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Exploring the price of motor vehicle collisions – A compensation cost approach

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ABSTRACT

Motor Vehicle Collisions (MVCs) accounted for an economic cost of $242 billion in the United States in 2010. A significant portion (42%) was associated with factors considered for compensation estimates – medical costs, lost earnings and reduced household productivity. This study proposes a methodology that accounts for these costs by using expected compensation costs (ECCs). Our approach differs from prior studies as we consider all injuries suffered by an individual in the MVC, rather than only the 'most severe' injury. We estimate ECCs for each injured occupant by linking the injuries suffered with guidelines on injury compensations, allowing for ECCs to be linked directly with collision factors. To demonstrate the ECC system, we conduct a cross-sectional mediation analysis to study the relationships between collisions and compensation. delta-V (the change in a vehicle's speed pre- and post-crash) remains a primary factor in the severity of MVCs and so it serves as a focal point in our study. We find that some collision factors influence compensation estimates because of the effects of delta-V, while others influence ECCs regardless of delta-V. The ECC system we introduce can mitigate litigation risk and highlight future approaches to road safety, as it bridges the gap between crash characteristics, injuries suffered, and economic damage. Our results support policy recommendations that promote seatbelt use and warn against alcohol-impaired driving, and support the proliferation of safety-enabled vehicles whose technology can mitigate the economic damage associated with detrimental crash types.

1. Introduction

Blincoe et al. (2015) report that motor vehicle collisions (MVCs) accounted for an economic cost of $242 billion in the United States in 2010, or 1.6% of GDP. The study compiled by Blincoe et al. (2015) examines a comprehensive range of variables associated with the cost of an MVC, ranging from household productivity loss to the associated environmental impact. They find that factors that are typically considered in compensation estimates – medical costs, lost earnings and reduced household productivity – made up almost 42% of the $242 billion total economic cost due to MVCs. However, Blincoe et al. (2015) acknowledge that their economic cost estimates are conservative since they only consider the most severe single injury sustained in the incident. Our study, therefore, attempts to address this drawback by providing an alternative perspective on the partial economic costs associated with MVCs. We complete this by extending compensation estimates to consider the indemnities associated with all injuries suffered by an occupant, rather than only considering the most severe injury. Our approach allows for further granularity when estimating injury costs associated with road accidents, while also allowing for further analyses detailing the crash factors that influence the economic costs associated with MVCs.

The partial economic costs, or expected compensation costs (ECCs), estimated in our study are derived by linking injuries suffered in MVCs with standardised guidelines on the appropriate court-awarded compensation to be provided for incidents in which there is medically supported evidence of pain and suffering. The guidelines for expected compensations are derived from the Book of Quantum (Personal Injuries Assessment Board, 2016), which is commonly used in judicial hearings in Ireland to award personal injury claims relating to MVCs. The data in our analysis is derived from the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) for the years 2010–2015, which details collision factors involved in a national sample of MVCs through on-site inspections, police records and reconstruction software, and combine them with the injuries that were sustained in the incident. A further combination with the Book of Quantum can allow for an examination of MVC collision factors and their economic and road safety implications.

The initiation of an expected compensation cost (ECC) system can bridge the gap between crash characteristics and the severity of the stated clinical picture. Court-awarded compensations are generally based on readily-available injury data. Given the shift toward a data-driven society, technological advances in vehicles can allow collision factors to be recorded at the time of an incident and thereafter combined with the injuries suffered in an

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incident. Providing an initial estimate for the compensation costs that are accrued in an MVC can prove beneficial in mitigating litigation risk in the domain of legal proceedings (accounting for $11 billion in U.S. economic costs in 2010) and administration relating to motor insurance providers ($20.5 billion). Compensation costs also affect society in that they lead to higher insurance premiums and divert medical resources away from other medical needs, such as medical research, disease prevention and control, and basic public health needs. As such, implementing methods such as those described in our study can improve the efficacy of actuarial estimates, decrease uncertainty risk, and benefit both corporate entity and client.

Following the initiation of the ECC system, we address an additional gap in the literature by investigating the contribution of individual crash factors toward total ECCs. This allows crash factors that significantly contribute to court-awarded compensation costs to be identified. In particular, we discern the extent of the role that delta-V plays on partial economic costs, as it relates to other crash factors. We carry out this examination on the basis that collision velocity is the most significant factor in determining the damage owing to a motor vehicle collision (MVC). $52 billion in economic costs (2010 USD) was attributed to crashes in which drivers were driving too fast for conditions, and speeding was associated with 20% of non-fatal and 32% of fatal crashes (Blincoe et al., 2015). The delta-V of an MVC, or the difference between a vehicle's immediate pre-impact and post-impact velocity, is a significant determinant of the severity of an MVC and is a useful predictor of expected injuries (Richards and Cuerden, 2010). Kockelman and Kweon (2002) and Carter et al. (2014) also find that an increasing delta-V raises the likelihood of sustaining serious injuries in all crash types examined, and small reductions in speed can affect injury and fatality risk (World Health Organization, 2018).

As such, we use a mediation analysis to not only investigate the influence that a set of environmental, kinematic, and anthropometric crash factors have on ECCs, but also to investigate the mediating role that delta-V has on these crash factors, as well as its independent role in contributing to expected compensation. A mediation analysis allows for insights in to the variance that is captured by a specified mediator variable, and can be thought of as a series of regression models that partitions the effects of independent variables on dependent variables into three parts – direct effects, indirect effects, and total effects. The direct effect model is a linear regression describing the typical relationship between predictors and response variables, where the mediator (delta-V) is included as a factor. The indirect effect model is a linear regression describing the relationships between the predictor variables and the mediator variable, multiplied by the linear relationship between the mediator and the outcome variable. The total effects model is a summation of the direct and indirect effects, and measures the impact of the predictors on the outcome following the exclusion of the variable of interest – the mediator variable.

An examination of the direct, indirect and total effects allows for the influence of the mediator on other predictors to be identified, as well as revealing concealed relationships that may impinge on the nature of the predictor-outcome relationship. As well as determining the independent impact that delta-V has on expected court-awarded compensation costs, a mediation analysis clarifies the extent to which delta-V influences other crash factors and expected compensation costs. This allows for a closer examination of the role that delta-V plays in determining the partial economic costs attributable to MVCs. Significant effects between crash factors and ECC are uncovered because of our approach that would otherwise go unnoticed in analyses that focus on directly examining the relationship between crash factors and economic damages. These effects are examples of competitive partially-mediated relationships, wherein a variable's positive association with increased compensation is coupled with a negative association with delta-V. This leads to a net insignificant total effect. The implication of this result is that if delta-V is not included as a factor, neither the positive association with compensation nor the negative association with delta-V would have presented as significant, allowing for potentially influential results to go unnoticed.

The following sections address the methods used in this study to identify the mediating effect that delta-V has on MVC severity and court-awarded compensation estimates. Using these methods, a discussion ensues on the crash factors that are significant in influencing MVC severity and ECCs with and without the influence of speed. Section 2 introduces the data used as part of this mediation and regression analysis, as well as outlining the characteristics of the data and addressing potential data issues. Section 3 briefly outlines the statistical methods used to explore MVC severity before Section 4 presents the results of the models. The results detail the factors that heavily influence compensation costs. Section 5 includes a case study demonstrating the effectiveness of the model derived in Section 4. We further compare our ECC estimates with previously established measures of economic costs, as well as discussing the implications of the standardised and unstandardised estimates provided by our ECC model in Section 4. We also discuss the potential application of the ECC system in a practical setting, as well as offering recommendations based on the findings of the models. The study concludes by highlighting the main findings of the study, as well as proposing future avenues of research.

2. Data description and derivation

2.1. Inclusion Criteria

The data examined in this paper is derived from the National Highway Traffic Safety Administration's (NHTSA) National Automotive Sampling System Crashworthiness Data System (NASS-CDS) for the years 2010–2015, commissioned by the U.S. Department of Transportation. The establishment of NASS-CDS allows for a combination of medical and engineering research, with the goal of promoting traffic safety and reducing human and economic costs stemming from motor vehicle collisions (MVCs). NASS-CDS data includes police-reported MVCs in which at least one involved vehicle is towed away due to damage. A variety of factors influencing the outcome of the MVC is recorded, crash reconstructions are completed, and police records are examined. Thereafter, all injuries suffered by each occupant, including those suffering only minor injuries, are recorded using a 6-digit classifier along the Abbreviated Injury Scale (AIS).

The six digits of the AIS classify the injury suffered, the anatomical structure damaged and the area affected. A single digit adjoins the classifier, indicating the injury's severity along a 6-level scale, ranging from '1' (minor) to '6' (currently untreatable). The final digit can also be used to identify the most severe injury suffered by an occupant. The 'most severe injury' indicator is otherwise known as the Maximum Abbreviated Injury Scale (MAIS) and is measured on an ordinal scale. According to Gennarelli and Wodzin (2006), an MAIS of 4 or over (severe injury or worse) poses at least a 15% chance of loss of life, which is a significant increase in mortality rate relative to an MAIS of 3 or below (1.5%). Although the database is extensive, for the purpose of this analysis, emphasis is placed on cases where all necessary information is available – cases with missing or incomplete information are removed prior to examination to ensure reasonable accuracy. Incidents with an MAIS of 6 are also removed from the analysis, as these injuries are largely associated with fatalities and are not covered under the compensation estimates provided in the Book of Quantum (detailed below). In addition, only cases that achieved accurate delta-V reconstructions are retained, resulting in final sample size of $N = 2520$ cases.

