Crashworthiness Improvements of the Vehicle Fleet

Luke Gaylor, Rocio Suarez del Fueyo, Mirko Junge

Abstract The self-protection standards of the vehicle fleet were hypothesized to have decreased as a function of manufacturing year. The hypothesis was tested using GIDAS data from 2000-2015, for both the belted and unbelted populations. Occupant injury was assessed using an iteration of the New Injury Severity Score, the NISSx. Injury rates were described by point estimates and were plotted against vehicle manufacturing year. Vehicle mileage was considered an exposure measure when determining injury rates. For a given sample of injured occupants, the greatest decrease in injury rate was associated with a NISSx>1 (MAIS2+) injury. The reason for the strong reduction to this injury severity was attributable to the mitigation of 1≤NISSx<2.5 injuries. Logistic regression models were developed to identify factors that have caused this injury mitigation. Euro NCAP compliancy and a deployed frontal airbag for the belted population had significantly reduced effects of mitigating injury. Results also indicated the rate of 2.5≤NISSx<5 injuries has remained constant. Future development of vehicle platforms should consider safety measures to mitigate injuries of these severities.

Keywords Euro NCAP, injury rate, manufacturing year.

I. INTRODUCTION

The number of global road traffic deaths has plateaued since 2007. Yet when considering the global population growth and increased motorisation, road safety efforts have saved lives [1]. Taking a high-income country, like the United States for example, has shown encouraging results. When normalised against exposure, the US fatality rate in 2009 was 1.14 people per million miles travelled as opposed to a rate of 1.55 for the period 10 years earlier [2]. Research from Germany showed no raw difference in fatalities over the last 4-5 years, however the number of injured people has decreased as a function of the crash year [3].

A study which reviewed 21 years of GIDAS accident data revealed that the frequency of occupants being injured, for various AIS injury severities, has declined, near linearly, over time. The year of the crash was used to show this declining trend and was group into 5 year intervals. The reductions to injury rates were attributable to the enforcement of road safety policies and innovations in car engineering and emergency medicine [4]. To take this approach further, we hypothesis that occupant protection has improved as a function of vehicle manufacture year. This comes in light of a government report out of German which highlighted a constant reduction in the number of traffic related fatalities from 1997-2006, however the numbers of those heavily injured has remained relatively unchanged [5].

Sampling requirements for vehicle collision databases generally require an injured occupant; therefore collisions without injury are not recorded. Considering a sample of injured occupants, the study first aims to show how the frequency of the seriously injured occupants has reduced as a function of vehicle manufacture year. This is shown by point estimates of injury rates normalised by exposure. Secondly, a logistic regression model is developed which intends to predict the occurrence of these injuries as a function of specific crash parameters.

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II. MATERIALS AND METHODS

Materials

Data Source

GIDAS commenced in 1999 and investigates traffic accidents in two German regions. Any form of traffic accident the inspecting police officer deems an occupant injured is reported to the GIDAS team. Each case is then reconstructed and coded into the database with about 3,000 variables per case. Annually 2,000 accidents involving various traffic participants (vehicle occupants, pedestrians, cyclists, etc.) are recorded in a statistical random procedure representative of the national accident statistic [6]. The dataset included collisions from 2000-2015.

In addition to the sampling criteria outlined in the above assumptions, inclusion into the study required the occupants to be: travelling in a passenger car and seated in the front row. All occupants aged 15 years and younger were excluded [7].

The following assumptions were outlined to complement the hypothesis:

1. Crashworthiness is the ability of a structure to protect its occupants during an impact. Therefore, colliding against a vulnerable road user is not likely to inflict injury to the vehicle occupant. These collisions were excluded from the analysis.
2. The expected lifespan of a vehicle in Europe varies from 12-15 years [8]. To ensure sufficient data, a conservative lifespan of 15 years was selected. As the available dataset to the analyst included data from 2000 onwards, all vehicles manufactured prior to 1985 were excluded
3. Medical documentation in collision databases serves 2 main goals: (1) Document the main diagnoses and treatment for which monetary compensation can be claimed and (2) document sufficiently to fulfil the minimal legal requirements [9]. To eliminate the threat of any bias from slightly-injured, financially motivated occupants, a minimum injury standard was set. That required 2x AIS1+ injuries, NISSx>1.
4. The class of vehicle owner is dependent on the age of the vehicle. In Germany, regardless of vehicle age, monthly tax rates for leasing are calculated on the new retail price. Thus, it would not be economical for vehicles to be leased over extended periods. Additionally, vehicles experience a rapid depreciation in value over time, therefore the majority of people owning older vehicles are anticipated to be students. We hypothesis the following vehicle owner groups:
    a. Vehicle age < 3 years: Leased vehicles driven by educated professionals
    b. Vehicle age between 4-7 years: Family cars
    c. Vehicle age > 7 years: vehicles driven by students. Fatal collisions with teenager drivers showed that the majority were driving vehicles between 6-11 years [32]
    d. The influence of the unemployed was ignored as they have limited access to transport measures [33]
5. Any vehicle which appeared in the database was damaged beyond repair and thus could not reappear at a later time
6. ESC aims to prevent a possible instability of a vehicle when a car does not follow the steering angle [10]. It has shown to yield significant effectiveness estimations [11]. The issue with ESC is that it has mitigated injuries by avoiding the accident all together. Thus the crashes do not appear in accident databases and our hypothesis cannot be tested with the regression model.

