards

We modelled two explicit deterministic rules for each standard, one conservative and one optimistic, to quantify the reduction in fatalities: see Table II. The rules were based on the crash conditions described in the standards and an analysis of the relationship between impact speed and injury risk of crashes in Germany after the standards took effect.

Here is an example of how we modelled the deterministic rules, using the standard *ABS for PTWs*. ABS for PTWs prevents skidding by regulating the brake pressure on the wheels, preventing loss of control. For the conservative rule, we filtered for all crashes involving PTWs without ABS in which the PTW skidded longitudinally, one or both wheels locked up, and at least one rider was fatally injured. For the optimistic rule, we included more crashes: we considered the fatal crashes involving PTWs without ABS (or ABS status unknown) in which the PTW skidded longitudinally and/or laterally, irrespective of the wheel lock-up status. If a crash met the specified conditions, it was assumed that the ABS would mitigate or prevent the crash, and that the lives of the persons who died in the crash would be saved. Similar rule sets were modelled for all the safety standards illustrated in Table II. For simplicity, we assumed that CBS would be as effective as ABS, so we did not model it separately.

TABLE II
VEHICLE SAFETY STANDARDS AND CORRESPONDING CRASH PARAMETERS

Standard	Optimistic rule	Conservative rule
Offset frontal crash	M1 vehicle front impacting a collision partner with overlap > 20% + delta V < 75 km/h or unknown delta V	M1 vehicle front impacting a collision partner with overlap > 20% + delta V < 40 km/h
Side crash - Moving deformable barrier -	M1 vehicle side impacted by a collision partner with damage to passenger compartment + delta V < 55 km/h or unknown delta V	M1 vehicle side impacted by a collision partner with damage to passenger compartment + delta V < 25 km/h
Pedestrian protection	M1 vehicle front impacting a pedestrian with an impact speed < 65 km/h or	M1 front impacting a pedestrian with an impact speed < 25 km/h+

	unknown impact speed+ fatal injury to pedestrian (head or thorax injury due to contact with front of vehicle)	fatal injury to pedestrian (head or thorax injury due to contact with front of vehicle)
Seat belt reminder	M1 vehicle driver and front passenger unbelted or unknown belt usage + no catastrophic intrusion or unknown intrusion + fatal injury	M1 driver and front passenger unbelted + no catastrophic intrusion + fatal injury
Overspeed alert	M1 vehicle travel speed > 80 or unknown travel speed + overspeed a cause of crash	M1 vehicle travel speed > 120 + overspeed a cause of crash
Reverse parking alert	M and N (Excluding tractors) + Fatal injury to pedestrian (impacting rear or left and right rear corners of vehicle while backing up)	M and N (Excluding tractors) + Fatal injury to pedestrian (impacting rear of vehicle while backing up)
ABS for >125 cm^3/CBS for<125 cm^3 Powered Two-Wheelers	L1 or L3 user fatal + no ABS installation or unknown ABS installation + skidding laterally or longitudinally	L1 or L3 user fatal + no ABS installation + skidding longitudinally + wheel lock-up

The vehicle safety standards, aiming at serious and fatal injury prevention, specify the impact speeds for front (56 km/h) and side (50 km/h) crashes. However, in the real world, occupant protection evaluated for fatality prevention might cover a wide range of speeds, due to factors such as type of collision partner, impact speed, and vehicle overlap. To take speed variability into account, we generated risk curves from the GIDAS data for passenger cars (which met similar vehicle safety standards) involved in offset frontal crashes (for MAIS 3+ injury severity) and side crashes, and then we extracted Delta V to determine safe speeds for the rules. Similarly, for pedestrian protection, we extracted the threshold impact speed of M1 vehicles from the risk curves. Risk curves and their calculations are given in the Appendix. With respect to offset frontal crash, the level of occupant protection offered of a safety standard-compliant car today in India would be similar to that of a car that complied with the same standard in Germany approximately 20 years ago. Risk curves and their calculations are given and discussed in the Appendix.

The rules were applied to the in-depth crash data from RASSI. The remaining (non-prevented) fatalities are expected to describe the road traffic fatalities of India’s near future.

