Early Data and Insights from the Vulnerable Road User Injury Prevention Alliance (VIPA)

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Abstract Real-time crash surveillance data in the United States are needed to guide efforts to improve protection of Vulnerable Road Users (VRUs). The Vulnerable Road Users Injury Prevention Alliance (VIPA) is a consortium of academic researchers, automobile manufacturers, consumer metric organizations as well as state and local governmental agencies from Michigan. VIPA has been designed to produce high dimensional data describing crash conditions and VRU injuries. The VIPA database consists of two independent data collection efforts—the VIPA Limited data (a random sample from all police reported VRU-motor vehicle crashes in the state of Michigan combined with injury data from medical records), and the VIPA In-Depth data (complete reconstruction of VRU crashes that include on-scene vehicle photographs and complete medical records including imaging). Data definitions and collection methods were harmonised with those of international research organisations. Categorical factors that contribute to VRU outcomes include: demographics, VRU kinematics types, and injury severity. The most disproportionately observed group were females between 20-29 in the VIPA In-Depth, and males 20-29 in the VIPA Limited dataset. The most prevalent VRU trajectory type observed in passenger cars and multipurpose vehicles (MPV) were forward projection (16%, 14%) and wrap trajectory (20%, 14%). Most VRUs were slightly injured and showed no difference by vehicle type. Recent changes to the increased proportions of MPV's in the US vehicle fleet have resulted in differential VRU-interactions from those previously described in the US or globally.

Keywords Active safety, Passive safety, Crash investigation and analysis, Pedestrian safety, VRU

I. INTRODUCTION

Vulnerable road users (VRUs), such as pedestrians and bicyclists, are those with little or no external protection devices capable of absorbing energy in a collision [1]. Among the global 1.35 million road traffic mortalities in 2016, 26% were pedestrians and bicyclists [2]. Similarly, in the USA, 19% of traffic crash victims are pedestrians and non-vehicle occupants [3]. Motor vehicles are tailored to employ safety features specifically designed to increase the survivability for vehicle occupants during and after a collision, while in the same situation, extraneous VRU individuals without such safeguards face disparate, devastating consequences [4]. Recently, in higher income countries, car manufacturers and public health officials have begun to implement safety standards to specifically benefit VRUs [1,2].

Historically, data collection efforts to study and describe pedestrian-motor vehicle crashes in the USA have been limited. The National Highway Traffic Safety Administration (NHTSA) Pedestrian Injury Causation Study (1970-1980), and the Pedestrian Crash Data Study 1994-1998 are among strong efforts at collecting population level and case study data regarding VRUs [5,6]. Unfortunately, as much of this research was performed more than 20 years ago, it may not reflect the current makeup of vehicle fleet and traffic safety designs. Further compounding the problem is the possible underestimating of injury and crash data from governmental and police records due to infrequent reporting of minor and/or nonfatal crashes, and the lack of standardised procedural reporting for VRUs [1,7].

The Vulnerable Road Users Injury Prevention Alliance (VIPA) is a joint consortium developed by the International Center for Automotive Medicine (ICAM) at the University of Michigan. The mission of the Center is to better understand, treat, and prevent crash injuries. The primary goal of VIPA is to conduct real time

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surveillance that will produce high dimensional data describing vehicle crashes involving VRUs. Providing this data with partners such as car manufacturers, consumer metric organizations that rate vehicle safety, state agencies, police departments, and medical centres informs policies, contributes to preventive measures, and reduces injury in VRUs. It is the intent of this consortium to provide regular, periodic summaries of the data to the scientific community to enhance global safety efforts. This analysis will briefly report on early observed trends in the VIPA Limited and VIPA In-Depth datasets regarding VRU-motor vehicle interactions, including vehicle descriptions and kinematics.

II. METHODS

Data Documentation and Collection

The VIPA database consists of two independent data collection efforts. The VIPA Limited dataset is a random sample of all police-reported VRU motor vehicle crashes in the state of Michigan. The VIPA In-Depth dataset are a selected subset of case studies that have a complete crash reconstruction including on-scene vehicle photographs, detailed medical records and injury causation analysis. Table 1 describes the data obtained in both the Limited and In-Depth VIPA datasets. The In-Depth dataset contains additional granular variables from conducting field investigations and defining mechanisms. The In-depth cases are not an extension or overlap with the Limited dataset, and are separate case studies selected in the state of Michigan.