2.2. Expected compensation costs (ECCs)

The expected compensation costs (ECCs) stemming from injuries sustained in an MVC are taken from the Book of Quantum (Personal Injuries Assessment Board, 2016). The Book of Quantum offers standardised guidelines on the appropriate court-awarded compensation to be provided for accidents in Ireland in which there is medically supported evidence of pain and suffering. The availability of these standardised guidelines can mitigate the subjectivity and large variability that are often exhibited in court-awarded compensation judgements (Schoeters et al., 2017). The Book of Quantum is commonly used in judicial hearings in Ireland to award non-fatal personal injury claims relating to MVCs, and as such, we use them as a set of guidelines to measure the ECCs. We act under the assumption that the physiological differences in drivers in both the United States and Ireland are minimal, so that the severity of MVCs can be taken as constant between the two territories and measured using the guidelines set out in the Book of Quantum.

Assessments provided by the Book of Quantum cover compensation for “pain, suffering and loss of enjoyment of life”, loss of past and future earnings, and current and future medical bills. As such, the assessments align with the economic compensation approach of Blincoe et al. (2015). However, there is an additional consideration given that “loss of enjoyment of life” is also a factor in the award amount. Both primary and secondary injuries are considered, in contrast to previous approaches (Blincoe et al., 2015; U.S. Department of Transportation, 2016). The Book of Quantum offers value ranges for injury compensations for the most severe injury sustained by an occupant in the incident, in categories similar to the AIS system. The scale is then adjusted based on the number of secondary injuries and their associated severities. To combine the injuries recorded in the NASS-CDS data with the guidelines provided by the Book of Quantum, the following steps are taken:

1. Variables that may serve as predictive indicators of the severity of an incident are gathered. 21 variables are chosen, comprising the delta-V of the collision, ‘Road Surface Conditions’, ‘Lighting Conditions’, ‘Weather Conditions’, ‘Road Profile’, ‘Road Controls’, ‘Crash Type’, ‘Current Age of Vehicle’, ‘Vehicle Weight’, ‘Vehicle Type’, ‘Pre-Crash Avoidance Manoeuvre’, ‘Occupant Age, Weight, Gender, and Height’, ‘Drink Driver in Vehicle’, ‘Evidence of Seatbelt Use’, ‘Seat-track Position’, ‘Multiple Airbags Deployed in the Vehicle’, and ‘Occupant Position in Vehicle’. Most categorical variables contain multiple levels; for example, there are 7 varieties of collision types included within Crash Type. Each level of a multi-category variable is included as a separate binary variable. This results in a total of 46 independent variables being subject to examination within the sample, of which 10 act as control variables.
2. Collision factors for each vehicle in the incident are assigned a unique Case Number ID by collating a number of parameters. This involved concatenating the year in which the case was recorded, the sampling location (PSU), the stratification category describing the damage sustained in the MVC (STRATIF), the case number corresponding to each sampling location (CASENO), and the vehicle number for each case (VEHNO). Thereafter, occupants can be connected with any given incident by additionally concatenating the occupant number for each vehicle. The latter step provides each casualty with a unique Occupant Injury ID, allowing all injuries suffered by each individual to be associated with crash factors directly.
3. The 7-digit AIS codes, which serve as descriptors of the specific injuries suffered by each casualty, are separated to allow for an association with the expected compensation costs. Given the level of detail provided by the Book of Quantum, only 3-digit identifiers (AIS-code digits 1, 2 and 7) are included in the analysis. Digit 1 describes the body region affected (Head, Thorax, etc.), digit 2 specifies the anatomical structure that was damaged (Skin, Bone, etc.), and digit 7 reports the severity of the injury (1 = Minor, 2 = Moderate, 3 = Serious, 4 = Severe, 5 = Critical, 6 = Maximum). Special compensations are also taken – for example, AIS codes beginning with 14 (Head, Organ) and 16 (Head, Loss of Consciousness) are assumed to be brain traumas.
4. Guideline compensation cost ranges are extracted from the Book of Quantum and combined with the 3-digit identifier found in step 3. The injury severity categories originally associated with AIS digit 7 are straightforward to match. Since the Book of Quantum does not offer guidelines for non-survivable and fatal injuries, occupants with AIS code ‘6’ injuries are removed from the analysis. Thereafter, minor injuries are associated with AIS Code 1, Moderate injuries with AIS Code 2, Moderately Severe injuries with AIS Code 3, and Severe and Permanent Conditions are assigned AIS Codes 4/5. Injury costs are found by taking the average of the ranges provided in the Book of Quantum. In cases where there are multiple ranges for similar injuries (for example, broken finger and broken thumb have different ranges of values to consider), the average of the averages is taken, and so on. Consideration is provided to individuals that suffered multiple injuries in an incident. It is stated within the Book of Quantum that when considering the case of multiple secondary injuries, “it is not appropriate to simply add up values for all the different injuries to determine the amount of compensation. Where additional injuries arise there is likely to be an adjustment within the value range” (Personal Injuries Assessment Board, 2016). In order to ensure conformity to the ranges specified within the Book of Quantum, the final cost is derived by providing a 0.7x multiplicative weight to the primary injury (to ensure it is on the lower scale of its range), and any following secondary injuries receive a 0.3x multiplicative weight. In other words, 70% of compensation is due to the primary injury, while 30% of compensation is made up of the remaining secondary injuries.
5. The costs derived in step 4 are associated with the crash factors, by combining the Occupant Injury ID and the Case Number ID outlined in step 2.

The final distribution of the ECCs, as derived in step 4, is presented in Fig. 1. The distribution follows a lognormal or gamma shape, as is commonly found in actuarial representations of MVC compensation claims (Eling, 2012). Also provided in Fig. 1 is the upper limit of compensation that should be expected for an occupant's most severe injury, according to the Book of Quantum. The highest ECC estimate in our sample is €386,000, while the maximum upper limit provided by the Book of Quantum is €450,000 (spinal cord injury with MAIS 4+, with the possibility of quadriplegia). 6 occupants in our sample suffered an MAIS 4+ spinal injury. The mean ECC estimate in our sample is €31,000, while the median ECC estimate in our sample is €20,500, on account of a large number of minor abrasion and contusion injuries (over 20% of occupants had a compensation estimate less than €10,000). Nevertheless, 86.3% of our cost estimates align with the ranges outlined by the Book of Quantum. The remaining 13.7% can partially be accounted for in Fig. 1 by the overspill extending beyond €100,000. Beyond this mark, 27 occupants suffered injuries that have upper compensation limits above €100,000 according to the Book of Quantum. However, our ECC estimates contain 123 such occupants, given the extent of their secondary injuries.

2.3. Addressing data issues

2.3.1. Generality of findings

NASS-CDS contains details of around 3700 accidents each year from 2010 to 2015. However, given the wide variety of parameters for which information is recorded, the majority of cases are partially incomplete or contain details recorded as ‘unknown’. The restrictive filters put in place for this study (accurate delta-V reconstruction, all injuries recorded, no fatalities, complete crash and occupant details), means that the final number of observations ($N = 2520$) represents an average of 420 observations from each year, or around 11.5% of each year's qualifying MVCs. This impacts on the generality of our findings.

NASS-CDS sampling has a sophisticated selection design that deliberately oversamples crashes with higher severities. The NASS-CDS database provides case weights that are used to account for sampling bias, but since the retention rate for incidents from each year hovers around 11.5%, correcting for the sampling method using the weightings provided yields unwieldy initial results. This difficulty has previously been highlighted for NASS-CDS related data (Sam et al., 2019). As a result, the observations that are subject to analysis in Section 4 are unweighted. The unwieldy initial results are evidence that the retained data is overrepresented by higher severity MVCs. However, since over 86% of observations remained within the compensation limits set out in the Book of Quantum, and as further detailed with comparisons to prior compensation estimates in Section 5.4, the loss of generality is not too severe.