III. RESULTS

In this study we counterfactually simulated the recently implemented vehicle safety standards in India. With the optimistic estimates, overspeed alerts and offset frontal crash and seatbelt reminders will be the three safety standards most effective at reducing fatalities. With the conservative estimates, the seatbelt reminder will be the only notably effective safety standard (Fig. 1). The standards with the least effect on number of fatalities in India were the side-impact crash test and reverse parking alert. The large difference in optimistic and conservative estimates suggests the model uncertainty, which indicate that the simplified rules covers a range of conditions. However, both the optimistic and conservative estimate consistently indicate that the implemented standards are insufficient to meet the target of halving fatalities on Indian roads.

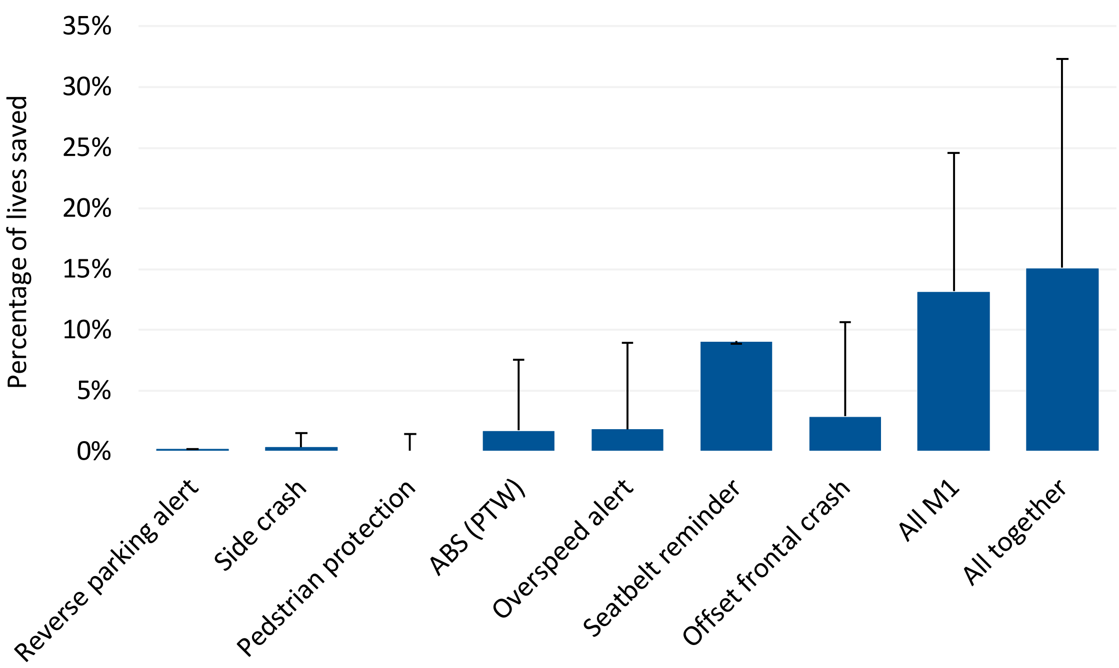


Fig. 1. Percentage of lives saved by recently implemented vehicle safety regulations in India (bars indicate conservative estimates and error bars indicate optimistic estimates).

Figure 2 Illustrates the share of lives saved in different types of road users that will be saved by these standards when they take full effect. Among all crash participants, M1 vehicle occupants had the highest reduction in fatalities (Figure 2). However, the proportion of PTW-user fatalities, already the highest of all participants, will increase further. Hardly any changes were observed for buses, trucks, bicycles, and motorised three-wheelers.