This resulted in a total of 5354 collisions fitting our sample criteria. The Venn diagram in Figure 1 describes the distribution of collisions. Initially, ~46,000 collisions involved an occupant seated in a passenger vehicle. Applying initial filtering, it was shown that:

- ~5,600 were injured to minimum injury severity as outlined in 3 (shaded in green)
- Majority of the sample were vehicles with vehicle manufacture year post 1985 (shaded in yellow) and seated in the front row (shaded in purple)
- ~3,000 collisions involved those seated in a passenger vehicle but did not collide against a fixed object or vehicle (outside the blue shading)

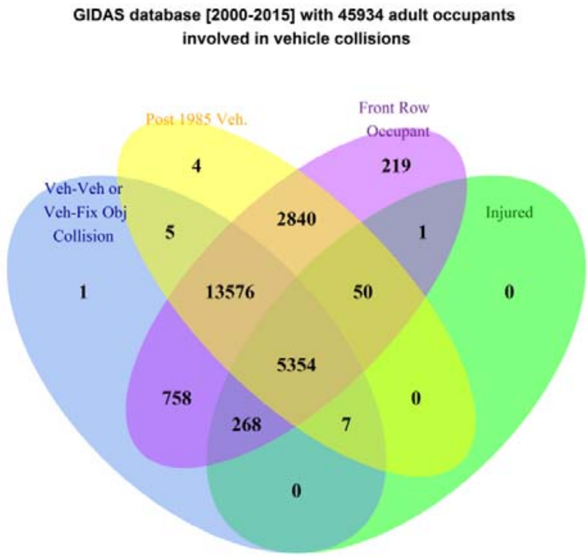

Figure 1 Venn diagram showing initial filter criteria applied to the GIDAS data

Methods

Injury Scaling

The measure of injury scaling was based on an adaption of the New Injury Severity Score (NISS) and consequently the Abbreviated Injury Score (AIS). The following section explains the adaption. The NISS takes the 3 most severe injuries and aggregates without distinguishing body regions [12]. The scale transformation from an ordinal to ratio scale was achieved by squaring the AIS-values [13];

$$NISS \coloneqq \sum_{i=1}^{3} AIS_{[i]}^{2}$$

where *i* denotes different AIS-coded injuries. However it can be shown that this transformation is not injective, i.e. there are cases were more than one injury triple leads to a given NISS value. Table 1 outlines the differences between certain injury severities for the different scaling methods. An AIS triple refers to the (potential) three different injuries suffered by the occupant.

TABLE I

TABLE I SHOWS THE EQUIVALENCE BETWEEN THE AIS TRIPLES OF THE MOST SEVERE INJURIES, NISS SCORES AND THE NISSX COEFFICIENT FOR THE LOWER INJURY SEVERITIES

AIS triple	NISS	NISSx	AIS triple	NISS	NISSx
1, 0, 0	1	0.29	2, 2, 1	9	2.46
1, 1, 1	2	0.58	3, 0, 0	9	3.24
1, 1, 1	3	0.87	2, 2, 2	12	3.25
2, 0, 0	4	1.08	3, 1, 0	10	3.53
2, 1, 0	5	1.37	3, 1, 1	11	3.82
2, 1, 1	6	1.67	3, 2, 0	13	4.32
2, 2, 0	8	2.17	3, 2, 1	14	4.61

It is therefore proposed one should convert the ordinal scale AIS code to an interval scale, known here on in as AISx. The proposed exponential transformation is then injective and linearizes the AIS scale with respect to lethality.

$$AISx_{[i]} \coloneqq 25 * \frac{(e^{AIS_{[i]}} - 1)}{(e^{5} - 1)}$$

In the same way as NISS, scaled from 0 to 75, the injury severity of an AIS triple can be calculated by the sum of the respective AISx. This leads to the definition of the NISSx coefficient, also scaled from 0 to 75.

$$NISSx \coloneqq \sum_{i=1}^{3} AISx_{[i]}$$

The linear relationship of the mortality rate for lower NISSx-injury severities is shown in Figure 2.

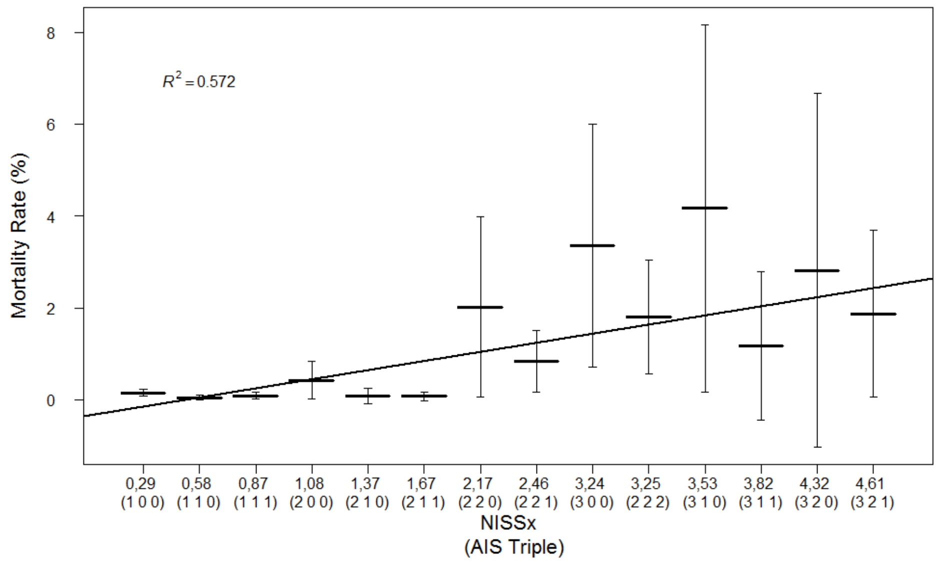

Figure 2 The linear mortality rate amongst the lower severity NISSx injuries

Point estimates of injury rate

Point estimates for the injury rate for each manufacturing year were calculated using:

$$IR_i = \frac{\sum injured_i}{\sum driving\ population_i}\ ;i = manufacture\ year\ [1980{,}2012]$$