2.3.2. Potential bias among occupants

The focus of our analysis is on calculating the compensations costs associated with each injured party in an MVC. The data collection method

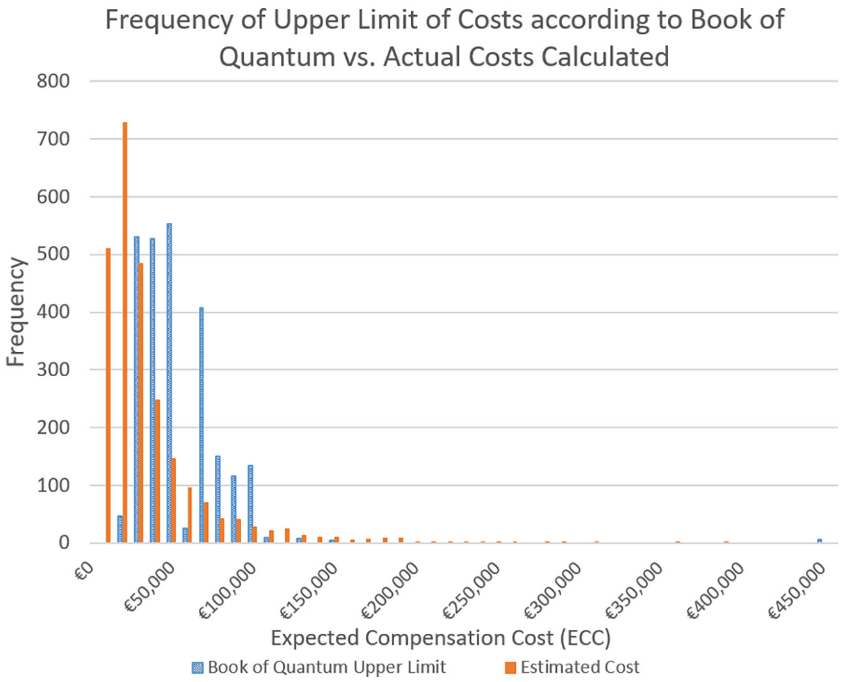

Fig. 1. Distribution of compensation payments owed to casualties in a motor vehicle collision (MVC), as estimated using the methodology described in Section 2.2. The costs are found by relating injuries with expected compensation guidelines detailed in the Book of Quantum. Also presented is the recommended upper limit of compensation for each occupant in the sample, based on the most severe injury (MAIS) they suffer, according to the Book of Quantum.

indicates that all injured occupants are recorded after a police-investigated incident in which at least one vehicle is towed away. While most cases contain only one injured individual, regardless of the number of people that are originally involved in the incident, there are numerous cases where multiple casualties are recorded in a single incident. 45% of observations in our study, or 1134 of the 2520 occupants, are made up of multiple individuals that are injured in the same incident. Each individual in our sample set is recorded as an independent observation. The inclusion of these observations has the potential to bias the dataset and results.

To examine the data for potential bias, the sample is split in to two subsamples. The first subsample contains observations in which the incident has only one injured occupant included in the sample, and the second subsample contains occupants where multiple observations are recorded for each incident. The distribution of each subsample is examined to determine if any significant differences exist between the subsamples. This includes graphical measures of the subsamples' dispersions (Figs. 2, 3), as well as significant tests to measure differences in mean and variance. A correlation analysis using Pearson's product-moment correlation test is also carried out, where subsample 1 observations are coded as 0, and subsample 2 observations are coded as 1. A statistically significant correlation coefficient would indicate an association toward one subsample of data over the other – potentially introducing bias to the study's sample.

Fig. 2 demonstrates that the subsample of MVCs where multiple casualties are included in our dataset exhibits a wider variation of compensation costs relative to accidents in which only one casualty is recorded. The results in Table 1 confirm that the difference in dispersion is statistically significant. The reason for the mismatched dispersion is the presence of outliers in the 'Multiple Injured Occupants' subsample that extend past

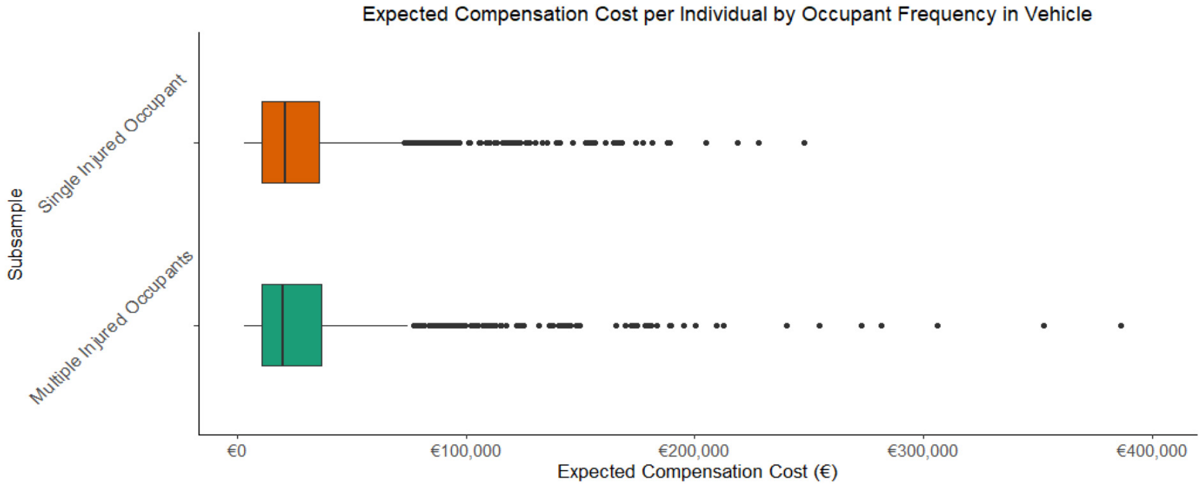

Fig. 2. Dispersion of expected compensation cost (ECC) estimates for each occupant, depending on the number of occupants with recorded injuries in the vehicle. A significant difference between boxplot dispersions at the upper end of ECCs indicates a biased dataset.

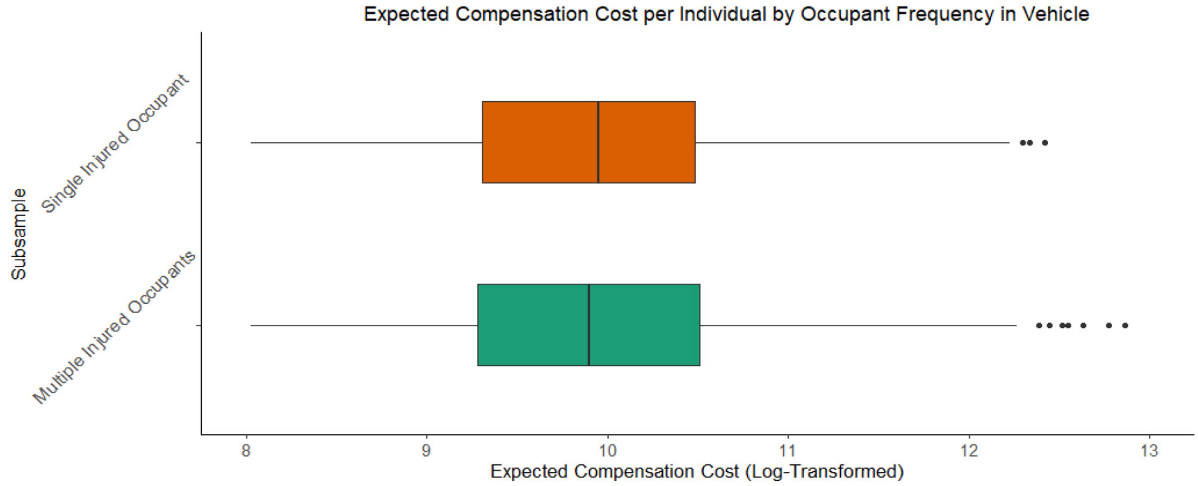

Fig. 3. Dispersion of log-transformed expected compensation cost (ECC) estimates for each occupant, depending on the number of occupants with recorded injuries in the vehicle. A significant difference between boxplot dispersions would indicate a biased dataset, however there appears to be no statistically significant difference.

€300,000, whereas single-casualty recordings have a maximum compensation of €250,000. Nevertheless, the outliers are legitimate observations and so are retained in the analysis. Parity exists among the two samples in terms of central tendencies (non-significant *t*-test) and there is no clear indication of bias (non-significant correlation).

To ameliorate the dispersion issue, the outcome variable ‘Expected Compensation Cost’ is log-transformed prior to analysis, and the two subsamples are again subject to bias testing. The resulting boxplot and significant tests are provided in Fig. 3 and Table 2, respectively. Both Welch's t-test for difference of means, and Levene's Test for Homogeneity of Variance return t- and F-values that fail to reject the null hypotheses of a lack of significant differences, while no apparent association for either subsample is present in the correlation analysis.

Table 1

Statistical tests to detect the presence of bias in the dataset. Although two examinations return non-significant results (Welch's Test for difference of means, and Pearson's Product-Moment Correlation Test of outcome-association), Levene's Test for difference of variance is highly significant. The latter result indicates a large difference in dispersion among the two subsamples, mostly due to high-cost outliers.

Measure of association	t-Statistic	F-value	Correlation coefficient	p-Value
Welch's t-test	1.127	–	–	0.260
Levene's Test	–	9.424	–	< 0.001
Pearson Product-Moment Correlation	–	–	0.023	0.249

Table 2

Statistical significance tests to detect the presence of bias with a log-transformed outcome measure. All three examinations – Welch's Test (difference of means), Levene's Test (difference of variance) and Pearson's Product-Moment Correlation Test (association with outcome measure) – return non-significant or near-non-significant results. These results indicate that compensation estimations for incidents where a single casualty is recorded and incidents where multiple casualties are recorded share common distributions and are not subject to bias.