Data elements collected in both data sets include VRU and driver involved demographic variables, scene data, vehicle data and medical data. The scene data includes environmental elements, weather conditions, and examining street types and crosswalk locations. Vehicle data includes but not limited to the year, make, and model, and movement data. All data is collected, catalogued, and populated into a localized database. Data collection began in 2015 and is ongoing.

The In-depth case studies include photos of the involved vehicle and inspection that documents isometric measurements of the body type profile. Using a coordinate system (x,y,z) the VRU damage contacts are located on the vehicle. Utilising VRU contact locations allows assessment and defining the interaction type (such as run-overs, roof-vaults, wrap trajectories, etc.), as well as, analysing injury sources. Associated causal mechanism are further interpreted by using MADYMO simulations that incorporates the isometric shape of the vehicle, and medical imaging data that provides insight into body contact and anatomic injury locations. Data is also obtained through Analytics Morphomics, a method for obtaining granular quantification of body dimensions and composition from computer tomography. In depths case are also peer reviewed by an interdisciplinary panel of experts.

TABLE I.
COMPARISONS OF VIPA DATASETS

Variable	Limited	In-Depth
Environment variables	X	X
Vehicle information	X	X
Demographics	X	X
GIDAS--based crash coding	X	X
Height, Weight, BMI	X	X
Triage, transport, treatment, outcomes	X	X
AIS injury coding from medical records	X	X
Scaled scene diagram and scene photos	--	X
Vehicle contact point photos and measurements, exemplars	--	X
Detailed injury information including imaging if performed		X
Kinematics - MADYMO	--	X
Injury source, mechanism, and confidence	--	X

Inclusion Criteria and Screening for In-Depth case studies

For consideration and inclusion into the In-Depth dataset, cases must have been police reported. Vehicles must have been of model year 2000 or newer; the vehicle had not been altered with the addition of heavy equipment; and the vehicle type must be a car, multipurpose vehicle (MPV) (for this study includes pickup trucks, vans, or Sport Utility Vehicles). Exclusion was performed in the case of an unknown make/model of the vehicle; and if the vehicle in question was a heavy truck, bus, train or motorcycle. The pedestrian or bicyclist had to be upright during the interaction and at least have a suspected injury level and involve treatment and transport to a medical facility. Pedestrian and bicyclist crashes are surveilled daily within the state of Michigan. The surveillance system includes local city and county officials who notify the ICAM team of potential cases. Main collection sites include Greater Southeast Michigan (Washtenaw, Livingston, Jackson, Lenawee, and Oakland counties), the Greater Lansing Area (Ingham, Clinton, and Eaton counties), and Greater Southwest Michigan (Kent, Allegan, Barry, and Kalamazoo counties).

In-Depth Case Investigations and Reconstruction

Police reports are obtained for all cases-- including vehicle photographs taken on scene, vehicle measurements and damage contact locations. For local jurisdictions, the crash location is visited by a VIPA investigator to photograph and complete a scaled map of the environment locating impact evidence and final rest locations. Satellite measurement tools are also utilised to document scene locations. VIPA investigators arrange a secondary inspection of the vehicle involving additional photographs and obtain isometric measurements of the vehicle with reference measurements of contact location points using X, Y, Z coordinates and wrap distances from the ground. In instances of inaccessible vehicles, proxy by exemplar is utilised and compared with on-scene photos and written documentation. Using impact and final rest locations of the VRU and vehicle that were documented on scene, reconstruction formulas for both the vehicle stopping distance and VRU throw distance are utilised to estimate an impact speed. The isometric measurements and dimensions of the vehicle are replicated into MADYMO R7.6 to simulate possible interaction scenarios of the pedestrian or bicyclist with vehicle in relations to the observed VRU injury and vehicle damage locations. Impact speeds within the estimated range and differential VRU positions relative to the striking vehicle are parametrically modelled.

Injury

All injuries are documented using Abbreviated Injury Scale (AIS) with medical record reviews, including assessing radiology or body photos, and are coded and validated by trauma nurses and surgeons [8]. Within the VIPA network, an ordinal “Injury Severity” scale that reflects expert opinion for injuries sustained post-crash. These include, but are not limited to MAIS scores, injury location, and magnitude of injuries. Cases were reviewed on an individual basis, and valued. In most cases, those who received MAIS (Maximum AIS) scores of 0-1 were considered “Not Injured,” those with MAIS-2-3 may have “Slightly Injured,” those with MAIS-3-4 could have been “Seriously Injured”, those with MAIS-4-5 were “Severely Injured”, and those with MAIS-6 were “Killed.”