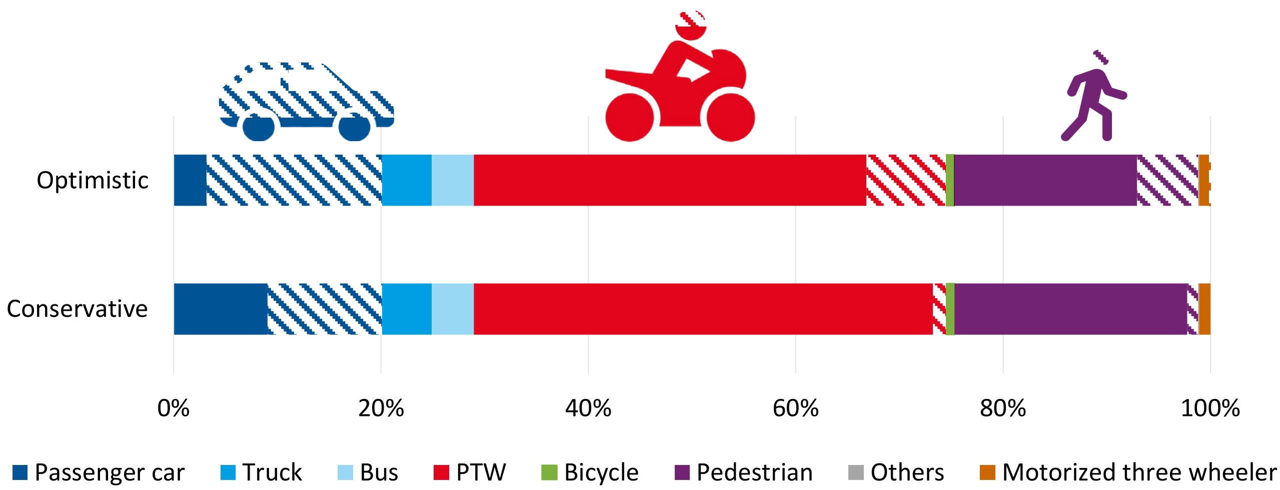
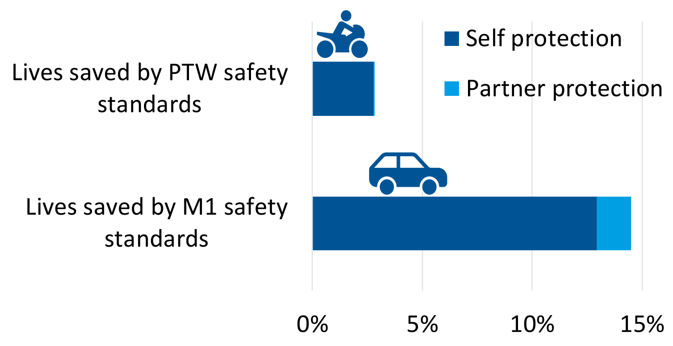


Fig. 2. For all fatal crashes, percentages indicate different road users (by colour). Hatching indicates the proportion of lives saved and solid colour indicates the proportion of remaining fatalities.

Protecting collision partners is one important pillar in the safe system approach. Notably, our results show that the recently implemented safety standards offer much more self-protection than partner protection (Figure 3a).



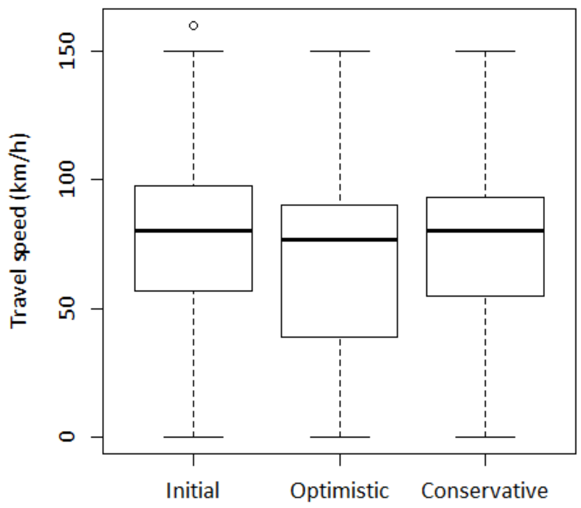


Fig. 3. (a) Potential self-protection and partner-protection of M1 and PTW category safety standards. (b) Travel speed distribution.

Looking at the travel speeds, extremely high-speed crashes were averted with optimistic rule sets. However, the reductions in the mean travel speeds were not substantial in either the optimistic or conservative estimate (Fig 3b). We did not see any substantial changes in crash locations, road types, or configurations of the fatal crashes attributable to the new vehicle safety standards.