Measure of association	t-Statistic	F-value	Correlation coefficient	p-Value
Welch's t-test	− 0.528	–	–	0.598
Levene's test	–	2.759	–	0.097
Pearson product-moment correlation	–	–	− 0.011	0.595

2.4. Exploratory data analysis

Summary statistics for the variables in our study are presented in Table 3. As mentioned previously, the outcome variable is the log-transformed expected compensation cost (ECC) pertaining to a motor vehicle collision (MVC). This transformation also satisfies the normality assumption required by a mediation analysis by eliminating the heavy skew existing in the distribution of the ECC estimates (Figs. 1, 2). The log-transformed ECCs have a range between 8.03 and 12.86, with a mean of 9.95 and standard deviation of 0.88.

The primary focus in our statistical analysis is on measuring the impact that delta-V has on other crash factors, based on the belief that delta-V plays a large role in determining the severity of an MVC. As with the ECC distribution, the delta-V values are skewed and are linearly transformed to conform to the normality assumption required in our mediation analysis. The log-transformed values range from 1.39–4.57, with mean 3.19 and standard deviation 0.46. These values represent a downward-slope corrected mean of $\mu = e^{3.19+\frac{0.46^2}{2}} = 27km/h$. Both occupant age and vehicle weight are also linearly transformed to attain normality. Occupant ages range from 0 to 4.54, with mean 3.49 and standard deviation 0.66, while vehicle weights range from 6.45–8.37, with mean 7.37 and standard deviation 0.21. The remaining continuous and non-binary discrete variables are analysed in their raw form.

The ‘current’ age of the vehicles (measured from 2019) range from 4 to 19. This parameter is included as a proxy variable to accounts for the increase in safety measures in vehicles since the 1990s (Griffin et al., 2018). The average weight and height of injured casualties in the sample are 75.6 kg and 167 cm, respectively. Almost 59% of the sample are females, indicating a bias toward female representation. A large majority wore their seatbelt (79.5%). Almost 5% of collisions had drivers under the influence of alcohol. A sizeable portion of crashes had multiple airbags deploy in the vehicle (13%). Backseat passengers, who make up over 10% of the sample, only have access to 2 airbags (curtain and torso), while front seat passengers (20%) and drivers (70%) have access to 4 (steering wheel/dashboard, knee, torso, and curtain). This may influence the number and severity of injuries, and hence the level of compensation, that backseat passengers are subjected to relative to front-seat passengers.

Most of the incidents occurred in clear (75%) and dry conditions (81%) during daylight hours (68%). These three variables represent controls for their respective binary classifications. As such, relatively few incidents occurred in adverse environmental conditions. A relatively high number of incidents occurred in roads with a gradient steeper than 0.5% – uphill and downhill crashes make up almost 29% of the sample. Over 47% of the incidents occurred near traffic signals or cautionary signs. Most incidents also

Table 3

Summary Statistics for variables included in the analysis. Frequencies are provided for binary variables, while means and standard deviations are provided for non-binary numerical data.

Observed variable	Category coding	Frequency	Mean	Std. dev
Outcome variables				
Expected compensation cost (Ln)	Range of 8.03–12.86	–	9.95	0.88
Mediator variable				
delta-V (Ln)	Range of 1.39–4.57	–	3.19	0.46
Environmental factors				
Surface conditions	Dry 1, no 0	2048	–	–
	Wet 1, no 0	369	–	–
	Snowy or icy 1, no 0	103	–	–
Lighting	Daylight 1, no 0	1710	–	–
	Dark 1, no 0	810	–	–
Weather	Clear 1, no 0	1899	–	–
	Cloudy 1, no 0	319	–	–
	Rain, snow, smoke or fog 1, no 0	302	–	–
Road profile	Level ground 1, no 0	1791	–	–
	Uphill 1, no 0	350	–	–
	Downhill 1, no 0	379	–	–
Road controls	No control signals 1, no 0	1327	–	–
	Traffic signal 1, no 0	962	–	–
	Stop/yield 1, no 0	196	–	–
	Other regulation signs 1, no 0	35	–	–
Crash factors				
Crash type	Single vehicle collision 1, no 0	361	–	–
	Rear-end collision 1, no 0	366	–	–
	Head-on collision 1, no 0	241	–	–
	Turning across path collision 1, no 0	957	–	–
	Intersecting paths striking vehicle 1, no 0	287	–	–
	Intersecting paths struck vehicle 1, no 0	304		
	Backing up 1, no 0	4	–	–
Current vehicle age	Range of 4–19	–	12.56	3.36
Vehicle weight (Ln)	Range of 6.45–8.37	–	7.37	0.21
Vehicle type	Automobile 1, No 0	1696	–	–
	SUV 1, No 0	516	–	–
	Vans or light trucks 1, no 0	308	–	–
Pre-crash avoidance manoeuvre	No manoeuvre to avoid 1, no 0	1536	–	–
	Brake to avoid 1, no 0	708	–	–
	Accelerate or swerve to avoid 1, no 0	276	–	–
Occupant characteristics				
Age (Ln)	Range of 0–4.54	–	3.49	0.66
Weight	Range of 6–150 (kg)	–	75.63	23.30
Gender	Female 1, male 0	1478	–	–
Height	Range of 45–201 (cm)	–	166.74	16.98
In-vehicle dynamics				
Drink driver in vehicle	Yes 1, no 0	124	–	–
Seatbelt used	Yes 1, no 0	2003	–	–
Seat track	Front-most track position 1, no 0	98	–	–
	Between front and middle 1, no 0	280	–	–
	Middle or non-adjustable seat track 1, no 0	656	–	–
	Between middle and rear 1, no 0	625	–	–
	Rear-most track position 1, no 0	609	–	–
Multiple airbags deployed in vehicle	Yes 1, no 0	336	–	–
Seat position	Driver 1, no 0	1764	–	–
	Passenger 1, no 0	495	–	–
	Backseat 1, no 0	261	–	–

occurred in automobiles (67%); however, a sizeable portion occurred in SUVs (20%) and Light Trucks or Vans (12%). A large portion of collisions in this sample involve vehicles that turned across the path of another vehicle, or vice versa (38%). However, to gain an insight in to the dichotomous relationship between rear-end collisions and other crash types, read-end collisions serve as the control (14.5%). The remaining crash types are well-represented – single vehicle collisions in which the vehicle diverted off-road or struck an object (14%), head-on collisions (9.5%), vehicles struck directly from the side (12%) and vehicles striking directly from the side (11%) are also subject to analysis.

More occupants tend to have their seat set further back (49%) from the default centre position (29%) than those who set their set further forward (15%). Seats set to their centre position acts as the control in this analysis. A high number of collisions involve drivers that attempted to brake to avoid an incident (28%), while a smaller number attempted to accelerate or swerve to avoid (11%). No recorded manoeuvre (61%) acts as the control.

3. Methodological approach

The methodological approach is this study follows a mixture of a regression analysis and a mediation analysis. The latter can be considered as a reverse engineering and breakdown of a regression analysis, wherein a series of regression equations with slight deviations are created and simultaneously computed to measure the specific influence of a target variable. Our approach therefore considers a mixture of statistical significance (using unstandardised estimates and *p*-values) and practical significance (using standardised estimates, effect sizes and confidence intervals). Considering both the statistical and practical significance of our results is recommended by the Task Force on Statistical Inference (Wilkinson, 1999), and has specific utility in the field of road traffic safety given the inherent randomness that exists among each accident.

3.1. Mediation analysis using log-linear regression

Mediation analyses are often used in economic and social science settings to not only measure the effects that predictors have on outcomes, but to explore the process by which these effects occur. As such, mediation analyses move beyond regression analyses and the effects that observational data may have on a specified dependent variable, to determine the effects that a third, intervening variable may have on influencing these relationships. We place emphasis on measuring the intervening effect that delta-V has on related crash factors in determining expected court-awarded compensation. While a linear regression model may assess the impact that an independent variable has on a specified outcome, a mediation model partitions the total effects in a linear model into two parts – measuring the indirect effects through the intervening variable, and measuring the direct effects of all predictors, including the mediator.

In short, mediation identifies the indirect effect that a variable of interest accounts for in the relationships between independent variables and dependent variables. The goal is to isolate the impact of the mediator variable so that the strength of the relationship between predictor and outcome can be analysed, and concealed factors that may impinge on the nature of the predictor-outcome relationship can be identified. The chosen mediator is the mechanism through which the focal independent variable is able to influence the dependent variable of interest and therefore, established evidence must exist of a relationship between the predictor, mediator, and outcome. Evidence of these relationships are presented in the attached Appendix (Table A1, Table A2). There is an abundance of evidence that our chosen mediator, delta-V, influences severity outcomes (Kockelman and Kweon, 2002; Richards and Cuerden, 2010; Carter et al., 2014; Shannon et al., 2018), while evidence of the predictors' relationships with the outcome variable (without the mediator) is available in Table A3. Furthermore, the mediator must follow the predictor variables in temporal order, but precede the outcome variable (Kraemer, 2008).