Reviews

All VIPA in-depth cases are reviewed by an interdisciplinary team of crash investigators, radiologists, trauma care surgeons, automotive engineers, law enforcement, and others. The team votes on and finalises interactions, speeds of impact, validates simulations, and determines mechanism of injury that correlates with component contact sources. Decisions with uncertainty are noted in the database. Our group reviews the data, discussions are held and conclusions are based on anonymous voting until majority is achieved. Level of confidence in mechanism is documented.

III. RESULTS

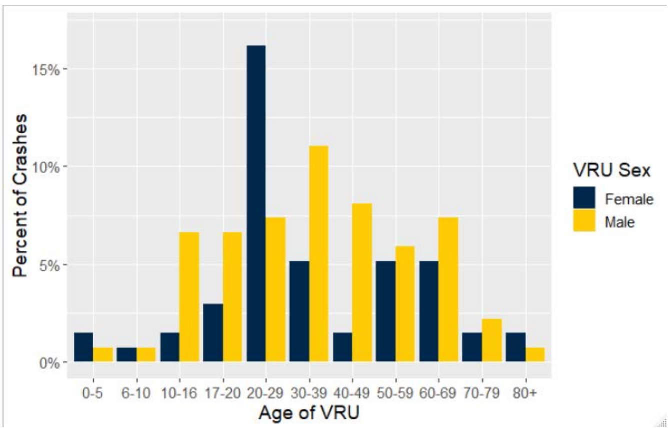
Table II reports the descriptive statistics for the VIPA Limited and VIPA In-Depth datasets. The VIPA Limited dataset included 454 cases, while the VIPA In-Depth dataset included 137 observations. The average age among those in the VIPA Limited dataset was 35 years (SD 19.5), while the VIPA In-Depth dataset’s average age was 36.7 years (SD 20.3). In the VIPA Limited dataset 42% of study subjects were female, while the VIPA In-Depth dataset had 30.6% female study subjects.

Table II
Descriptive Statistics VRU-Motor Vehicle Interactions in two VIPA Datasets

Variable	Limited (n =454)	In-Depth (n=137)
Age	35.0 (19.5)	36.7 (20.3)
Female	139 (30.6%)	58 (42.3%)
VRU Type		
Pedestrians	231 (50.4%)	102 (74.5%)
Bicyclists	227 (49.5%)	35 (25.5%)
Vehicle Type		
Passenger Car	191 (42.1%)	72 (52.9%)
MPV	222 (48.9%)	64 (47.1%)
VIPA In-Depth Specific Variables		
Trajectory Types		
Fender Vault	--	4 (2.9%)
Forward Projection	--	47 (35.0%)
Roof Vault	--	13 (9.5%)
Run Over	--	5 (3.7%)
Side Impact	--	6 (4.4%)
Wrap Trajectory	--	47 (35.0%)
Unknown/ Not Applicable	--	15 (9.5%)
Injury Observed	--	
Not Injured	--	21 (15.4%)
Slightly Injured	--	56 (41.0%)
Seriously Injured	--	18 (13.2%)
Severely Injured	--	14 (10.2%)
Killed	--	27 (20.0%)

Reported as Mean (SD) or Frequency (%).
Due to rounding, percent additions may not equal 100%.

Fig. 1a reports the VRU age distributions, stratified by sex among those in the In-Depth Database. Both sexes had a similar unimodal distribution – most VRUs were between 17 and 29 years of age. Males made up a larger proportion of all VRUs (59%), and were disproportionally represented among the age groups between 11–16 years and 30–79 years 79. Females were disproportionately represented in the 0–5 age group as well as in the 17–29 age group of the In-Depth dataset. Fig. 1b reports the VRU age distributions, stratified by sex among those in the VIPA Limited database. The highest proportion of interactions were observed among the 20—29 age groups and among both sexes. Males made up a larger proportion of all VRUs (42.3%). While the shape of the distribution among females was unimodal, the highest proportion of crashes among males was observed among the 20—29 and 50—59 age groups.



