Development of Accident Reconstruction Using In-Depth Accident Investigation Data in India

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Abstract This paper describes the development of delta-V and pre-crash speeds by crash type and vehicle type for crashes on Indian roads as part of Road Accident Sampling System – India (RASSI), an in-depth database of India road accident data. In addition, it highlights some of the difficulties faced in reconstructing accidents in a developing country. The paper includes analyses of approximately 1,000 accident cases from 2011 to 2014 in RASSI. The RASSI project is modeled on well-known crash data studies and databases from countries such as the USA, UK, and Germany, but uses India-centric collection methodologies. Reconstruction was done for approximately 700 vehicles, and analysis was made of impact speeds of cars, trucks and motorized two-wheelers, including comparison with available data for US counterparts. Results show that 19% of crash-involved vehicles in India have a delta-V less than 5 mph (8 km/h), while in the US, 5% of crashes have a delta-V less than 5 mph. Nearly 30% of vehicles involved in a crash in India have a delta-V greater than 25 mph (40 km/h) whereas only 4% of the crashes in the US have a delta-V greater than 25 mph (40 km/h). These differences could be due to factors including the size/weight incompatibility seen on Indian roads between colliding vehicles, travel speed and higher percentage of rear-end crashes.

Keywords Accident reconstruction, delta-V, impact speeds

I. INTRODUCTION

The value of on-scene, in-depth accident research studies has been recognized internationally. When it comes to addressing problems relating to road safety, in-depth information concerning on-road accidents is essential to making meaningful interventions and taking corrective measures. One part of the process of building an in-depth road accident database is to collect detailed crash information on road, vehicle and occupant-related factors associated with the crash. Detailed, in-depth crash data also enables analysts to reconstruct accidents to understand crash severity, vehicle performance and injury mechanisms. In addition, reconstructions can provide answers that are not readily available at the crash scene. Such information includes the speeds vehicles were travelling prior to the crash, delta-V and the impact speeds. Under the internationally-supported database project, the Road Accident Sampling System – India (RASSI), such answers are being sought for India.

Objective

A crash reconstruction study has been undertaken using data from the RASSI in-depth real world accident database to reconstruct Indian road crashes. The primary objective of the work reported here is to identify the impact speed ranges for vehicle body types and crash configurations seen on Indian roads. This paper presents the preliminary findings of that study and highlights some of the difficulties faced in reconstructing cases with an absence of India-specific vehicle specifications in standard reconstruction software and vehicle damage databases.

Background

Road accident data collection and research in India was taken up as a scientific study for the first time by JP Research India Pvt. Ltd. (JPRI), and since 2011 it has been supported, under the RASSI project, by an international consortium of automobile and component manufacturers [1-2]. The RASSI database was designed specifically to follow the patterns of, and be compatible with, such high-profile national crash databases as the US National Automotive Sampling System – Crashworthiness Data System (NASS-CDS), the German In-Depth Accident Study (GIDAS), and the UK's Co-operative Crash Injury Study (CCIS), while addressing issues unique to India.

Accident reconstruction adds to the information that can be gathered by detailed investigation of the crash scene, vehicles, and injuries. Being able to model and "see" an accident unfold provides a deeper insight into the

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sequence of events leading up to the crash and the vehicle behaviors in the crash event, as well as providing a logical "check" to assumptions made strictly on the basis of crash evidence. Two important parameters that are deduced based on accident reconstruction are delta-V and impact speeds (closing speeds). These directly translate to crash severity.

To ensure that RASSI reconstructions are as accurate as possible, a team of reconstructionists was trained in accident research techniques by GIDAS and NASS-CDS experts and also worked with the company that developed and specializes in application of the reconstruction software PC-Crash [3] to use that program as a tool for reconstructing India-specific accidents. The research team has collective experience reconstructing over 500 cases involving various crash configurations, from head-on to rollover, and vehicle body types ranging from motorized two-and three-wheelers to trucks and tractor trailers, and even pedestrians. This paper presents their findings, with an emphasis on methodology established in reconstructing cases. Example cases are presented, as well as a discussion of the challenges posed to crash reconstructionists by specifically Indian conditions.

II. METHODS

Data Used

To address the deficit of in-depth accident data in India, a consortium of automotive original equipment manufacturers came together in 2011 to support development of the RASSI database. Accidents that happen on public roads within a selected study area are considered for RASSI. Cases in which occupants were either fatally or seriously injured and for which an accident scene was identifiable through evidence such as tire marks, debris or any pool of vehicular or bodily fluids are studied in-depth, with over 400 variables coded for the RASSI online database. Cases with minor or no injury are considered if the vehicle had tow-away damage and the accident scene was identifiable by evidence. In the initial years of the RASSI database development effort, data was collected from the city of Coimbatore in the state of Tamil Nadu, where three national and state highways spanning over 200km were demarcated as the study area. Ramesh et al, 2013 [2] details the establishment of the accident investigation methodology.