The mediation analysis is set up by considering a standard linear regression model based on the maximum-likelihood estimates,

$$\ln Y = \beta_0 + \beta_j x_{j-1} + \varepsilon_{\ln Y} \tag{1}$$

The response variable Y is log-transformed and dictated by response effects β_j, where $j = 1, \ldots, n + 1$. The regressors and errors for $\ln Y$ are represented as x_{j-1} and ε. Note that the generalised Eq. (1) uses $j - 1$ as an index notation for each independent variable to ensure that the estimated variables in Eqs. (2) and (3) conform in Eq. (5), despite Eq. (3) estimating one fewer predictor variable than Eq. (2). Furthermore, this notation ensures that the intercept is included in both Eqs. (2) and (3). x_0 represents the mediator, the ln $(delta - V)$, or $\ln DV$, variable. In addition, the standardised effects are reported due to the difference in scales among the variables in the analysis. Including standardised effect sizes can be useful for comparing the relative magnitude of information captured by estimators in the sample, if the sample size and the scales among the estimators are comparable. $Std\ \ln Y(\beta_j)$ is used for binary independent variables and signifies the change in $\ln Y$ standard deviation units when an observation for x_{j-1} changes by one unit. $Std\ \ln YX(\beta_j)$, on the other hand, is used to report results pertaining to the response effects of a continuous variable, and is interpreted as the change in $\ln Y$ standard deviation units when an observation for x_{j-1} changes one standard deviation.

$$Std\ \ln Y(\beta_j) = \frac{\beta_j}{SD(\ln Y)}$$

$$Std\ \ln YX(\beta_j) = \frac{\beta_j SD(x_{j-1})}{SD(\ln Y)}$$

$\ln Y$ is partitioned into two perspectives – those defining the direct effects of the explanatory variables on the response variable relating to ECCs, and the effects of the predictor variables on the mediator, where the response variable is delta-V. The expanded *n*-factor effect models are stated as

$$\ln Y = \beta_0 + \beta_1 \ln DV + \beta_2 x_1 + \ldots + \beta_n x_{n-1} + \beta_{n+1} x_n + \epsilon_{\ln Y} \tag{2}$$

$$\ln DV = \gamma_0 + \gamma_1 x_1 + \gamma_2 x_2 + \ldots + \gamma_{n-1} x_{n-1} + \gamma_n x_n + \epsilon_{\ln DV} \tag{3}$$

where β_j denote the weights for each x_{j-1} among the regression equation. Eq. (2) is the direct effects model, while Eq. (3) describes the relationship between crash factors and delta-V. Note that the mediator, delta-V, is included as a factor in the ECC measure $\ln Y$ (Eq. (2)). This can be considered as a typical regression model between dependent and independents, including the mediator. The residuals of $\ln Y$ are assumed to be uncorrelated with the residuals of the $\ln DV$ effect equation.

The indirect effects are found by inserting the $\ln DV$-dependent direct effect equation in to $\ln Y$,

$$\ln Y = \beta_1(\gamma_0 + \gamma_1 x_1 + \gamma_2 x_2 + \ldots + \gamma_{n-1} x_{n-1} + \gamma_n x_n + \epsilon_{\ln DV}) + \ldots \tag{4}$$

which when restated as a reduced form equation, the combined model of total effects (5) are a summation of indirect effects (4) and direct effects (2)

$$\begin{aligned} \ln Y = {} & \beta_0 + \beta_1\gamma_0 + (\beta_2 + \beta_1\gamma_1)x_1 + (\beta_3 + \beta_1\gamma_2)x_2 + \ldots \\ & + (\beta_n + \beta_1\gamma_{n-1})x_{n-1} + (\beta_{n+1} + \beta_1\gamma_n)x_n + \beta_1\epsilon_{\ln DV} + \epsilon_{\ln Y} \end{aligned} \tag{5}$$

The bias-corrected bootstrapping method is used to calculate the standard errors of the effects in our model. While effect coefficients can be estimated by a single run of the ML-estimated log-linear model, 5000 random samples (with replacement) are also drawn from the data. The bootstrap estimates represent the mean estimate of the 5000 samples, along with a 90% degree of confidence of the possible range of the estimates (Efron and Tibshirani, 1994). The bias-correction is a representation of the difference of the mean sample estimate and the original estimate from a single run of the log-linear model. The bias-corrected bootstrapping method proves robust to violations in model assumptions such as non-normality and heteroscedasticity, and reduces Type-1 error rates (Muthén et al., 2017). Considering (Eq. (4)) shows that, for each x_{j-1}, the indirect effect of x_{j-1} on $\ln Y$ is $\beta_1 \times \gamma_{j-1}$, and the direct effect is β_j:

$$Indirect: \beta_1 \gamma_{j-1}\left(x_{j-1}(1) - x_{j-1}(0)\right)$$

$$Direct: \beta_j\left(x_{j-1}(1) - x_{j-1}(0)\right)$$

The $x_{j-1}(0)$ value is the reference value to which the $x_{j-1}(1)$ value is compared. We consider only binary and continuous variables in our analysis – there are no ordinal or nominal factors included. A binary x results in a unit change from 0 to 1, while a continuous standardised x indicates that $x_{j-1}(0) = 0$ and $x_{j-1}(1) = 1$ is a one standard deviation increase from the mean. In addition, all independent factors in the model are co-varied. The model is therefore saturated and has no degrees of freedom remaining, so a χ^2 test of overall model fit is unavailable.

4. Results

As mentioned previously, relationships must be established or theorised between all 3 components of a mediation analysis (Independents, Mediator,

Table 4

Significant relationships among the mediation environment, detailing crash factors that influence ECCs through the indirect indicator of delta-V.

	delta-V (Ln) (independent ➔ mediator)	Direct effects/regression (Table 6) (independent ➔ dependent)	Total effects/Regression w/o delta-V (independent ➔ mediator ➔ dependent)
delta-V (Ln)	–	[a]	–
Snowy or icy road		[b]	[b]
Dark conditions	[a]		
Cloudy conditions		[b]	[b]
Downhill gradient	[b]		
Single vehicle collision	[a]	[a]	[a]
Head-on collision	[a]	[a]	[a]
Turning across path	[b]		
Intersecting path – striking vehicle	[b]		
Intersecting path – struck vehicle	[a]	[a]	[a]
Backing up	[a]		
Vehicle weight (Ln)	[a]		
SUVs		[b]	
Light vans and trucks		[a]	[b]
Brake to avoid	[a]		[a]
Accelerate or swerve to avoid	[a]		
Age (Ln)	[b]	[a]	[a]
Weight		[b]	[b]
Gender	[a]	[b]	
Height		[a]	[a]
Driver DUI (alcohol)	[a]	[b]	[a]
Seatbelt use	[a]	[a]	[a]
Seat set to forward-track position	[b]		
Seat set to back-track position	[b]		
Multiple airbags deployed in vehicle	[a]	[a]	[a]
Backseat passengers	[a]	[b]	

[a] Indicates 1% significance level,

[b] Indicates 5% significance level.

and Outcome) for effects to be interpretable. Significant relationships are summarised in Table 4.

Furthermore, as outlined in Section 3.1, standardised effects are included in our analysis due to a difference in scales among the independent variables. Reporting standardised effects allow for variables with significant influence to be identified regardless of the initial magnitude or unit of the variable. For example, while the variance of the 'occupant weight' variable is 543 kg, the variance of the 'current vehicle age' measure is 11 years, and standardised reporting allows for the contribution of an occupant's weight to be compared against the contribution of a vehicle's age. Standardised effects are presented and discussed in Section 4.1. However, while standardised estimates can be used to compare the relative contributions of crash factors toward ECCs, they cannot be used to infer practical ECC predictions based on the results of the model. To estimate predictions for expected ECCs after providing a set of inputs, the unstandardised raw estimates must be reported. These unstandardised results are equivalent to regression effects and are presented and discussed in Section 4.2. Section 4.2 focuses on the direct effects model, which is a regression model describing the relationships between crash factors (including delta-V) and log-transformed ECCs.

4.1. Standardised mediation estimates

Applying the mediation analysis approach discussed in Section 3.1 produces results detailed in Table 5. Table 5 partitions the total effects of crash factors on expected compensation cost (ECC) in to direct effects and indirect effects (through delta-V). The standardised direct effects (column 1) signify the relative magnitude of the estimates borne from a linear regression on ECC when all factors are included, including the mediator. The standardised total effects (column 3) signify the same model when the mediator is excluded. As such, the standardised indirect effect estimates (column 2) signify the extent to which delta-V plays a role between predictor and outcome. The significant direct effect results are the effects to be mediated according to the (Baron and Kenny, 1986) approach. However, we also follow the direction of (Zhao et al., 2010), who argue that significant total effects do not need to be present in order for mediation to occur. Competitive partial mediation relationships may also be present and may be reported upon, wherein significant direct and indirect effects with opposing signs can sum to a net insignificant result.