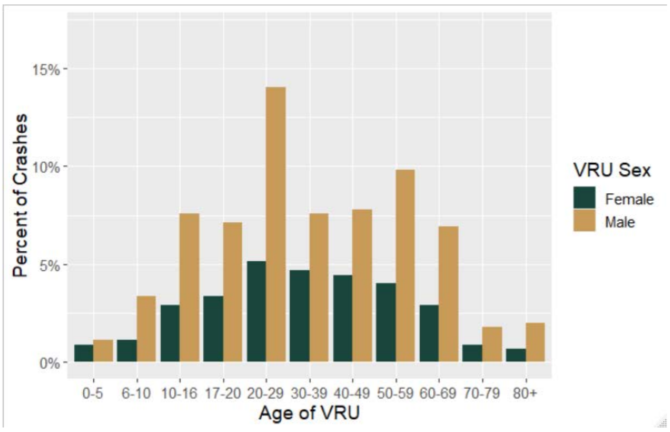
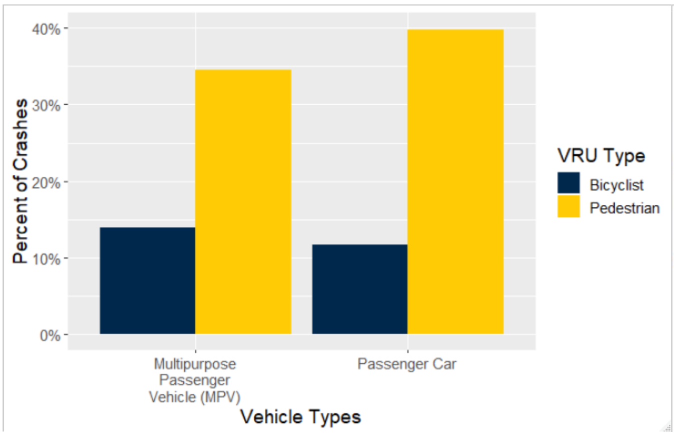
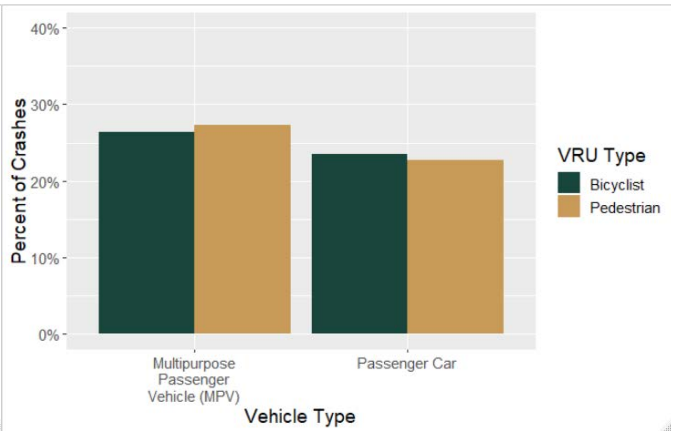


Fig 1a. (left) Age Distributions of VRUs in the VIPA In-Depth Database (n=137).
Fig 1b. (right) Age Distributions of VRUs in the VIPA Limited Database (n=434).

Figure 2a reports the percentages of VRU-motor vehicle interactions by VRU type. Pedestrians made up the majority of interactions in the VIPA In-Depth dataset. Passenger car-pedestrian interactions had a higher proportion (40.4%) than MPV-pedestrian interactions (34.8%). MPV-bicyclist and passenger car-bicyclist were proportionally the same (12%). Figure 2b reports the percentages of VRU-motor vehicle interactions by VRU type in the VIPA Limited dataset. MPV-bicyclist interactions made up 26.4% of total crashes while MPV-pedestrian interactions represented 27.4% of the interactions. Passenger car-bicyclist interactions made up 23.4% of all interactions, while passenger car-pedestrian interactions made up 22.8% of total interactions.





Fig, 2a. Vehicle Type Stratified by VRU Type in the VIPA In-Depth dataset (n=137).

Fig. 2b. Vehicle Type Stratified by VRU Type in the VIPA Limited dataset (n=434).

Figure 3 reports the distributions of the most commonly observed kinematics (VRU trajectories) among the vehicle types. Among passenger cars, the most common observed trajectories were the wrap trajectory (20.6%), the forward projection (16.1%) and roof vault (7.4%). Among MPVs, the most common trajectories were the forward projection (18.4%) and the wrap trajectory (14.0%).