Comparison of RASSI and NASS-CDS Data

The NASS-CDS data is a probability sample of tow-away crashes in the US. Every crash in the NASS-CDS database has been investigated in depth, and the data in this representative sample database is used to make national projections of the types of crashes and injuries occurring on US roads. Like RASSI, NASS-CDS oversamples accidents with higher injury severity. In order to generate national projections, probability weights for each observation are defined by NHSTA and must be used for estimates.

To date, the RASSI data is not a representative sample of accidents in India, although procedures are being developed to obtain sampling weights to represent the nation from this data. Due to limited accessibility to roads and limitations on police notification of crashes in India, the RASSI teams currently focus on crashes occurring on highways and in rural regions. Regardless, a comparison is made in this study between the weighted distribution of delta-V in NASS-CDS and the raw distribution of delta-V in RASSI in order to ascertain some of the differences between crashes in India versus those in Western countries (as typified here by the US). The data used for the purposes of this comparison is restricted to passenger cars and light trucks (including hatchbacks, sedans, SUVs, MUVs and vans).

Reconstructed RASSI Cases Used for Study

From 2011 to 2014, in-depth information on over 1,150 accidents in India has been collected and finalized for the RASSI database from three key sample regions: Coimbatore, Pune and Ahmedabad, and over 500 of these cases have been reconstructed. Reconstruction and delta-V estimates were developed for over 700 vehicles involved. A significant portion of reconstructed crashes were head-on (frontal) collisions. A good portion of crashes in India also involve underrides and heavy trucks, and this limits the use of PC-Crash software.

An attempt was made to reconstruct all RASSI cases investigated, barring the obvious cases that can be rendered not reconstructable (e.g., motorized two-wheeler self-fall, cases with little-to-no detailed evidence on point of impact or final rest positions of the colliding partners post-impact, cases with complex road structures or vehicle maneuvers, etc.). Such reconstruction is done to better understand the accident and to validate the evidence gathered and statements recorded from scene and vehicle investigations. The prime motive in reconstructing a case is to estimate the travel speeds, impact speeds and delta-V, as well as the vehicle/driver behavior from the vehicle trajectory. If a case demands numerous assumptions to be made, making the values unreliable, that case is not reconstructed.

Approach

A proper crash reconstruction requires reliable information, including crash scene evidence (e.g., tire marks, final resting positions) and vehicle evidence (e.g., vehicle crush). Using this data, pre-crash speeds (impact and travel speeds) and direction of force are estimated. The results are validated and optimized using PC-Crash software. In cases where vivid brake marks exist, a reliable speed calculation is made using Newton's equations of motion and assuming deceleration values based on the available brake marks.

Assumptions on Deceleration Values

Deceleration assumptions are based on established results from the Western world. While these may or may not exactly replicate the subject vehicles' characteristics due to differences in road surfaces and individual vehicle braking characteristics, it is still a good starting point. Since there is a dearth of such research results in India, reliance on Western data becomes necessary and reasonable.

When Scene Evidence is Not Available

When there is no evidence of braking or swerving, the damages suffered by vehicles are taken as the starting point for reconstruction. The damage patterns on the colliding partners are studied in minute detail to understand the direction of force and ultimately the way the colliding partners engaged with each other at the point of impact. With not much evidence on scene, the damage suffered by the vehicle becomes the only baseline for speed estimation. This estimation is done in one of two ways: 1) a comparison with available crash test data (i.e., information on damage suffered by a similar vehicle in a crash test) or 2) using other sources including the Equivalent Energy Speed (EES) catalog (a database of vehicles with damages that lists the impact speeds) which is provided in PC Crash software. The "similar" vehicles are chosen based on weight and vehicle type (sedan, SUV, pickup, or coupe).

Using Crash Test Data

In the US, data on crash tests performed by NHTSA and the IIHS are publicly available. Currently in India, there are no such crash test data on Indian vehicles available in the public domain. Consequently, the reconstructionist has to resort to finding a "representative" vehicle, closely resembling the mass and type of the subject vehicle, for which a crash test has been done at a particular speed and the damage and speeds are known. Though vehicle stiffness and vehicle structure parameters might be significantly different between the Western World and India, it is deemed appropriate to use these crash tests as a starting point.

Another difficulty in accident reconstruction in India is associated with the annual number of road accident deaths (about 140,000). It is expected that some areas become "black spots" or recurrent scenes of accidents. In such cases, it is essential to differentiate between evidence from a previous accident and evidence of the current accident. The RASSI crash investigation teams have extensive experience collecting data in the same study areas, and are often able to identify evidence from previous accidents due to road familiarity and maintenance of crash data on that specific study area in their electronic files. If such data is not available, a careful study of the scene and vehicle is done in greater detail to find a tread pattern, the way the grass has moved, etc., that correlates with the direction the tires lead to and the overlap and direction of force for the subject vehicle. This in-depth scrutiny of the collected evidence and data can paint a reasonably reliable picture of the accident occurrence. Comprehensive quality control checks are frequently performed by the crash investigation teams of engineers to ensure accurate representation of accident scene for reconstruction.