For sampling reasons, vehicle manufacture years were grouped into two year intervals at either tail and vehicles manufactured between 1990-2006 were assessed on a per-year basis. To increase certainty that a reduction in the rate of injuries had occurred, 95% confidence intervals (CI) for the point estimates were developed using a Clopper-Pearson approximation [14]. The CI advises the reader of a range of estimations that the point estimate should lay between. The distribution within this range is not normal, but uniform.

A retrospective study of Canadian data in 1980 identified the head/face and chest as the most frequently injured body regions [15]. Thus if vehicles have become safer, the greatest injury mitigation effect should have been seen within these body regions. From here on in the abbreviation HFN_THO referred to injury incurred to the head/face/neck and/or thorax.

An exposure measure was needed to account for the risk of people incurring injury. In 2008 a government report was released which predicted the anticipated mileage of a specific vehicle as a function of vehicle age and type [16]. The year the report was released correlates to the mean collision year. This would form the basis of the exposure measure. For example, if you drive a newer vehicle, your risk is greater because you drive more kilometers than with an old vehicle. Furthermore, if you drive a large vehicle, you would drive a greater distance than smaller vehicle and consequently have a greater probability to be involved in a vehicle collision.

The predicted mileage of each manufacturing year interval was determined. Resultant injury rates were normalised by:

$$NIR_i = IR_i * \frac{1000}{\overline{VMT_i}}\ ; \qquad where\ \overline{VMT_i} = \frac{\sum VMT_i}{n_i}$$

Linear trend lines were fit to the normalised point estimates to assist the reader in inference of results.

Logistic regression model to predict the occurrence of injury

A series of logistic regression models were formulated to predict the occurrence of HFN_THO injuries at various severities. Models were additionally stratified by belt status. The following section outlines the collision parameters deemed important to predict injury.

In Europe frontal airbags are passive systems designed to work together with the load limiter and pretensioner of the safety belt. This is different to conditions in the US where Federal Motor Vehicle Safety Standards 208 (FMVSS208) specifies crash testing with an unbelted dummy. Manufacturers have the option to certify vehicles using the sled test specified in the standard versus the 48 km/h (30 mph) vehicle-into-barrier crash test [17]. They have a larger volume and interact in a different way compared to the European counterparts. Their influence in injury prevention is investigated amongst the belted population.

The technical-severity of the collisions was described by the change of velocity (Δv) of the car in which an injured occupant was travelling. In GIDAS this is defined as the absolute difference of the vector between immediate post-crash and pre-crash velocity [18].

As indicated in the 2015 GIDAS study, the orientation of the collision was a significant factor in predicting injury [4]. Collisions were consequently defined as frontal, small overlap, side, rear or rollover. This study extends on the original understanding by combining the collision orientation with the belt status, where population sizes were sufficiently large. The seatbelt is best suited for frontal collisions [19], therefore by setting this as the baseline, a relative measure of injury risk for unbelted frontal-occupants and other orientations can be obtained.

The concept of consumer testing was introduced to educate the car-buying public about relative safety performance of competing vehicles [20]. It was in 1997 that the first European New Car Assessment Program (Euro NCAP) results were released [21]. This involves replicating a vehicle collision whereby a crash dummy measures the forces and deflection incurred. Measurements are assessed using dummy-based injury risk functions and aggregated results are made available to the public. The majority of new vehicles score very well during this process indicating a safe environment for the occupant during a collision. Lie and Tingvall found a correlation between the Euro NCAP scores and risk of serious and fatal injury [22]. They found that a 12% per star risk reduction was associated for severe and fatal injured occupants, meanwhile no association was found between Euro NCAP scores and minor injury crashes. Contrary in an efficacy case-control study of Euro NCAP vehicles, it was shown that no statistically significant relationships between the EuroNCAP safety scores and real-world death or severe injury outcomes existed [23]. As such Euro NCAP compliancy was deemed an important parameter to be assessed.

Two significant advancements in seat belt technology were the introduction of belt pretensioner and the load limiter. The pretensioning device pulls the belt snug as a crash begins; meanwhile load limiters allows the belt to yield slightly during a crash to reduce the risk of injuries from belt loading. The purpose of the pretensioner is to maximise the time and distance over which belt forces are applied and applies greater restraining forces earlier during the collision [24, Chp 8]. Minimising the belt slack reduces the risk of submarining [25], whilst the combination of devices has been shown to reduce crash dummy loading in vehicle collisions with barriers [26].

Literature indicated that belt loading had contributed to thoracic injuries under certain loading conditions, especially among older occupants [15, 27-29]. Thus load limiters were coupled with the pretensioners in the 1990s. The coupling of this belt technology is expected to reduce the frequency of HFN_THO injury. The coupling of this belt technology occurred around the same period that Euro NCAP was introduced. Therefore, a test of correlation was needed to ensure no confounding of results.