IV. Discussion

We used the RASSI database to estimate the effectiveness of recently implemented safety standards in India. An overall estimated fatality reduction of 15 to 33% is far from reaching the target of halving fatalities. While progress in self-protection for M1 vehicle occupants is apparent, partner protection remains rudimentary. Travel speeds are not expected to substantially reduce, and given the expected future fatality outcomes, cannot be characterised as safe. Consequently, it does not appear that safety for pedestrians and motorcycle riders has improved substantially; these vulnerable road users are expected to account for the majority of future fatalities in India.

The frontal, side, and pedestrian crash standards, which are based on European standards, have been proven to be effective in reducing fatalities of vehicle occupants and pedestrians in many countries. Our findings were within the estimated effectiveness range (2.4 to 15%) for Latin American countries implementing basic The Economic Commission for Europe vehicle safety standards [19].

Frontal crash protection was estimated to contribute substantially more to saving lives than side crash protection. Frontal crashes are more common than side crashes, as seen in the US (approximately 50% frontal versus 20% side crashes) [23] and in our data (54% frontal versus 22% side crashes). Therefore, it seems logical for frontal crash protection to save more lives, but the number of estimated lives saved for side crashes seems low, considering the crash occurrence rates; this anomaly needs further investigation. Perhaps the standard can be made more effective, or the translation into simple rules needs further refinement.

Pedestrian protection, implemented for M1 vehicles, was shown to contribute to saving lives. However, many pedestrian fatalities remain. The overspeed alert is perhaps activated at too high a speed to protect pedestrians. Furthermore, the majority of pedestrian fatalities on Indian roads involve not M1, but other vehicles. Improved pedestrian protection for trucks and buses (such as underride prevention and softer front ends, already implemented in other parts of the world [24]) might contribute to further reducing pedestrian fatalities. Mandating pre-crash safety technologies like Autonomous Emergency Braking system as a safety standard can complement the existing safety standards and substantially reduce number of lives lost in road crashes in the near future in India.

Among the standards, reverse parking alert seemed to be the least effective system. We suspect, however, that its effectiveness was underestimated. One possible reason is that the RASSI database has as a selection criterion that the crash has to be in a public area, so the data do not include any crashes which may have occurred in private parking areas. A second reason is that the latest national data do not include specific categories for crashes within parking areas or reversing accidents in which a pedestrian was fatally injured. This lack of information, which prevents an accurate estimate of the benefit of the reverse parking alert safety standard illustrates the need for the collection and reporting of robust, detailed crash data at the national level.

Our estimated effectiveness of ABS for PTW were less than half what was reported by [20]. Our detailed analysis of PTW-involved crashes not prevented by ABS found that most of the riders either did not brake or did not apply sufficient brake pressure to lock up the wheel. Perhaps enforcing the proper usage of a good quality helmet can help reduce PTW-user fatalities. A deeper look into the crash partners' compatibility and causations would be the way forward to achieve a more significant fatality reduction.

Among the seven standards, six standards were applicable for M1 vehicles, one for N vehicles and one for PTW. As expected, the results indicate that the proportion of lives saved in M1 vehicles that comply the new standards is high compared to these proportions for PTWs or N vehicles that comply the new standards (Figure 2). This is unfortunate as PTW users accounts for nearly 37% of the fatalities in India and M1 vehicle users accounts for only 16% of the fatalities [4]. In high-income countries the situation is the opposite; the results from this study clearly indicate that India cannot simply adopt the regulations from other countries, rather priorities should be decided based on the evidences from regional data.

Speeding was the most common police reported contributing factor leading to the road crashes in India [4]. The overspeed alert system does not seem to provide reduced speeds (recall Figure 3b). However, it has to be noted that the speed limit warning is set for a constant speed. The speed limits designated at urban areas, where pedestrians and cyclists are more prone to interact with motorized vehicles, have speed limits lower than the warning threshold, which makes the system effectiveness only to high speed limit road sections. Intelligent speed adaptation would be an alternate solution where the system detects the location and informs the exact speed limit of the specific road section and warns driver if speeding, which comes with added cost. Alternative way to reduce average travel speed is by installing cameras and enforce the speed which has been proven effective and also could prevent other violations as well for all vehicles [25].