All the estimates of speed and delta-V are made based on these objective assessments, using measurements from the Western world and the researchers' experience as references (often after consultation with crash/reconstruction experts from other countries for specific clarifications when there are doubts). Due to a lack of published India-specific values, RASSI researchers have had to create reliable interim solutions. The data from this study is a first step towards addressing the India-specific road, vehicle, and crash conditions with higher accuracy so that in the future, India will have its own standard values to refer to, verified by real world crash data collected on Indian roads.

Finalizing the speed calculations

Once the speeds are estimated and a scaled scene diagram is readied, the estimates are validated and optimized using PC-Crash software, using crash scene evidence as the control parameters. Representative vehicles are chosen from the vehicle library based on weight and shape and are configured to reflect the crashed vehicle. PC-Crash allows the analyst to replicate the crashed vehicle by starting from a vehicle available from its library and modifying key parameters to match. The built-in vehicle database of PC-Crash has very few Indian vehicles but it provides for customization to suit the subject vehicles. The elementary dimensional customization (e.g., length, weight, wheelbase) is done based on product catalogues or online sources. But customization of other parameters, such as center of gravity, has been assumed based on a range of inputs from Western countries.

Based on the aforementioned methodologies, output information on delta-V, EES and optimized pre-crash speeds are obtained from PC-Crash software.

III. RESULTS

At present, roughly half of the RASSI cases from the three sampling centers have been reconstructed. For the reconstructed accidents, the study compared the distributions of delta-V estimates for the US (using 2000-2013 NASS-CDS data maintained by NHTSA) versus India (represented by 2011-2014 RASSI data).

Table 1 and Figure 1 present the cumulative percentage of vehicles in crashes, by delta-V, for the NASS and RASSI data.

TABLE 1

CUMULATIVE DISTRIBUTIONS OF DELTA-V FOR US AND INDIAN ROAD CRASHES – PASSENGER CARS AND LIGHT TRUCKS

Speed in mph	US Crashes			India Crashes		
	Raw Count	Weighted Percentage	Weighted Cumulative	Count	Percentage	Cumulative
0 -5	891	5.0%	5%	56	18.5%	19%
5-10	9,037	36.8%	42%	59	19.5%	38%
10-15	10,541	33.3%	75%	36	11.9%	50%
15-20	6,720	15.4%	90%	35	11.6%	62%
20-25	3,673	5.6%	96%	27	8.9%	71%
25-30	1,887	2.4%	98%	24	7.9%	78%
30-35	1,045	0.8%	99%	13	4.3%	83%
35-40	564	0.4%	100%	14	4.6%	87%
40-45	307	0.2%	100%	17	5.6%	93%
45+	358	0.2%	100%	21	7.0%	100%
Total	35,023	100%	-	302	100%	-

Source: US crashes from NASS-CDS data. India crashes from RASSI data. Rollovers are excluded.

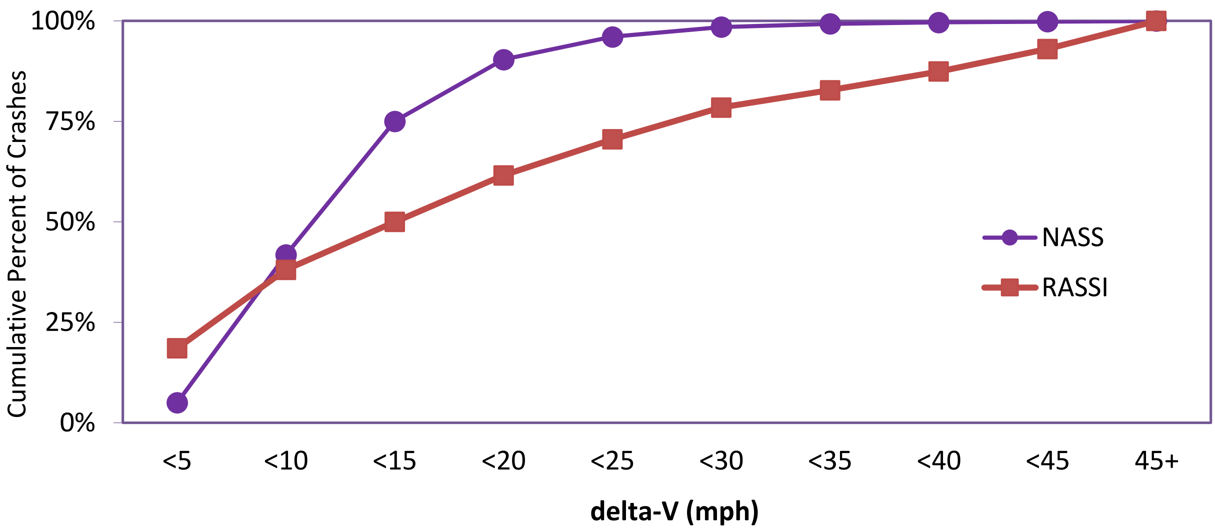

Fig. 1. Cumulative distributions of delta-V by 5 mph (8 km/h) increments. (Source: US crashes from NASS-CDS data. India crashes from RASSI data. Rollovers are excluded).