Additionally the occupant age and collision partner were included as predictor variables in the model. In keeping with the assumptions, the categories of vehicle owner were included. Insurance premiums remain high for younger, less experienced and more likely to take risks drivers. For this reason, one can expect differing levels of injury predictions within for the three-level category.

III. RESULTS

Occupant injury as a function of vehicle manufacture year

The injury rates, normalised to exposure (taken here as predicted mileage) for HFN_THO at different injury severities were plotted for NISSx>1 and NISSx>2.5. The relationships are shown in Figure 3. The NISSx>2.5 injury severity represents an occupant incurring at least one AIS3 injury, or three AIS2 injuries.

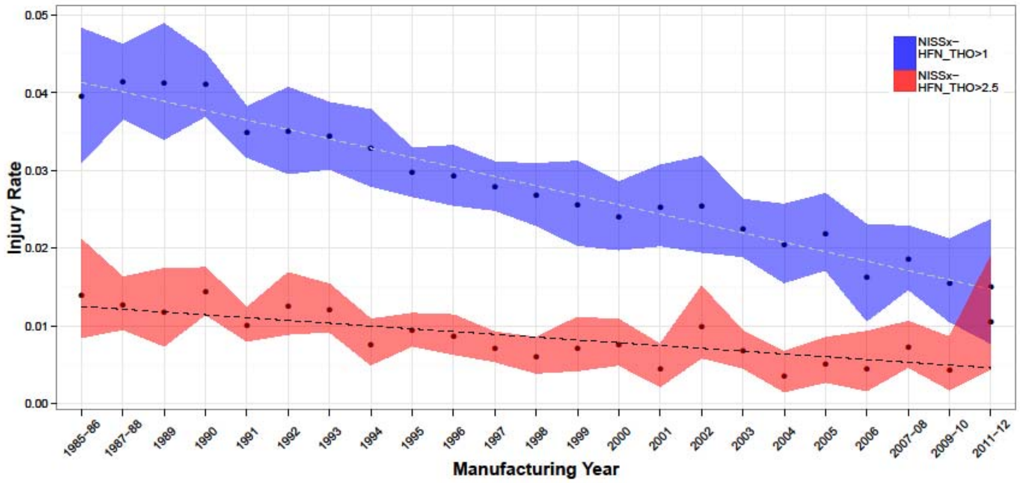

Figure 3 Point estimates for the incurred injury as a function of vehicle manufacture year. Vehicle mileage was treated as an exposure measure. The shaded regions show the 95% confidence intervals. The dashed lines represent the linear trend line fitted to the point estimates.

When plotted against manufacturing year, a declining NISSx>1 HFN_THO injury rate was apparent. A similar trend, but of much lower magnitude occurred for the NISSx>2.5 HFN_THO injuries. The downward trend of the NISSx>1 curve was supportive of the proposed hypothesis. The curves may not represent the most severe injuries, but the ones most frequent in vehicle collisions [15].

The NISSx>1 group may be termed an open injury–severity group as it encapsulated a range of severely injured occupants and those fatally injured. It is also well accepted that fatalities have reduced as a function of manufacturing year and may be confounding the slope. Therefore those injured within the NISSx>1 environment were stratified further by injury severity. Groups were created by separating HFN_THO injuries into 1≤NISSx<2.5 and 2.5≤NISSx<5 populations. As an upper limit was applied to the injury severity, these groups are referred to as closed groups. Those injured NISSx>5 were not investigated due to small sample size. In a similar manner, the point estimates were plotted for the so called closed-group populations.

Figure 4 shows a reduction to the incurred 1≤NISSx<2.5 HFN_THO injury rate, yet no difference for the 2.5≤NISSx<5 HFN_THO group. This result suggests that the significant decline in NISSx>1 HFN_THO injuries as indicated in Figure 3 is more reflective of those HFN_THO injuries incurred at the 1≤NISSx<2.5 severity. Consequently, a logistic regression model was sought to clarify such.

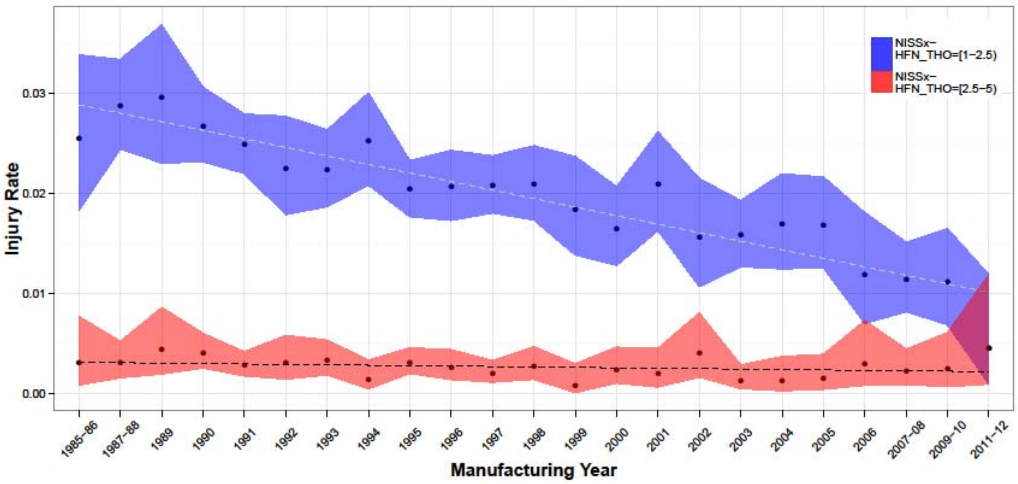

Figure 4 Point estimates for the closed injury as a function of vehicle manufacture year. Vehicle mileage was treated as an exposure measure. The shaded regions show the 95% confidence intervals. The dashed lines represent the linear trend line fitted to the point estimates.