The study had some limitations. For example, although the modelling approach using simple, deterministic rules to quantify safety benefits and analyse residual crashes has been employed widely by researchers, simplified rules do not reflect all the possibilities in the real world. For instance, warnings can be ignored by the driver, and then the system will not be effective. This study did not account for that possibility. Perhaps education and driver training might help society adapt to new vehicle technologies. Further, the CBS mandated for PTWs with an engine capacity less than 125 cm^3 could not be modelled, since the system applies both front and rear brakes in a specific ratio when the rider activates a single lever. CBS helps reduce stopping distance, but the complex information required to model it was not captured in the database, so we could not differentiate it from ABS. However, the deterministic method allowed us to model several standards effectively and analyse combined effects without double-counting (recall Fig. 1; the combined effectiveness is lower than the sum of all the individual estimates).

This forecasting study assumes that the current road traffic conditions remain largely unchanged in the near future. The study did not consider growth and improvements in road infrastructure, emergency rescue and health care services, a significant shift to newer transportation modes, additional changes in regulations etc. These changes could affect road traffic injuries but are difficult to accurately estimate. Forecasts based on the analysis of historical crash data have been employed before [14], [17], [26]. Reference [16] validated the accuracy and usefulness for a 10-year prediction horizon in Sweden. For our forecast to hold true, road traffic in India would need to be free of drastic changes for the next 15 to 20 years. While that is a bold assumption, it seems motivated by previous research and by the need to guide action in this time horizon.

The safe system principle assumes that humans will inevitably make mistakes which can lead to crashes. Safer speeds, along with user acceptance and compliance with the rules, are the building blocks of the safe system approach. The speed limits, safer cars and safer infrastructure are interrelated. For example, a safer road infrastructure with safer cars will allow a higher speed limit. Policies focusing on safer road design, along with lowering speed limits in cities and separating traffic on high-speed roads, might also bring about prevention of traffic conflicts and thus fatalities. A faster adoption of ESC in the Indian vehicle fleet, specifically for M and N class of vehicles, is expected to reduce the number of crashes even further. Protecting occupants and road users outside the vehicle are also of prime importance. Our analysis indicates that in the future, with these standards, India will be able to prevent some fatalities inside the M1 vehicles, but they may not have similar effectiveness on road users outside the vehicles. This disparity implies that, to achieve significant fatality reduction, strategies for improving the safety of PTWs and pedestrians are required. Further, improvements in crashworthiness, such as underride prevention and softer front ends for trucks and buses, and increased use of good helmets, are needed.

V. CONCLUSIONS

The newly implemented safety standards would help to reduce fatalities by 15 to 33%. However, these standards alone will not be sufficient to halve traffic fatalities by 2030. The safety standards noticeably increase the self-protection for M1 vehicle occupants but fail to have a similar impact on pedestrians and motorcyclists. Future policies should focus on the protection of vulnerable road users, improving crashworthiness, and lowering travel speeds, along with policies for increasing seatbelt and helmet usage.

VI. ACKNOWLEDGEMENT

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VIII. APPENDIX

We have assumed that M1 vehicles in Germany, before implementing the European New Car Assessment Programme which meet United Nations regulations, would offer similar level of protection, when the M1 vehicles in India meets the recently implemented vehicle safety regulations. So, the delta-V would also be comparable as delta-V is a predictor for injury severity. Hence, we identified M1 vehicle crashes (Model year 1998-2007) from GIDAS (frontal, side) where front row adult occupants had suffered maximum Abbreviated Injury Scale 3 or greater (MAIS3+) to generate risk curves with 95% confidence intervals. From the risk curves, we chose delta-V corresponding to 5% risk upper confidence interval for conservative estimates (for frontal 40 km/h) and for optimistic estimates we chose delta-V corresponding to 30% risk from the lower confidence interval (75 km/h). We employed the same method for pedestrian protection, we extracted vehicle collision speed. There were not enough fatal crashes for the model years, and hence we selected MAIS 3+ to generate risk curves. The risk curves generated are presented in Figure A1, A2 and A3.

The assumption that the safety level of older cars in a high-income country is similar to the safety level offered by present day cars in low- or middle-income countries were made in other literature as well. For instance, reference [14] used estimated effectiveness in Latin America assuming safety characteristics of 1990's cars in USA.