As the figure shows, the RASSI crash data has a higher percentage of crashes with very low delta-Vs and very high delta-Vs compared to the NASS crash data for the US. [Note that percentages may not add up to 100% due to rounding.] For example, 19% of Indian road crashes have a delta-V less than 5 mph (8 km/h) whereas only 5% of US crashes have a delta-v less than 5 mph (8 km/h). Similarly, about 29% of Indian road crashes have a delta-V higher than 25 mph (40 km/h) compared to only 4% of US crash data. A significant portion of US crashes (70%)

have a delta-V between 5 mph (8 km/h) and 15 mph (24 km/h) while, for India, only 31% of crashes have a delta-V between 5 mph (8 km/h) and 15 mph (24 km/h).

To investigate the potential influence of crash configuration on these results, namely different crash configurations in the US and India biasing the results, the distribution of delta-V for vehicles that experienced frontal impacts in the NASS and RASSI data was examined. A frontal impact was determined by the direction of force for the vehicle in question and the general area of damage. The results are presented in Table 2 and Figure 2. Similar results are found when considering frontal crashes only, with many more low and high delta-V impacts being found in the RASSI data. Seventeen percent (17%) of frontal impacts in RASSI are below 5 mph (8 km/h) delta-V compared to only 1% of NASS frontal impacts. Additionally 36% of RASSI frontal impacts are above 30 mph (48 km/h) compared to only about 2% of NASS frontal impacts. It is also worth noting that almost two-thirds of the RASSI vehicles with delta-V defined involve frontal impacts (207/302) compared to only about one-third of the raw NASS vehicles that have delta-V defined (12,398/35,023). An investigation of the percentages of vehicle crash configuration within both datasets, using NASS-CDS weights, is presented later.

TABLE 2

CUMULATIVE DISTRIBUTIONS OF DELTA-V FOR US AND INDIAN FRONTAL ROAD CRASHES – PASSENGER CARS AND LIGHT TRUCKS

Speed in mph	US Frontal Crashes			India Frontal Crashes		
	Raw Count	Weighted Percentage	Weighted Cumulative	Count	Percentage	Cumulative
0 -5	179	1.1%	1%	35	16.9%	17%
5-10	4,640	32.4%	34%	38	18.4%	35%
10-15	6,407	36.8%	70%	24	11.6%	47%
15-20	4,316	18.2%	89%	16	7.7%	55%
20-25	2,417	6.7%	95%	21	10.1%	65%
25-30	1,255	2.8%	98%	19	9.2%	74%
30-35	743	1.0%	99%	10	4.8%	79%
35-40	416	0.5%	100%	11	5.3%	84%
40-45	217	0.3%	100%	15	7.2%	91%
45+	286	0.2%	100%	18	8.7%	100%
Total	12,398	100%	-	207	100%	-

Source: US crashes from NASS-CDS data. India crashes from RASSI data. Rollovers are excluded.

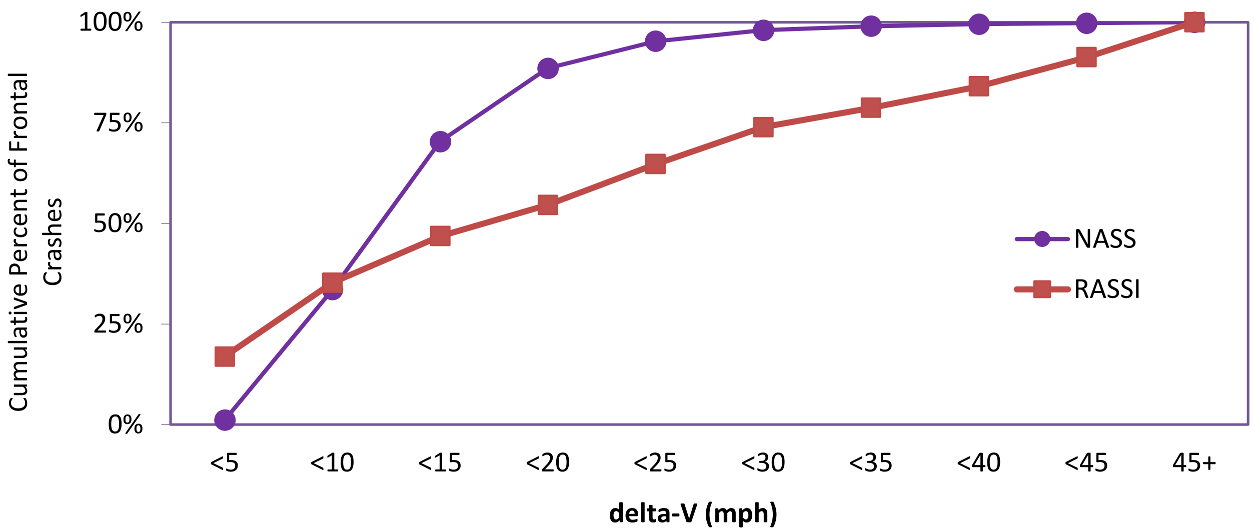

Fig. 2. Cumulative distributions of delta-V in frontal crashes by 5 mph (8 km/h) increments. (Source: US crashes from NASS-CDS data. India crashes from RASSI data. Rollovers are excluded).