Table 5 shows that although delta-V has a significant direct relationship with expected compensation (0.294, with standard error 0.019), a number of relationships appear to be unrelated to the delta-V of the collisions. The results indicate that collisions on snowy or icy roads are largely associated with decreased compensations (direct effect = −0.057, S.E. = 0.025), which is unmediated by delta-V. Light vans and trucks also have a significant effect in mitigating the severity of an MVC on individual occupants with a non-negligible effect size (−0.060, S.E. = 0.023), as does an occupant's height (−0.070, S.E. 0.027). This effect is unmediated by delta-V, which indicates that these variables result in lower ECCs, regardless of delta-V. The opposite relationship is found for 'cloudy conditions' (0.040, S.E. = 0.019) and an occupant's weight (0.057, S.E. = 0.024). These factors have positive direct relationships with the compensation expected from the incident with non-negligible effect sizes. These relationships are not mediated, indicating that despite controlling for delta-V, MVCs occurring in cloud conditions and increased occupant weight are expected to result in higher compensations.

Table 5 also provides evidence of relationships between collision factors and expected compensation that is partially mediated by delta-V. This is indicated by relationships in which the direct, indirect, and total effects on expected compensation are all statistically significant. Partial mediation stipulates that even though including delta-V weakens the relationship between the independent variables and the severity of the incident (due to a significant indirect relationship), their direct and total effects remain significantly different from zero (0) after controlling for delta-V. As such, these collision factors have a significant relationship with expected compensation, with and without the influence of delta-V. Collisions that occur while the driver is under the influence of alcohol, and collisions in which multiple airbags are deployed, incur a higher level of compensation. In addition, single-vehicle collisions and head-on collisions lead to a higher level of compensation relative to rear-end collisions. In contrast, occupants that wear their seatbelt tend to incur a lower level of compensation. These relationships hold when delta-V is both included and excluded from the model.

A number of partially mediated relationships are also present in which the direct effects and indirect effects have opposing signs. This is evidence of relationships with a competitive partial mediation, wherein collision factors that have a positive relationship with ECCs also have a negative relationship with delta-V, or vice versa. For example, the positive relationship between ECCs and occupant age (direct effect = 0.179, S.E. = 0.026) is offset by the negative relationship between occupant age and delta-V (indirect effect = −0.014, S.E. = 0.007). Two conclusions can be drawn from this – older occupants tend to suffer from greater bodily damage and hence increased ECCs, even though older occupants tend to be involved in accidents with lower delta-Vs. This relationship also holds for vehicles that are directly struck from the side – an increase in the severity and frequency of injuries in these areas is offset by their occurrences at low velocities. More pressingly, significant increases in expected compensation for female occupants (direct effect = 0.042, S.E. = 0.020) and occupants in the backseat (direct effect = 0.059, S.E. = 0.027) are offset by negative relationships with delta-V (indirect effects = −0.025 (0.006) and −0.021 (0.007), respectively). While females and backseat passengers are subject to a higher frequency and severity of injuries, and therefore higher compensation estimates, they are typically involved in incidents with a lower delta-V. Given that the total effect of these latter two factors are insignificant, neglecting to include delta-V in the model would have allowed these relationships to go unconsidered.

The results indicate that although braking to avoid a collision results in lower ECCs, this relationship is fully mediated by the delta-V of the crash. The standardised total effect of 'Brake to Avoid' (−0.055, with standard

Table 5

Mediation: bias-corrected, standardised direct, indirect, and total effect sizes describing the relationship between crash factors and expected compensation cost (ECC) through the mediator, delta-V. Note that the standard errors are in parentheses.

	Expected compensation cost (ECC) (Ln)		
	Direct (SE)	Indirect (SE)	Total (SE)
delta-V (Ln)	0.294 (0.019)[a]	–	–
Environmental factors			
Dry road	*(Control)*		
Wet road	−0.035 (0.027)	−0.002 (0.008)	−0.037 (0.029)
Snowy or icy road	−0.057 (0.025)[b]	0 (0.007)	−0.057 (0.026)[b]
Daylight	*(Control)*		
Darkness	−0.010 (0.019)	0.026 (0.006)[a]	0.016 (0.020)
Clear conditions	*(Control)*		
Cloudy conditions	0.040 (0.019)[b]	0.011 (0.006)	0.051 (0.020)[b]
Rain, snow or fog	0.038 (0.030)	0.002 (0.009)	0.040 (0.032)
Level ground	*(Control)*		
Uphill	0.004 (0.018)	0.002 (0.005)	0.006 (0.019)
Downhill	0.010 (0.019)	0.012 (0.006)[b]	0.022 (0.020)
No controls/other	*(Control)*		
Traffic signals	0.014 (0.021)	0.008 (0.006)	0.022 (0.022)
Stop yield signs	0.008 (0.020)	0.009 (0.006)	0.016 (0.021)
Other regulation signs	0.014 (0.016)	−0.004 (0.005)	0.009 (0.017)
Crash factors			
Single vehicle collision	0.161 (0.026)[a]	0.033 (0.009)[a]	0.193 (0.027)[a]
Rear-end collision	*(Control)*		
Head-on collision	0.142 (0.023)[a]	0.057 (0.008)[a]	0.199 (0.024)[a]
Turning across path	0.045 (0.027)	−0.018 (0.008)[b]	0.027 (0.028)
Intersecting path – striking vehicle	−0.013 (0.023)	−0.017 (0.007)[b]	−0.030 (0.023)
Intersecting path – struck vehicle	0.113 (0.023)[a]	−0.045 (0.008)[a]	0.068 (0.024)[a]
Backing up	0.004 (0.008)	−0.008 (0.004)[a]	−0.004 (0.009)
Current vehicle age	−0.031 (0.019)	−0.006 (0.006)	−0.037 (0.020)
Vehicle weight (Ln)	0.034 (0.025)	−0.063 (0.008)[a]	−0.029 (0.026)
Automobile	*(Control)*		
SUV	−0.043 (0.022)[b]	0.011 (0.006)	−0.032 (0.023)
Light trucks and vans	−0.060 (0.023)[a]	0.011 (0.007)	−0.049 (0.024)[b]
No avoidance manoeuvre	*(Control)*		
Brake to avoid	−0.030 (0.020)	−0.025 (0.006)[a]	−0.055 (0.021)[a]
Accelerate/swerve to avoid	0.007 (0.019)	−0.021 (0.006)[a]	−0.014 (0.020)
Occupant characteristics			
Age (Ln)	0.179 (0.026)[a]	−0.014 (0.007)[b]	0.165 (0.027)[a]
Weight	0.057 (0.024)[b]	−0.005 (0.007)	0.052 (0.025)[b]
Gender	0.042 (0.020)[b]	−0.025 (0.006)[a]	0.017 (0.021)
Height	−0.070 (0.027)[a]	−0.006 (0.008)	−0.077 (0.028)[a]
In-vehicle dynamics			
Driver DUI	0.050 (0.022)[b]	0.028 (0.007)[a]	0.078 (0.023)[a]
Seatbelt used	−0.123 (0.019)[a]	−0.015 (0.006)[a]	−0.138 (0.020)[a]
Seat at front track position	0.004 (0.018)	0.015 (0.006)[a]	0.019 (0.019)
Seat in front – mid position	0.006 (0.020)	0.004 (0.006)	0.010 (0.021)
Seat in mid/unadjusted	*(Control)*		
Seat in mid – rear position	−0.011 (0.021)	−0.011 (0.006)	−0.021 (0.022)
Seat at rear track position	−0.007 (0.021)	−0.014 (0.006)[b]	−0.021 (0.022)
Multiple airbags deployed in vehicle	0.091 (0.019)[a]	0.027 (0.006)[a]	0.118 (0.019)[a]
Occupant in driver seat	(Control)		
Occupant in passenger seat	−0.003 (0.019)	−0.004 (0.005)	−0.007 (0.020)
Occupant in backseat	0.059 (0.027)[b]	−0.021 (0.007)[a]	0.038 (0.027)

[a] Indicates 1% significance level,

[b] Indicates 5% significance level.

Table 6
Linear Regression: Corrected, unstandardised Maximum Likelihood estimates describing the relationship between crash factors and expected compensation cost (ECC).