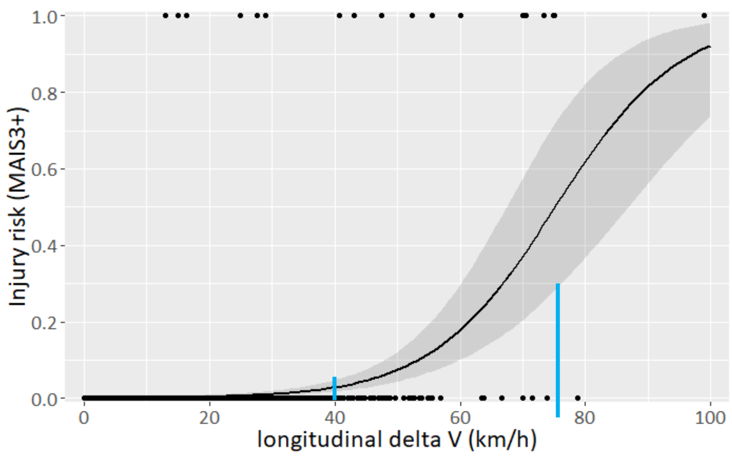

Fig. A1. MAIS3+ injury risk for adult occupants in car subjected frontal crash with overlap more than 20%.

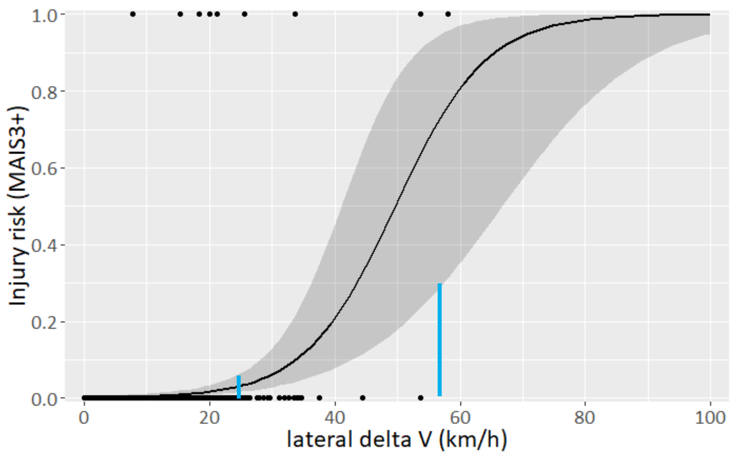

Fig. A2. MAIS3+ injury risk for adult occupants in car subjected side crash impacted by wide objects and have damage to passenger compartment area.

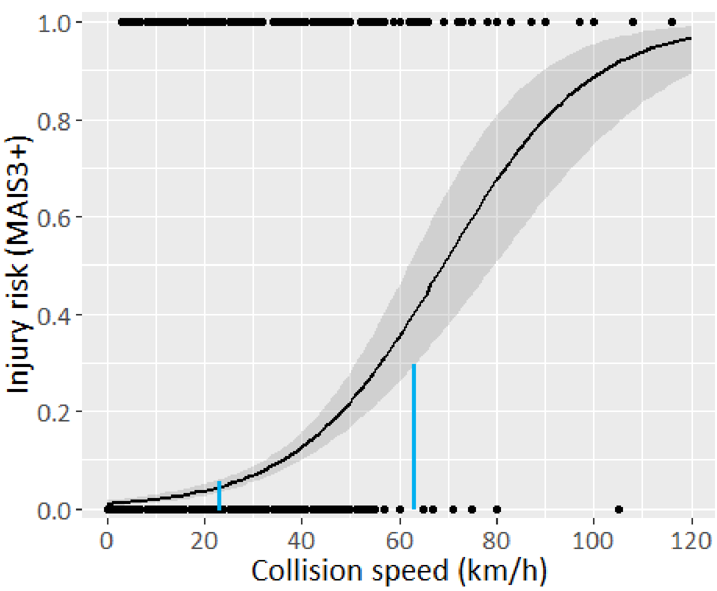

Fig. A3. Pedestrian MAIS3+ injury risk. The MAIS3+ injury risk as a function of impact speed for pedestrians hit by the front of a passenger car.