Logistic regression model to predict the occurrence of injury

As indicated in the methods section, the possibility of a correlation between coupled belt technology and the introduction of Euro NCAP testing protocols had to be investigated. As a first step, the respective vehicle fleet penetration in the sampling population was plotted.

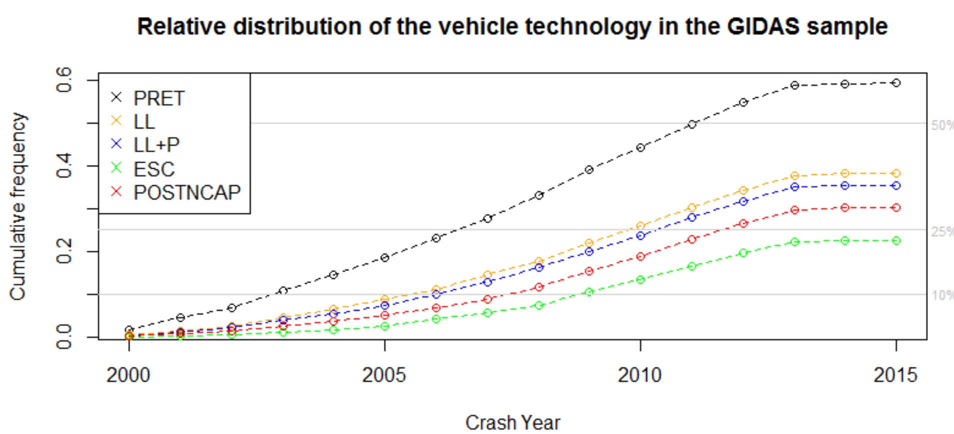

Figure 5 The penetration of various safety systems and consumer-test-built vehicles shown as a function of each crash year. PRET = pretensioner, LL = load limiter, ESC = electronic stability control

Figure 5 indicates that for the sample data, in year 2015, we have a 60% penetration of pretensioners. Likewise a 30% penetration of ESC occurs. It is obvious that the introduction of the load limiter occurred with the coupling of the pretensioner, as evident with the curves yielding very similar trends. The penetration of Euro NCAP vehicles in the sample does not show a difference compared to vehicles with coupled belt technology. The catalyst for this is most likely the introduction of small overlap test. As a result vehicles structures became stiffer to combat crash forces when only one primary loading member was engaged. Consequently the load limiter and pretensioner were coupled to combat the increased loading from such a test. For the remaining analysis, only Euro NCAP was considered as a predictor variable as thus was assumed to include any benefit associated with the seat belt.

Logistic regression models were then developed for the two populations (unbelted + belted and belted only) and summarised in Table 2. The outcome of interest was the occurrence of a NISSx>1 (open group) HFN_THO injury. It is worthy to note that N does not equal the value obtained in the Venn Diagram. That is because additional criteria was applied to the original 5354 collisions (for example, collisions with an unknown belt status unknown were removed).

TABLE II

SUMMARY TABLE FOR THE LOGISTIC REGRESSION MODELS STRATIFIED BY BELT STATUS. THE OUTCOME OF INTEREST IS THE OPEN-INJURY SEVERITY, WHERE N=INJURED AND N= SAMPLE SIZE. THE UNDERLINED VARIABLES ARE SIGNIFICANT $P<0.05$

	Belted and unbelted occupants: HFN_THO NISSx>1 n=1959 , N=5133			Belted occupants: HFN_THO NISSx>1 n= 1360, N=4327		
Variable	B (SE)	**OR**	95%CI	B (SE)	OR	95%CI
Intercept	-1.82	**0.16**	0.13-0.20	-1.47	**0.23**	0.18-0.29
Age						
<65	Baseline			Baseline		
65+	0.65	**1.91**	1.57-2.33	0.53	**1.69**	1.37-2.09
Δv	0.03	**1.03**	1.03-1.04	0.02	**1.02**	1.02-1.03
Accident Config (+ Belt status)						
Front + Belt	Baseline			Baseline		
Front + Unb	0.86	**2.36**	1.79-3.10			
Rear	0.19	**1.21**	0.96-1.53	0.11	**1.12**	0.87-1.43
Rollover + Belt	0.54	**1.71**	1.39-2.11	0.43	**1.55**	1.24-1.94
Rollover + Unb	1.23	**3.43**	2.02-5.94			
Side + Belt	0.42	**1.53**	1.30-1.80	0.22	**1.25**	1.05-1.49
Side + Unb	0.92	**2.51**	1.62-3.90			
Small Overlap	0.08	**1.08**	0.82-1.43	0.13	**1.13**	0.83-1.53
Owner						
Family	Baseline			Baseline		
Leasing	-0.27	**0.76**	0.57-1.01	-0.31	**0.73**	0.53-1.00
Student	-0.13	**0.88**	0.74-1.04	-0.15	**0.86**	0.72-1.03
Opponent						
Car	Baseline			Baseline		
Object	0.51	**1.67**	1.44-1.94	0.40	**1.50**	1.26-1.77
Other types of vehicle	0.31	**1.37**	0.91-2.06	0.22	**1.25**	0.78-1.96
Truck	0.38	**1.46**	1.20-1.78	0.32	**1.39**	1.11-1.73
Euro NCAP						
Before	Baseline			Baseline		
After	-0.18	**0.83**	0.70-0.97	-0.22	**0.80**	0.67-0.95
Frontal Airbag						
Not deployed		-	-	Baseline		
Deployed		-	-	-0.09	**0.91**	0.78-1.06
		Pseudo R^2 =0.147			Pseudo R^2 =0.062	