To further investigate the occurrence of high delta-V crashes in India, the collision partners of light cars were analyzed by crash configuration and delta-V suffered by the cars. Table 3 shows a distribution of delta-V for the car collision partner in car impact with car (car-car), car impact with motorized two-wheeler (car-M2W), and car impact with heavy truck (car-HT) crashes. Data is sparse; however, some trends can be seen that could explain the high and low delta-Vs in the RASSI data compared to the NASS data.

All of the car impacts with motorized two-wheelers resulted in a delta-V less than 25 mph (40 km/h). Additionally 32% of these crashes occurred at a delta-V of less than 5 mph (8 km/h). In the US data only 5% of accidents occurred at a delta-V of less than 5 mph (8 km/h). Perhaps the high number of motorized two-wheelers on the road is resulting in low delta-V impacts for subject vehicle cars and light trucks compared to the US. On the opposite end of the spectrum, there are also a high number of car impacts with heavy trucks. For these crashes, 16% of the cars experienced a delta-V of 45 mph (72 km/h) or higher. This is much higher than the percentages experienced in the US data. Both of these car-crash configurations provide evidence that vehicle incompatibility, namely large differences in mass and volume for colliding vehicles in the RASSI data, is possibly leading to some extreme delta-V measurements compared to the NASS data. Regardless, these findings may simply be idiosyncratic characteristics of the RASSI sample.

TABLE 3

CUMULATIVE DISTRIBUTIONS OF DELTA-V FOR INDIAN ROAD CRASHES, BY CAR IMPACT WITH VEHICLE TYPE

Delta-V (in mph)	Car Impact with Car			Car Impact with M2W			Car Impact with Heavy Truck		
	Count	Percent	Cumulative	Count	Percentage	Cumulative	Count	Percentage	Cumulative
0 -5	10	23%	23%	11	32%	32%	3	8%	8%
5-10	6	14%	36%	11	32%	65%	5	13%	21%
10-15	5	11%	48%	7	21%	85%	3	8%	29%
15-20	5	11%	59%	3	9%	94%	5	13%	42%
20-25	6	14%	73%	2	6%	100%	2	5%	47%
25+	12	27%	100%	0	0%	100%	20	53%	100%
Total	44	100%	-	34	100%	-	38	100%	-

Source: India crashes from RASSI data. Rollovers are excluded.

Figure 3 shows the cumulative distributions by collision partner for the passenger cars in India. From the figure it is clear that larger masses in collision partners are associated with a larger delta-V experienced by the subject vehicle. Regardless, when investigating car-car collisions in the RASSI data, we still see relatively extreme delta-Vs in comparison with the NASS data. This indicates that even if vehicle incompatibility is a possible reason for the delta-V differences between the US and India, it is not the only explanation.

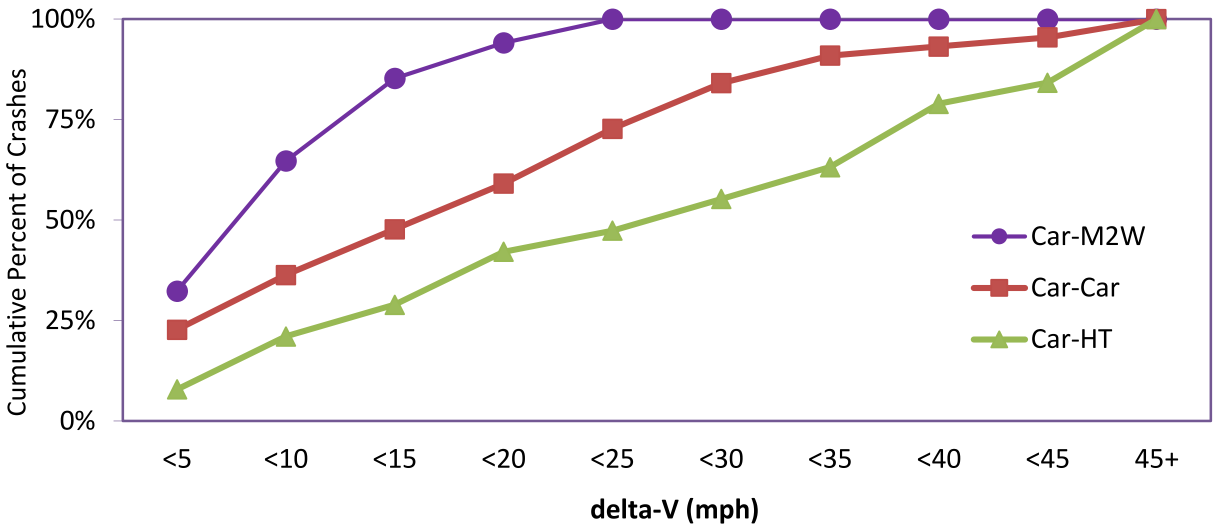

Fig. 3. Cumulative distributions of delta-V by 5 mph (8 km/h) increments for passenger cars by collision partner in Indian road accidents. (Source: India crashes from RASSI data. Rollovers are excluded).