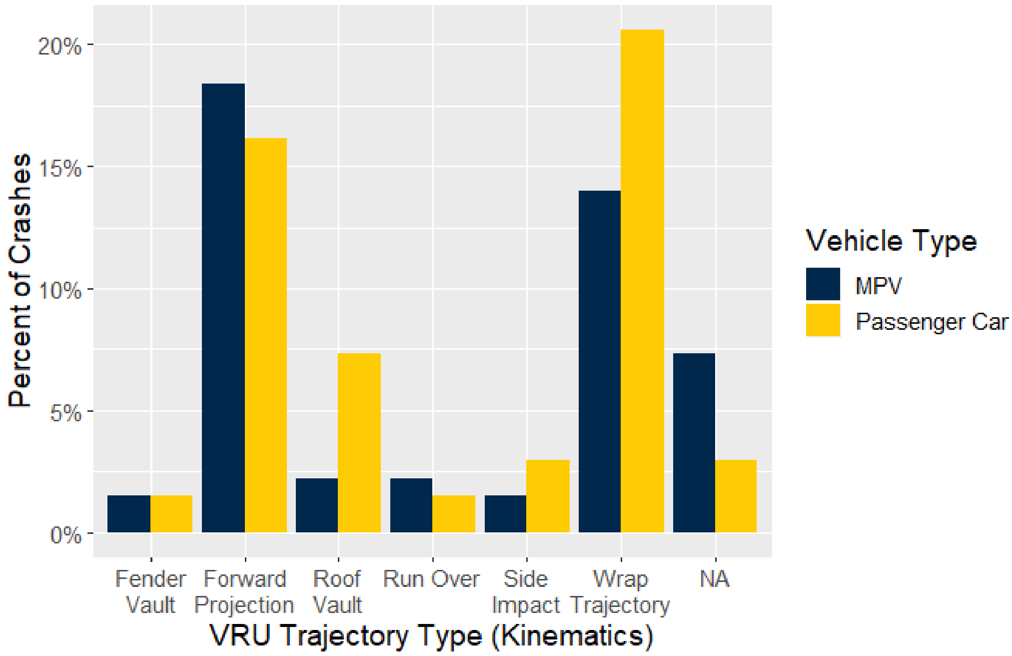


Fig. 3. Distribution of Most Commonly assessed VRU Trajectory Types (Kinematics) Stratified by Vehicle Types in VIPA In-Depth dataset (n=137).

Figure 4 reports the distribution of injury severity categories stratified by VRU type. Higher proportions of crashes among pedestrians were observed in all known injury groups. The highest proportion of injury severity observed was those among the slightly injured (Bicycle 13 %, Pedestrian 28%).

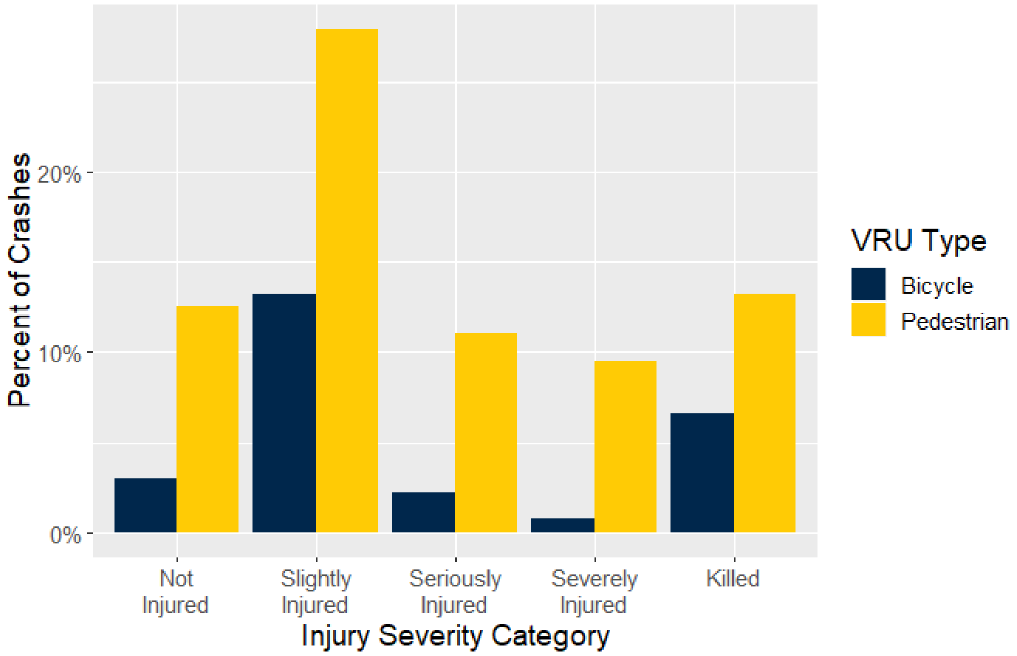


Fig. 4. Injury Severity Category Stratified by VRU Type in VIPA In-Depth Dataset (n=137).