The risk of injury for the occupant was represented by the odds ratio (OR) in Table 2. For the belted-only population risks were consistently lower in magnitude than those for the belted and unbelted population (right column compared to left). All crash configurations relative to frontal resulted in a greater risk of injury (OR > 1). The regression model that accounted for different belt status indicated greater risk of injury for the unbelted groups relative to those involved in the same configuration yet belted. A collision against anything other than another car resulted in greater injury risk for both models (OR > 1). Both the owners classed as leasing and students yielded lower OR than the family vehicles. The Euro NCAP parameters indicated a positive association of injury mitigating for the compliant models. Although not statistically significant, the deployed frontal airbag provided benefit amongst the belted population.

Yet the regression models had been developed for the open-injury groups. True benefits of the injury mitigation may have been masked as the outcome variable considered those fatally and non-fatally injured. Therefore secondary regression models were developed and were stratified by injury severity. In a similar method to validating the point estimates graphs, the so-called closed injury groups became the outcome of interest. Consider the following example: the outcome of interest becomes a 1≤NISSx<2.5 HFN_THO injury. Given that an upper limit for incurred injury severity (the outcome of interest) has been defined, it would not be sensible to consider the range of those injured both above and below this injury severity. Therefore, an upper limit of overall injury severity ($NISSx_{ALL}$) was also applied. As such, the outcome of interest becomes a 1≤NISSx<2.5 HFN_THO injury when the occupant is injured within the 0.5≤ $NISSx_{ALL}$ <2.5 constraints. This was additionally explored for a 2.5≤NISSx<5 HFN_THO injury. Tables 3 and 4 in the Appendix outline the results from the logistic models.

The regression models that considered the lightest injury severities in Table 3 showed that old age and Δv were significant predictors of injury for both closed-group injury severities. The OR for an unbelted frontal occupant yielded greater values of incurring a 1≤NISSx<2.5 HFN_THO injury than the baseline, however a lower OR was obtained for the greatest injury severity group (Table 4 - 2.5≤NISSx<5 HFN_THO injury). This reverse relationship was also seen for rear collisions. The Euro NCAP compliant vehicles had significantly lower OR for the 1≤NISSx<2.5 HFN_THO group however no association for the 2.5≤NISSx<5 HFN_THO group existed. The deployed frontal airbag was associated with a significantly lower risk of injury for the 1≤NISSx<2.5 injured but belted occupants (OR = 0.84 in Table 3).

IV. Discussion

Injury rates of HFN_THO injuries at various injury severities were plotted as a function of manufacturing year. Exposure to risk was considered and point estimates were normalised in regards to predicted mileage. Logistic regression models were then developed to identify factor which led to the trends evident in the injury plots.

The rate of injury as a function of model year shows a decreasing trend for the period 1985-2012. Linear models were applied to the point estimates by best fit to provide an indication of the magnitude of this decrease. One notices that for NISSx>1 HFN_THO injuries, a greater absolute decrease in the injury rate occurred than for the NISSx>2.5 HFN_THO injuries. Previous studies have also shown a linear decrease for injured occupants as a function of crash year [3-4]. By defining the crash year as the independent variable, one can assess the efficacy of the vehicle fleet as well as any changes in urban planning and/or legislation. However the aim of the presented research was to show a reduction in the injury rate solely attributable to the advancements associated with vehicle manufacture year. Ernstberger and colleagues proved a decreasing injury rates occurred across AIS2+ and AIS3+ whereby a greater reduction was attributable to the AIS2+ severity [4]. Although they grouped crash years into 5 year intervals, similar results were proved in the current study.

The differing slopes in the two graphs suggested that when assessing the so-called open injury severities (ie, NISSx>1, NISSx>2.5 HFN_THO) the true injury mitigation capacity may have been biased. Therefore the same methodology was applied to closed injury severity groups. In doing so, the results would indicate to which injury severity the true reduction in injury rate could be attributable. Results indicated that a significant reduction in the 1≤NISSx<2.5 HFN_THO injury rate occurred, whilst the 2.5≤NISSx<5 HFN_THO group plateaued over the assessed period. This result suggests that the sharp decrease in NISSx>1 HFN_THO injuries is caused by the saturation 1≤NISSx<2.5 HFN_THO injuries. As the rate of 2.5≤NISSx<5 HFN_THO injuries remained relative constant, yet the NISSx>2.5 HFN_THO graph showed a reduction, the cause of such would be traced to a reduction in fatalities. Results from the German government report showed road accident fatalities were 10,631 in 1992 and 3,377 in 2014 [3], whilst no definitive trend had occurred for heavily injured occupants [5].

A regression model was then sought to identify causes for the effect (the reduction in injury rate). Primary models were developed for the open injury groups. Models were additionally stratified by belt status. Absolute values of ORs were slightly lower in the belted models. The model which accounted for different belt status' emphasized the importance of wearing a seat belt. Relative to a belted occupant in a frontal collision, the OR for NISSx>1 injury for an unbelted occupant was significantly higher (OR=2.36, CI[1.79-3.10]). This result was obtained despite an overall buckle-up rate of ~85% within the accident population. Although not significant, the ORs for a rear collision remainder higher than a frontal collision. This is most likely accounted to the incorrect position of the head rests or their non-use. Likewise, non-significant increased ORs were seen for small overlap collisions. This may have resulted from less structural engagement and greater magnitude accelerations that occur in small overlap collisions and not in full width frontal collisions. Side collisions had significantly greater odds of injury relative to frontal collisions, a result also shown in the Ernstberger study [4]. This is due to the limited support offered by the side structure and the closeness of the intruding object in a side collision.