Vehicle crash configurations among vehicles with known delta-V in the US and India were also investigated to see if different crash types weigh more heavily in the US compared to India. Figure 4 provides a graphic comparison. It is clear from the distribution that there are many more rear impacts in India than in the US. Nearly 14% of the impacts in RASSI are rear impacts, and only 8% of the impacts in the NASS-CDS data are rear impacts among light vehicles with defined delta-V. There is also a higher percentage of rollover accidents, although these were not included in the delta-V distributions above and below. If rollover crashes are excluded, then there is a higher percentage of frontal crashes in India compared to the US. If these frontal impacts are head-on collisions, they would lead to significantly higher delta-Vs in the case of vehicle incompatibilities. The differences in crash configurations could also be a possible explanation for the higher and lower delta-Vs relative to the US data.

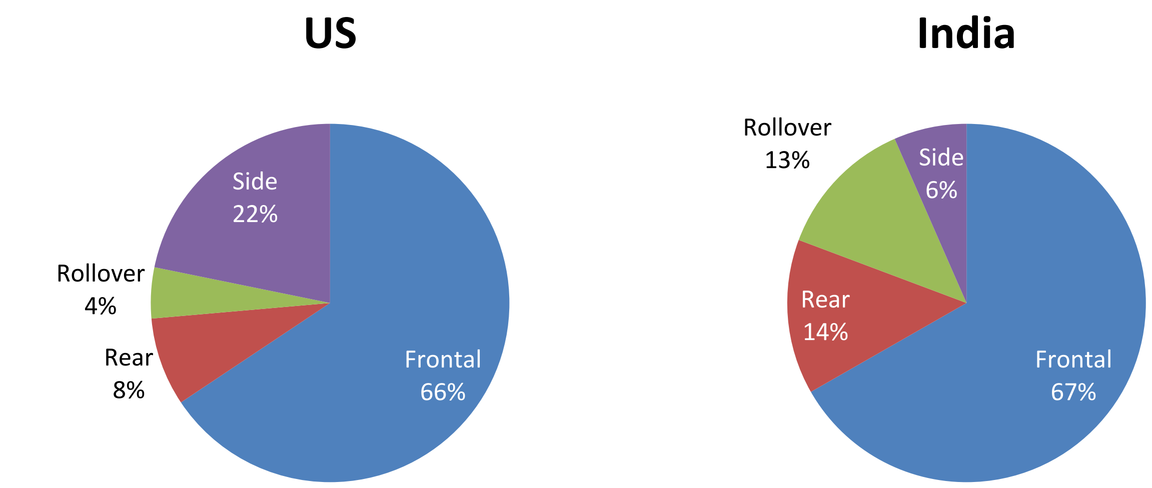

Fig. 4. Collision configurations for light vehicles in US versus India among vehicles with known delta-V. (Source: Weighted US crashes from NASS-CDS data. India crashes from RASSI data.)

Delta-V investigation is crucial because delta-V is so highly correlated to occupant injury severity. Figure 5 shows the risk of serious injury/fatality by delta-V. As shown in Figure 5, the risk increases as delta-V increases. Figure 6 outlines the cumulative distribution of fatally injured and serious/fatal injured occupants in Indian road crashes as compared to all occupants. As Figure 6 shows, 50% of the fatally injured occupants were in crashes with delta-V of 40 mph (64 km/h) or less. About 35% of fatalities and 60% of serious injuries occur in crashes with a delta-V of 35 mph (56 km/h) or less. India is in the process of developing motor vehicle safety standards similar to Euro NCAP and Global NCAP, and in-depth investigation data (as presented in Figure 6) must be taken into account when making standards that are Indian-road specific.