Figure 5 reports the distribution of injury severity categories stratified by Vehicle Type. Passenger cars had a higher proportion of participants not injured when compared to MPVs. Slightly injured participants were the highest proportion of observed injury outcome among both vehicle types. Chi-squared tests showed no significant difference in distributions (p=0.43).

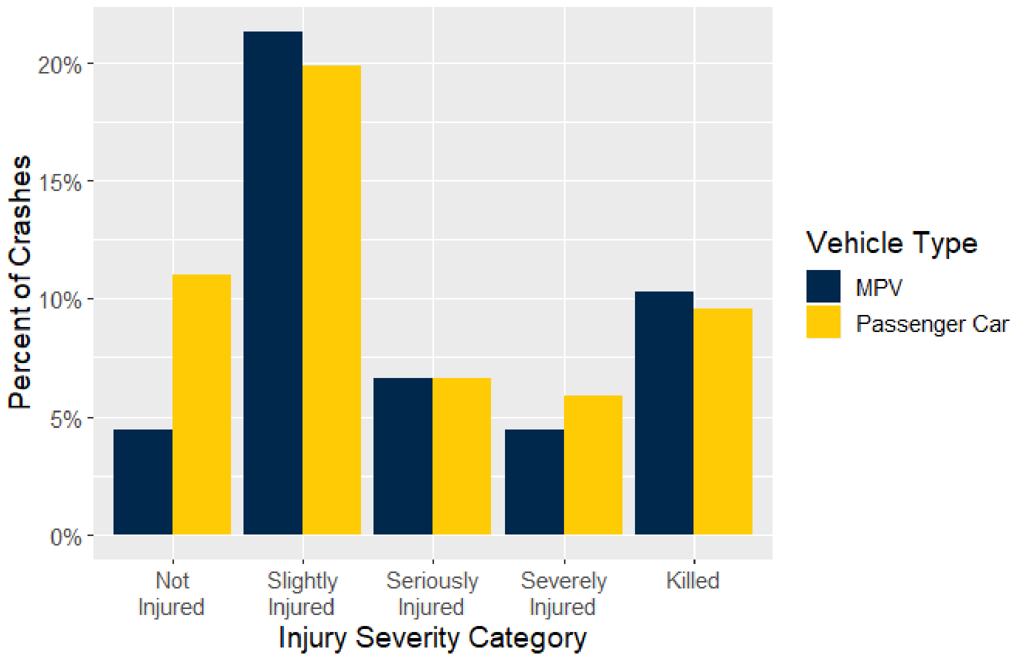


Fig. 5. Injury Severity Category Stratified by Vehicle Type .

IV. Discussion

Data collection efforts regarding VRU-motor vehicle interactions in the US have recently been limited and some conducted decades ago, may not reflect today's US vehicle fleet. VIPA, an interdisciplinary collaborative effort, aims to collect current high-dimensional data reflecting VRU-motor vehicle interactions that may enable engineers to examine more recent vehicle models and further improve countermeasures capable of improving motor-vehicle crash outcomes among VRUs. This analysis provided an initial overview of the most current VRU crashes and injuries from the VIPA network -- including demographics, kinematics, and injury severity.

Among both the VIPA In-Depth and the VIPA Limited datasets, those VRUs aged 20—29 years appear to be the most disproportionately represented. Within the In-Depth set, females made up a larger proportion of the total cases (19%), compared to males (13%). This was surprising as being male is typically a risk factor for being involved in a road traffic crash [9,10]. The excessive female risk was not observed in the VIPA Limited dataset, as males made up the majority of crash cases. We do not yet understand the factors underlying this observation.

In the VIPA In-Depth dataset, pedestrian-motor vehicle interactions were observed more frequently than bicycle-motor vehicle interactions. While passenger cars-pedestrian interactions were observed more than MPV-pedestrian interactions, the proportions of crashes among MPVs-bicyclists and passenger cars-bicyclists were the same (~13%). However, when compared to the sampling of the VIPA Limited dataset, there were similar distributions of VRUs among MPVs (bicyclists 26.4%, pedestrians 27.3%) and passenger cars (bicyclists 23.4%, pedestrians 22.7%).