Additionally the Ernstberger study showed the increased odds of injury associated when one collides against a commercial vehicle or fixed object, similar trends were presented in this study. In a study of American fatality data, Bedard and colleagues confirmed that older drivers are more vulnerable to the traumatic effects of crashes [30]. Whilst fatalities were not specifically investigated in this study, they were included in the open injury groups and thus our results show increased susceptibility to injury (fatal and non-fatal) for the elderly population. These statistics are alarming given their expected boom in the numbers of older adults predict in the coming years [31]. The impact severity was assessed on a continuous scale and the OR showed a significant increase associated per unit increase of severity (Δv in km/h). Although the Ernstberger study investigated 21 years of collisions, they provided no correction factor and group Δv into 10km/h intervals, as well as not accounting for exposure. Nonetheless they also found a significant increase associated per increase, which supports the results presented here. The results associated with the hypothesized vehicle owner did not yield any significant results; they suggested that the drivers of newer vehicles were less likely to be injured as too were students. Given no associated significance within these groups, results should be interpreted with caution. The Euro NCAP compliant vehicles were at significantly lower odds of causing injury across both populations. The associated ORs were slightly lower for the belted-only population than for both belt-status groups. This reason for such is most likely due to the manner in which vehicles are designed. For frontal consumer tests the dummy must be belted. Seat belts have been shown to be best suited for frontal collisions [19]. The airbag data suggested a protective effect associated with the deployment, although not significant. This is in conflict with the other GIDAS study which associated a significant reduction associated with the availability of an airbag, not necessarily if the airbag deployed or not [4]. Nonetheless the results associated with the airbag in the present study add to the body of knowledge of improved injury mitigation associated with a deployed airbag.

To further investigate the injury mitigation potential of the Euro NCAP compliant vehicles and those with a deployed airbag, additional regression models were developed. For these secondary models upper limits to the incurred injury were defined. The first model only assessed individual sustaining injury with the $0.5 \leq NISSx_{ALL} < 2.5$ constraints. The outcome of interest then became a 1≤NISSx<2.5 HFN_THO injury. Again the greatest protective effect associated with Euro NCAP compliancy was seen amongst the belted population, a result that was statistically significant. A deployed frontal airbag was also associated with significantly lower odds of injury for the same population. Meanwhile no association was apparent for Euro NCAP compliant vehicles and a 2.5≤NISSx<5 HFN_THO injury. Adverse effects are associated with both Euro NCAP compliant vehicles and a deployed airbag when only assessing the belted populations, however no significance is obtained. Caution must be issued when interpreting these results as the number of injured occupants in this more severe category is much lower than the lower severity injury (as per n in the appended tables). However conclusions may still be drawn from such a result. The odds of suffering a 1≤NISSx<2.5 HFN_THO injury when seated in a Euro NCAP compliant vehicle or being belted occupant with a deployed airbag are significantly lower. The analysis has indicated an efficacy measure for these factors for a given injury severity. No efficacy was associated for an injury severity of greater magnitude. This results suggest that engineers need to improve vehicle safety standards to combat the risk of suffering a 2.5≤NISSx<5 HFN_THO injury.

Several limitations must be considered in the following study. Although the GIDAS database is deemed representative of the national statistic, results indicated that despite 15 years of collecting data, the majority of the HFN_THO injured population was within the 1≤NISSx<2.5 injury severity bounds. Fewer than 150 accidents occurred where occupant injury was 2.5≤NISSx<5. Secondly, the rate of vehicle technologies appearing in the sampling population has showed slowed rates of penetration, despite an expected vehicle lifespan of 17 years.

The cumulative frequency plot showing the penetration of vehicle technology plateaus over that last few years. This is due to a significant number of collisions that have not completed the full investigation cycle. Thus it will be expected that penetrations rate of technology would increase with collision year. As a result, the conclusion presented here can be assumed a minimum standard of the current crashworthiness of the vehicle fleet. Additionally, ESC has been shown to have great crash avoidance efficacy, however its associated injury mitigation potential cannot be studied in the implemented approach, as the collision has been avoided. Only the benefits associated with Euro NCAP compliancy was assessed, further research should investigate the influence of performance in these tests.

V. CONCLUSIONS

HFN_THO injury rates as a function of manufacturing year were analysed for two injury severities and were shown to decrease. The rate of NISSx>1 HFN_THO injuries has reduced substantially more than NISSx>2.5 HFN_THO injuries. The reason for the vast reduction in NISSx>1 HFN_THO injuries was attributable to the reduction in 1≤NISSx<2.5 HFN_THO injuries. Logistic regression models were than developed to identify factors which may have caused the reduction seen in 1≤NISSx<2.5 HFN_THO injuries. Results indicated that Euro NCAP compliant vehicles and the presence of a deployed frontal airbag when belted are associated with significantly reduced risk of injury. Whilst the rate of 1≤NISSx<2.5 HFN_THO injuries has reduced as a function of model year, the rate of 2.5≤NISSx<5 HFN_THO injuries has plateaued. This suggests that the vast reduction in NISSx>1 HFN_THO injuries is due to the saturation of 1≤NISSx<2.5 HFN_THO injuries. The regression models showed no association between Euro NCAP compliance and a frontal deployed airbag for injuries at this greater injury severity. Future vehicle engineers need to consider safety measures that will reduce the rate of 2.5≤NISSx<5 HFN_THO injuries.