	Expected compensation cost (ECC) (Ln)			
	Estimate	Standard deviation	90% CI	Sig.
Intercept	6.841	0.809	[5.547, 8.246]	< 0.001[a]
delta-V (Ln)	0.562	0.037	[0.501, 0.622]	< 0.001[a]
Environmental factors				
Dry road	*(Control)*			
Wet road	−0.086	0.068	[−0.195, 0.030]	0.216
Snowy or icy road	−0.254	0.110	[−0.432, −0.068]	0.023[b]
Daylight	*(Control)*			
Darkness	−0.019	0.036	[−0.078, 0.038]	0.592
Clear conditions	*(Control)*			
Cloudy conditions	0.105	0.051	[0.023, 0.188]	0.040[b]
Rain, snow or fog	0.102	0.081	[−0.031, 0.238]	0.208
Level ground	*(Control)*			
Uphill	0.011	0.046	[−0.063, 0.088]	0.800
Downhill	0.024	0.047	[−0.053, 0.104]	0.584
No controls/other	*(Control)*			
Traffic signals	0.025	0.038	[−0.038, 0.088]	0.509
Stop yield signs	0.025	0.065	[−0.081, 0.134]	0.698
Other regulation signs	0.103	0.122	[−0.091, 0.312]	0.380
Crash factors				
Single vehicle collision	0.401	0.065	[0.294, 0.511]	< 0.001[a]
Rear-end collision	*(Control)*			
Head-on collision	0.423	0.068	[0.313, 0.537]	< 0.001[a]
Turning across path	0.082	0.049	[0.001, 0.161]	0.095
Intersecting path – striking vehicle	−0.036	0.064	[−0.139, 0.068]	0.586
Intersecting path – struck vehicle	0.303	0.063	[0.203, 0.412]	< 0.001[a]
Backing up	0.094	0.191	[−0.191, 0.453]	0.562
Current vehicle age	−0.008	0.005	[−0.017, 0]	0.104
Vehicle weight (Ln)	0.139	0.103	[−0.035, 0.303]	0.189
Automobile	*(Control)*			
SUV	−0.094	0.048	[−0.172, −0.015]	0.042[b]
Light trucks and vans	−0.160	0.060	[−0.261, −0.060]	0.006[a]
No avoidance manoeuvre	*(Control)*			
Brake to avoid	−0.058	0.039	[−0.119, 0.008]	0.148
Accelerate/swerve to avoid	0.020	0.053	[−0.066, 0.104]	0.678
Occupant characteristics				
Age (Ln)	0.237	0.034	[0.181, 0.293]	< 0.001[a]
Weight	0.002	0.001	[0.001, 0.004]	0.015[b]
Gender	0.075	0.036	[0.016, 0.135]	0.032[b]
Height	−0.004	0.001	[−0.006, −0.001]	0.010[a]
In-vehicle dynamics				
Driver DUI	0.203	0.088	[0.060, 0.350]	0.023[b]
Seatbelt used	−0.267	0.042	[−0.333, −0.193]	< 0.001[a]
Seat at front track position	0.018	0.080	[−0.119, 0.146]	0.852
Seat in front – mid position	0.016	0.055	[−0.080, 0.101]	0.777
Seat in mid/non-adjustable	*(Control)*			
Seat in mid – rear position	−0.022	0.042	[−0.095, 0.048]	0.556
Seat at rear track position	−0.014	0.043	[−0.088, 0.057]	0.728
Multiple airbags deployed in vehicle	0.235	0.048	[0.157, 0.317]	< 0.001[a]
Occupant in driver seat	*(Control)*			
Occupant In passenger seat	−0.006	0.042	[−0.072, 0.066]	0.903
Occupant in backseat	0.170	0.077	[0.050, 0.307]	0.018[b]

[a] Indicates 1% significance level,
[b] Indicates 5% significance level.

error 0.021) is highly significant and small but appreciable, according to the effect size benchmarks of (Cohen, 1992). However, the direct effect is insignificant, and ‘Brake to Avoid’ has a significant negative relationship with delta-V. This suggests that delta-V has a mitigating effect on braking to avoid an incident, and that delta-V explains much of the variance that was previously explained by this avoidance manoeuvre. In other words, since braking to avoid an incident inherently lowers the delta-V of the resulting collision, the final delta-V is a better predictor of crash severity than this pre-crash avoidance manoeuvre. As such, rather than indicating that braking prior to an incident will result in a lower severity crash, the combination of direct and indirect effects indicate that ‘Brake to Avoid’ crashes are less severe because they result in lower velocity incidents.

In addition, there are some relationships that are indicative of non-effectual mediation. Collisions occurring in darkness and collisions that occur on a downward slope, along with the collisions in which the lead vehicle directly impacts, backs into, or turns into the path of another vehicle, are examples of non-effectual mediation. These parameters, along with vehicle weight, accelerating or swerving to avoid an incident, and seat-tracks set to extreme positions, all have significant indirect effects, but non-significant direct and total effects. A significant indirect effect combined with non-significant direct and total effects demonstrates that there is a strong relationship between the independent variable and the mediator, but not with the compensation measure. For example, while larger vehicles tend to be in involved in incidents at lower delta-Vs, this relationship has no meaningful impact on expected compensation. As such, there appears to be no relationship between vehicle weight and ECCs, regardless of whether delta-V is included in the model.

4.2. Unstandardised direct effect (regression) estimates

Given that the effect that delta-V plays on the variables in this analysis has been established (Table 5), the bias-corrected unstandardised estimates in Table 6 can be interpreted with additional clarity. The direct effect model is a linear regression describing the typical relationship between predictors and response variables, where the mediator (delta-V) is included as a factor, allowing for predictions to be made about the expected court-awarded compensation. As such, the direct effect model is subject to closer examination, and the unstandardised estimates are reported. While the standardised estimates in Table 5 are used to compare the contributions of the variables in the analysis regardless of their initial magnitude, the unstandardised estimates in Table 6 allow for predictions to be made regarding the expected compensation for a given crash scenario.

All significant direct relationships in Table 5 are also significant in Table 6. The intercept dictates a base compensation estimate of $e^{6.841+\frac{.809^2}{2}} = €1,300$. delta-V remains highly significant, indicating that it plays a primary role in determining the elasticity of compensation expected from an MVC. For each percentage increase in delta-V, the base ECC estimate increases by 0.562%. The associated 90% Confidence Interval is [0.501%, 0.622%]. Anthropometric indicators also remain highly significant in determining the level of compensation, as the age, height and weight of the occupant influence ECC estimates. A percentage increase in the age of the occupant increases the ECC by 0.237%, within a 90% CI of [0.181%, 0.293%], while each additional kilogram of weight tends to increase the ECC by 0.2% (CI = [0.1%, 0.4%]). However, the height of the occupant decreases the ECC by 0.4% (CI = [−0.6%, −0.1%]), on average. Table 5 additionally highlights that incidents involving older occupants tend to occur at lower delta-Vs.

The remaining variables are binary variables. Since the dependent variable has been log-transformed, the geometric mean deviations ($e^{\beta_j} - 1$) are reported rather than the raw β_j changes in mean. Snowy or icy conditions result in a lower level of compensation ($[e^{-0.254} - 1]$ = 22.4%, CI = [−35.1%, −6.6%]), while MVCs in cloudy conditions increase ECCs by 11.1%, on average, within confidence intervals of [2.3%, 20.7%]. Single vehicle collisions, head-on collisions and vehicles that are struck directly from the side also induce a higher compensation cost relative to rear-end collisions. These crash types increase ECC estimates by 49.3%, 52.7% and 35.4% respectively, within 90% confidence intervals of [34.2%, 66.7%], [36.8%, 71.1%], and [22.5%, 51.0%]. Light passenger cars tend to incur in the highest level of compensation among vehicle body types in our sample, with SUVs reducing compensation estimates by 9% (CI = [−15.8%, −1.5%]), and light vans and trucks decreasing compensation estimates by 14.8% (CI = [−23.0%, −5.8%]).

Females in our sample tend to suffer greater bodily damage from MVCs, with increased ECC estimates of 7.8% within a 90% confidence interval of [1.6%, 14.5%]. Occupants that are involved in MVCs where the driver is under the influence of alcohol also tend to have more severe injuries, resulting in a 22.5% increase in ECCs (CI = 6.2%, 41.9%). In contrast, occupants wearing a seatbelt at the time of the crash tend to incur fewer injuries, resulting in an ECC decrease of 23.4% (CI = [−28.3%, −17.6%]). The latter two results concur with the findings of Blincoe et al. (2015), who conclude that these factors are significant determinants of the economic cost attached to MVCs. Incidents in which multiple airbags deploy in the vehicle result in higher levels of compensation (26.5%, CI = [17%, 37.3%]). The same result is found for occupants that are situated in the backseat, which increases the level of compensation by 18.5% on average (CI = [5.1%, 35.9%]). We surmise that rather than being detrimental to the occupants within the vehicle, the deployment of airbags may instead be a proxy for the overall severity of the incident. A high level of longitudinal delta-V is required to activate multiple airbags, which would require a higher level of crash energy and therefore, a higher risk of injury (Savolainen and Ghosh, 2008). In addition, backseat passengers have fewer safety features and have been previously shown to be exposed to a higher risk of serious injury (Atkinson et al., 2016), which may contribute to the higher level of compensation suffered.

5. Discussion – Exploring Expected Compensation Costs (ECCs)

5.1. Case study – NASS/CDS incident

To demonstrate the effectiveness of the unstandardised estimates (Table 6) in predicting the cost associated with an MVC, a sample case study is chosen from the 6th primary sampling unit (case number 130). The incident occurred in 2013. The stratum is denoted 'K', indicating a casualty admitted to hospital overnight after suffering an incapacitating but non-fatal injury, in an incident in which at least one 2010 or older vehicle is towed. The one-vehicle incident involved a 43-year-old male (height 173 cm, weight 86 kg) that had been driving a 2010 passenger car with curb weight 1190 kg. The injured occupant had set their seat back to the rear-most track position, and was not wearing a seatbelt when discovered. Point of contact features is unknown; however, one airbag had been deployed upon the driver. Site evidence and reconstruction software indicated a total delta-V of 18 km/h. The collision occurred at night in clear and dry weather, on a road with an uphill slope. After admittance to the hospital, the injured occupant was found to be under the influence of alcohol.