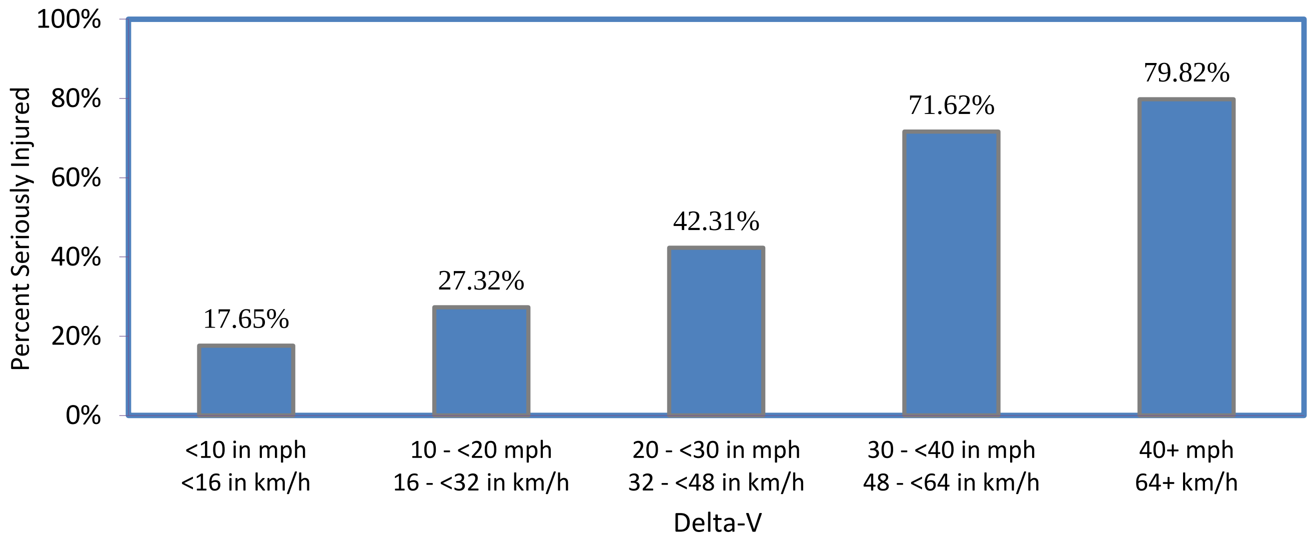

Fig. 5. Serious injury/fatality risk by delta-V in India for Passenger Cars and Light Trucks. (Source: India crashes from RASSI data. Rollovers are excluded.)

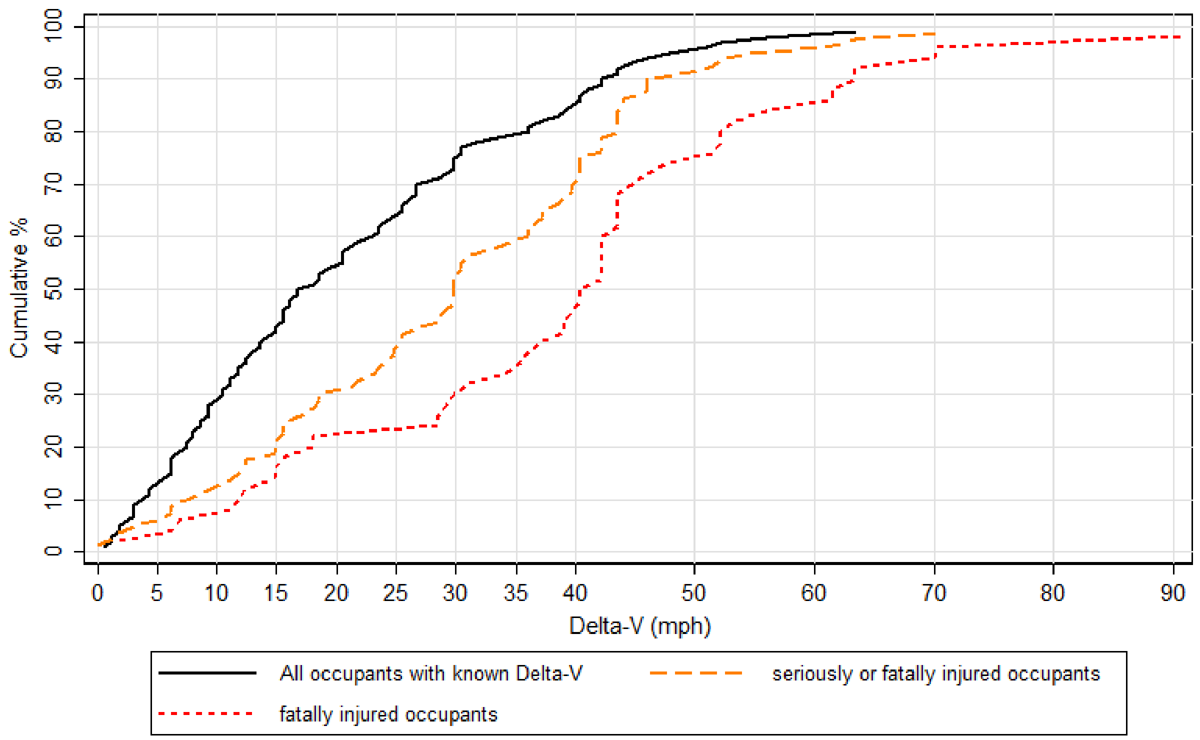

Fig. 6. Cumulative delta-V distributions for occupants in India. (Source: India crashes from RASSI data. Rollovers are excluded.)