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VII. APPENDIX

TABLE III

SUMMARY TABLE FOR THE LOGISTIC REGRESSION MODELS STRATIFIED BY INJURY SEVERITY. THE OUTCOME OF INTEREST IS THE CLOSED-INJURY SEVERITY, WHERE N=INJURED AND N= SAMPLE SIZE. THE UNDERLINED VARIABLES ARE SIGNIFICANT P<0.05

	Belted and unbelted occupants: HFN_THO = $1 \le NISSx < 2.5$, $[0.5 \le NISSx_{ALL} < 2.5]$ n=1306 , N=4418			Belted occupants: HFN_THO = $1 \le NISSx < 2.5$, $[0.5 \le NISSx_{ALL} < 2.5]$ n=1160 , N=4076		
Variable	B (SE)	**OR**	95%CI	B (SE)	OR	95%CI
Intercept	99.99	**0.23**	0.18-0.29	-1.40	**0.25**	0.19-0.32
Age						
<65	Baseline			Baseline		
65+		**1.57**	1.25-1.95	0.42	**1.53**	1.22-1.91
Δ v		**1.02**	1.01-1.02	0.02	**1.02**	1.01-1.02
Accident Config (+ Belt status)						
Front + Belt	Baseline			Baseline		
Front + Unb		**2.56**	1.89-3.46			
Rear		**1.20**	0.94-1.53	0.13	**1.13**	0.88-1.46
Rollover + Belt		**1.46**	1.16-1.84	0.36	**1.44**	1.14-1.82
Rollover + Unb		**1.38**	0.68-2,68			
Side + Belt		**1.25**	1.04-1.50	0.19	**1.21**	1.00-1.45
Side + Unb		**2.1**	1.27-3.43			
Small Overlap		**1.05**	0.76-1.44	0.12	**1.13**	0.81-1.55
Owner						
Family	Baseline			Baseline		
Leasing		**0.73**	0.53-0.99	-0.27	**0.76**	0.55-1.06
Student		**0.85**	0.71-1.02	-0.18	**0.84**	0.69-1.01
Opponent						
Car	Baseline			Baseline		
Object		**1.51**	1.28-1.79	0.38	**1.47**	1.22-1.75
Other types of vehicle		**0.99**	0.60-1.57	-0.15	**0.86**	0.49-1.43
Truck		**1.4**	1.12-1.74	0.33	**1.39**	1.10-1.75
Euro NCAP						
Before	Baseline			Baseline		
After		**0.82**	0.69-0.98	-0.22	**0.80**	0.67-0.96
Frontal Airbag						
Not deployed		-	-	Baseline		
Deployed		-	-	-0.17	**0.84**	0.72-0.99
	Pseudo R^2 =0.055			Pseudo R^2 =0.044		

TABLE IV

Summary table for the logistic regression models stratified by injury severity. The outcome of interest is the closed-injury severity, where n=injured and N= sample size. The underlined variables are significant p<0.05

	Belted and unbelted occupants: HFN_THO = 2.5≤NISSx<5, [0.5≤$NISSx_{ALL}$<5] n= 129, N=4707			Belted occupants: HFN_THO = 2.5≤NISSx<5, [0.5≤$NISSx_{ALL}$<5] n=114, N=4321		
Variable	B (SE)	**OR**	95%CI	B (SE)	OR	95%CI
Intercept	99.99	**0.00**	0.00-0.01	-5.89	**0.00**	0.00-0.01
Age						
<65	Baseline			Baseline		
65+		**3.51**	2.22-5.41	1.07	**2.92**	1.78-4.64
Δ v		**1.04**	1.02-1.05	0.03	**1.04**	1.02-1.05
Accident Config (+ Belt status)						
Front + Belt	Baseline			Baseline		
Front + Unb		**0.52**	0.12-1.45			
Rear		**0.42**	0.10-1.18	-0.66	**0.52**	0.12-1.49
Rollover + Belt		**2.04**	1.13-3.62	0.79	**2.20**	1.20-3.98
Rollover + Unb		**6,29**	2,00-16,54			
Side + Belt		**1.57**	0.97-2.50	0.53	**1.71**	1.04-2.77
Side + Unb		**2.73**	0.89-6.78			
Small Overlap		**1.06**	0.40-2.35	-0.33	**0.72**	0.21-1.81
Owner						
Family	Baseline			Baseline		
Leasing		**0.70**	0.25-1.70	-0.52	**0.59**	0.17-1.64
Student		**1.19**	0.72-2.03	0.48	**1.61**	0.94-2.90
Opponent						
Car	Baseline			Baseline		
Object		**1.49**	0.94-2.35	0.40	**1.49**	0.92-2.41
Other types of vehicle		**4.07**	1.74-8.63	1.48	**4.40**	1.80-9.67
Truck		**2.09**	1.20-3.54	0.77	**2.17**	1.21-3.77
Euro NCAP						
Before	Baseline			Baseline		
After		**0.96**	0.58-1.55	0.14	**1.15**	0.69-1.86
Frontal Airbag						
Not deployed		-	-	Baseline		
Deployed		-	-	0.33	**1.39**	0.91-2.12
	Pseudo R^2 =0.107			Pseudo R^2 =0.101		