The most common VRU trajectory types observed among MPVs and passenger cars was the forward projection (Overall 34%: MPV 18%, passenger car 16%) and the wrap trajectory (Overall 35%: MPV 14%, passenger car 21%). Wrap trajectories and forward projections have been consistently over-represented among VRU trajectories. For context, historical data from the United States describes the distributions of kinematic trajectories as wrap trajectories (45%), forward projections (35%), somersaults (13%), roof vaults (5%), and fender vaults (2%) [11, 12]. A convenience sample of videos depicting VRU-motor vehicle crashes demonstrated the wrap trajectory to be the most common VRU trajectory after collision [13]. *Han et al.* also demonstrated that roof vaults occurred at a higher rate of speed when the pedestrian is struck by a passenger vehicle versus SUVs and MPVs [13]. These findings are consistent with our observed proportions of vehicle type involvement in wrap trajectories versus roof vaults among MPVs and passenger cars.

Categorization of injury severity in the VIPA In-Depth dataset, most VRUs were coded as slightly injured (Bicyclists 13%, Pedestrians 28%). In the mid 1990's the Pedestrian Crash Data Study (PCDS) conducted similar case study selections and investigations of pedestrians. While the MAIS scores are not directly interpretable to VIPAs injury severity scores, there are similarities in the injury distributions. The frequency of MAIS in PCDS was also highest in the slightly injured group with a MAIS of "1" or "2" [6]. Additionally, in the PCDS, the least observed were those with no injury or killed. In the current VIPA In-Depth data, a greater percentage of cases were selected for inclusion where no injury occurred in order to provide data for automotive engineers to examine potential preventive measures along with a distribution across all injury categories [1].

Bicyclists that were killed comprised 7% of the observed cases and pedestrians killed made up 13% of the observed VIPA cases. Previous studies have estimated that ~70% of global pedestrian injury MAIS scores, and ~60% of those in the United States are between AIS 1 and 2, while those AIS scores above 5 make up 10% of all cases [11][14]. We observed similar injury severity among MPVs and passenger cars (chi-squared test comparing distributions 0.43) when not adjusting for impact speeds. This differs from findings from PCDS almost 20 years ago, wherein they observed higher risk of severe injuries from light truck vehicles when compared with passenger vehicles [15].

There are limitations to this study. This project was undertaken with an intent to provide current, real world data to automotive safety engineers to advance safety technologies that better protect vulnerable road users. Due to limitations in current active and passive safety technologies, the aim of VIPA is primarily toward the prevention of VRU crashes. The VIPA In-Depth dataset's requirement for vehicle contact/damage photos as well as detailed medical injury could have biased toward crashes with higher crash severity scores. However, our consortium balanced this bias with focused efforts to include low severity crashes. Overall, the distribution of kinematics and injury severity in this current In-Depth dataset is consistent with historical, as well as previously published peer reviewed studies. Secondly, VIPA's first year of data collection focused primarily on pedestrian, rather than bicyclist injury. As a result, the estimates for bicycle-motor vehicle interactions are likely underrepresented. This data is limited to cases from the state of Michigan located in the northern and middle portion of the US, and cases from the In-Depth dataset are limited to the screened cases with on-scene photos; as such extrapolation to larger populations may be inappropriate. Finally, as this data is observational and descriptive, causality cannot be inferred. Regardless of these limitations, VIPA represents a vigorous, interdisciplinary, primary data collection effort unseen in almost 20 years in the US.

V. CONCLUSIONS

The more current VRU data set reflects known recent increases in the proportion of MPV's in the US vehicle fleet. This has resulted in differential VRU interactions and injury proportions, as compared to the European and Asian fleets. In this study, forward projections and wrap trajectory interactions were the most prevalent VRU trajectory types that illustrated distinct observed injury severities with the highest incidences involving 20-29 year-olds. The distinct injury patterns observed with MPVs is the subject of several follow-up publications currently in preparation. VIPA data are uniquely poised to further document real time VRU crashes involving late model vehicles in current traffic way designs.

Disclaimer: This effort reflects the priorities of our consortium members who represent a substantial proportion of worldwide automotive manufacturers. VIPA has not been designed to replicate, disprove, or improve upon previous or concurrent studies undertaken for different purposes.

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