If it is the case that crashes in India have higher delta-V concentrations than crashes in the US, then regulations for India should not necessarily be identical to regulations in the US or in Europe. India-specific regulations should be considered based on Indian crash experience. To demonstrate this point, the following section presents a case study of a typical car to heavy truck crash that was reconstructed using PC-Crash.

Case Study

A minivan (labeled "Unit 1" in the diagram shown in Figure 7) with 5 occupants was travelling towards the east, and a truck ("Unit 2") with 1 occupant was traveling in the opposite direction. The driver of the minivan fell asleep while driving and gradually entered into the truck's lane. The truck came to a complete stop on seeing the oncoming passenger vehicle, but the minivan had a head-on collision with the truck, and all 5 occupants of the minivan were fatally injured. The minivan suffered a delta-V of 68 km/h in the collision, while the truck experienced a delta-V of only 7 km/h; the difference in results can be seen in the crash vehicles, Figure 8.

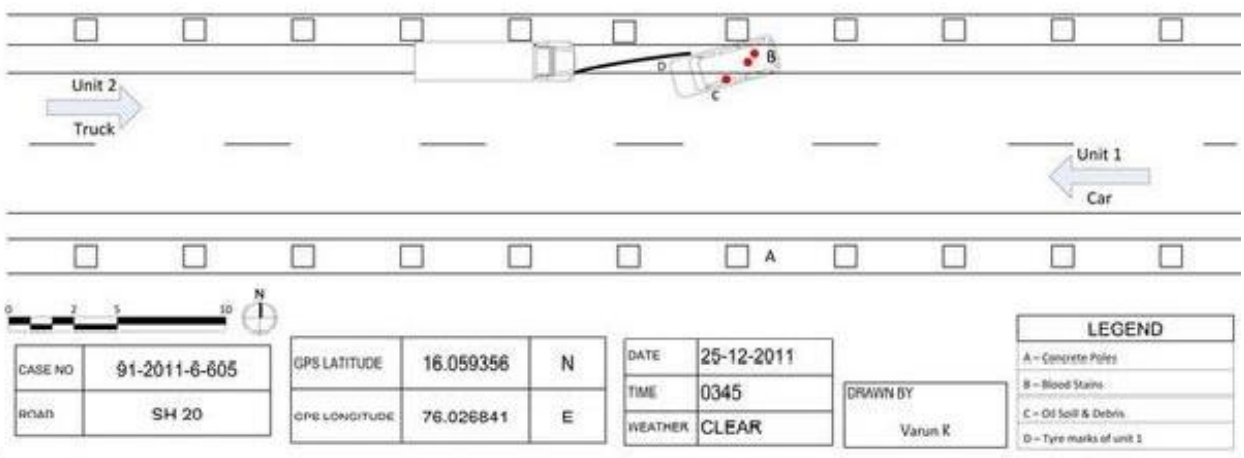

Fig. 7. Scene diagram for Case Study

Fig. 8. Vehicles involved in the accident (Case Study)

Clearly, size/weight incompatibility and a higher percentage (than seen in the well-documented developed countries) of motorized two-wheelers and pedestrians sharing the road space is something very typical of India and of other developing nations as well.

IV. Discussion

The researchers on this project were trained by experts from the Western world and used software that was developed for the Western world (developed countries) but that works on the universally-accepted laws of physics. The practices used by the Western world for road accident data collection have been tailored to suit Indian conditions [2], and in-depth data collection projects in delineated study areas have been ongoing in India for several years. As described under Methods, accident reconstructionists on these projects have had to make numerous adjustments to be closer to reality and specific to the Indian conditions.

Reconstructionists involved in the present study have performed their own drag tests to attempt to refine their data choices for dynamic friction [4], but this is a far cry from having a full catalog of data representative of local roads and vehicles. Developing such India-specific data would increase the representativeness of accident reconstructions and thereby improve the crash data set available for making data-driven road safety decisions and developing long-term strategies for India.

In addition, as discussed under Data Used, Approach and Results, there are numerous limitations to the data itself and to the conclusions that can be definitively drawn from these early results. However, the findings are intriguing and clearly suggest not only differences in the India and US crash experience but also highlight directions for further study. The purpose of the RASSI database project is to collect enough detailed crash information on road, vehicle and occupant-related factors across India to eventually allow for NASS-CDS styled extrapolations and analyses. This paper is a first attempt at making sense of the data from initial reconstruction efforts; further efforts will be refined by additional crash data, additional study locations, and the wealth of experience being directed to the project by the growing number of RASSI consortium members.

V. Conclusions

The research results from careful reconstructions and in-depth studies help form a basis for data-driven strategies and effective interventions and countermeasures for India. There are no easy solutions to the core problems. Crash tests specific to Indian road conditions and in-depth crash data collected for Indian roads are warranted to mitigate injuries. To date, the data clearly shows that there are significant differences between Indian and Western crash experience.

VI. Acknowledgements

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