The occupant sustained multiple rib fractures, a knee laceration, and a multitude of abrasions affecting the head, face, upper arm, and lower leg. As detailed in Section 2.2, the Book of Quantum recommends that the compensation range be based on the most severe injury. The most severe injury sustained in this incident was the multiple rib fractures with AIS level 3, categorized as a moderately severe injury. The range specified for moderately severe rib or chest bone fractures is €29,600 – €63,400. Using the methodology put forth in Section 2.2, the cost of injuries is calculated to be €55,281, while the cost predicted by the parameters in Table 6 is €42,548 (90% CI = [€11,000, €160,000]). Both of these costs are in accordance with the range of pay outs dictated by the Book of Quantum.

5.2. Implications of mediation effects

The results of Tables 5 and 6 indicate that delta-V plays an unequivocal primary role in the severity of an incident. However, the nature of a mediation analysis posits that further explorations can be made regarding the relationship between crash factors and crash severity. We find that incidents involving vehicles that brake prior to the collision typically result in lower levels of compensation, on average. However, after accounting for delta-Vs, the results of the mediation analysis suggest that merely performing this manoeuvre does not significantly influence ECCs. Rather, it is the resulting reduction in speed (and hence, delta-V), that significantly reduces crash severity.

Furthermore, conducting a mediation analysis allows for competitive partial mediation relationships to be identified, which presents a more nuanced view on the effect that delta-Vs have on MVCs and ECCs. The substantial increase, for example, in ECCs associated with females and backseat passengers is surprising given that their incidents tend to occur at lower velocities. The implication of these findings is that if delta-V was not included as a factor in our analysis, neither the positive association of these variables with injury severity nor their negative association with delta-V would have presented as significant, allowing for these influential results to go unnoticed. This may have also been the case for vehicles that are struck directly from the side. Occupants involved in these collisions suffer injuries with higher levels of compensation in our sample, despite the data suggesting that the collisions occur at lower velocities. Despite the offset in effect size due to a negative relationship with delta-V, the positive relationship with crash severity remains significant. These crashes have

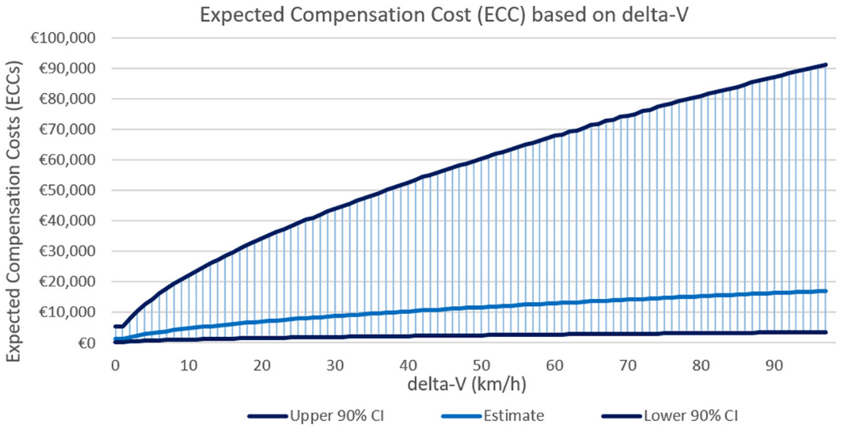

Fig. 4. Distribution of expected compensation costs (ECCs) with confidence bounds, solely based on delta-V (ceteris paribus). An array of significant factors combined with delta-V is possible but are not included.

previously been shown to result in higher severity incidents (Richards and Cuerden, 2010).

A number of relationships are also found between ECCs and crash factors despite the influence of delta-V. The significant changes in ECCs associated with anthropometric factors (such as occupant weight and height) and cloudy or adverse weather conditions (such as snowy or icy roads) are unrelated to the influence of delta-V. This conclusion is also evident for the relative safety afforded by vans or light trucks – they are typically involved in MVCs with lower levels of compensation, regardless of impact velocity. It has previously been posed that adverse conditions lead to reduced crash severities because they occur at lower crash velocities (Mannering and Bhat, 2014). However, the mediation results in Table 5 indicate that there is no apparent relation between snowy or icy roads and lower delta-Vs. It may therefore follow that driving in adverse weather conditions induces a heightened sense of awareness, which may lead to a higher level of safety exhibited by drivers. As such, any incidents that do occur may be less severe. The details of this relationship should be examined further in future studies.

5.3. Implications of regression effects

As previously noted, the unstandardised estimates from the log-linear regression analysis (Table 6) allows for predictions to be made regarding the average expected court-awarded compensation for a given crash scenario. There are no incidents in which there are no recorded injuries and therefore the baseline, where no collision factors apply, does not run through zero. Instead, the regression analysis indicates that when delta-V is set to 1 km/h and all other factors are set to 0, the expected range of ECC with 90% confidence is [€360, €5300], with a base estimate of €1300. The 1 km/h limit is used as a baseline as delta-V is log-transformed in our model, i.e. ln (1) = 0 represents no effect. As such, this methodology is not applicable for incidents in which there are no injuries suffered. As found in Section 4.2, a percentage increase in delta-V increases ECC by 0.562%, with a 90% Confidence Interval of [0.501%, 0.622%]. MVCs in our sample ranged from a delta-V of 4 km/h – 97 km/h, at which point the expected compensation costs solely due to the influence of delta-V is between €2850 and €17,000. The full range of associated ECCs, with 90% CI, is provided in Fig. 4.

In addition, the influence of significant crash factors (from Table 6) on ECC can be examined, ceteris paribus, along the range of values of the delta-V scale (Table 7). The age of the occupant (€3900 – €23,300), head-on collisions (€1500 – €9000), single vehicle collisions (€1400 – €8500) and vehicles struck directly in the side (€1000 – €6000) represent the largest increase to the base estimate for delta-Vs ranging from 4 to 97 km/h. Collisions in which multiple airbags are deployed (€750 – €4550), DUI collisions (€650 – €3900), and occupants situated in the backseat at the time of a collision (€550 – €3200) also add sizeable amounts to the economic detriment of MVCs. Increased occupant weight (€450 – €2600), collisions in cloudy conditions (€300 – €2000), and injuries to female passengers (€225 – €1350) also tend to add to the level of compensation due, albeit at a smaller level.

At the other end of the scale, a number of factors tend to be significantly associated with a reduction in compensation across delta-V levels. An occupant's height (decrease of €1900 – €11,350) largely offsets the increase in compensation from increased occupant age and weight. This would suggest that taller occupants tend to incur a lower level of bodily injury damage, whereas heavier and older occupants tend to suffer a higher level of bodily injury damage. The results of Table 7 also suggest that there is a relatively high level of safety afforded by seatbelts (decrease of €650 – €4000), light vans and trucks (decrease of €400 – €2500) and SUVs (decrease of €250 – €1500). Collisions occurring in snowy or icy conditions also result in lower levels of compensation (decrease of €600 – €3750). However, it must be noted that these figures are point estimates for the combination of significant factors with the lowest and highest recorded delta-V, and do not consider the 90% CIs that are provided in Fig. 4.

Table 7
Point estimates of significant factors when combined with delta-V. The 4 km/h and 97 km/h benchmarks represent the range of delta-Vs recorded in our sample. Note that confidence intervals are not provided with the point estimates.

	Expected Compensation Cost (ECC)			
	Effect on Estimate	1 km/h	4 km/h (min)	97 km/h (max)
delta-V (Ln)	–	€1304	€2843	€17,041
Snowy or icy road	*−22.0%*	€1018	€2219	€13,300
Cloudy conditions	*+11.2%*	€1451	€3163	€18,953
Single vehicle collision	*+49.6%*	€1953	€4255	€25,502
Head-on collision	*+53.0%*	€1997	€4351	€26,075
Intersecting path collision– struck vehicle	*+35.7%*	€1770	€3858	€23,119
SUV	*−8.9%*	€1189	€2591	€15,530
Light vans and trucks	*−14.6%*	€1114	€2428	€14,548
Age (Ln) (mean = 3.49, or 38.9 years)	*+0.24% (elasticity)*	€3107	€6760	€40,355
Weight (mean = 75.6 kg)	*+0.2%*	€1502	€3274	€19,621
Gender (females)	*+7.9%*	€1407	€3067	€18,381
Height (mean = 166.7 cm)	*−0.4%*	€436	€951	€5700
Driver DUI	*+23.0%*	€1605	€3497	€20,958
Seatbelt used	*−23.4%*	€1000	€2179	€13,060
Multiple airbags deployed in vehicle	*+26.6%*	€1652	€3601	€21,581
Occupant in backseat	*+18.9%*	€1551	€3381	€20,259

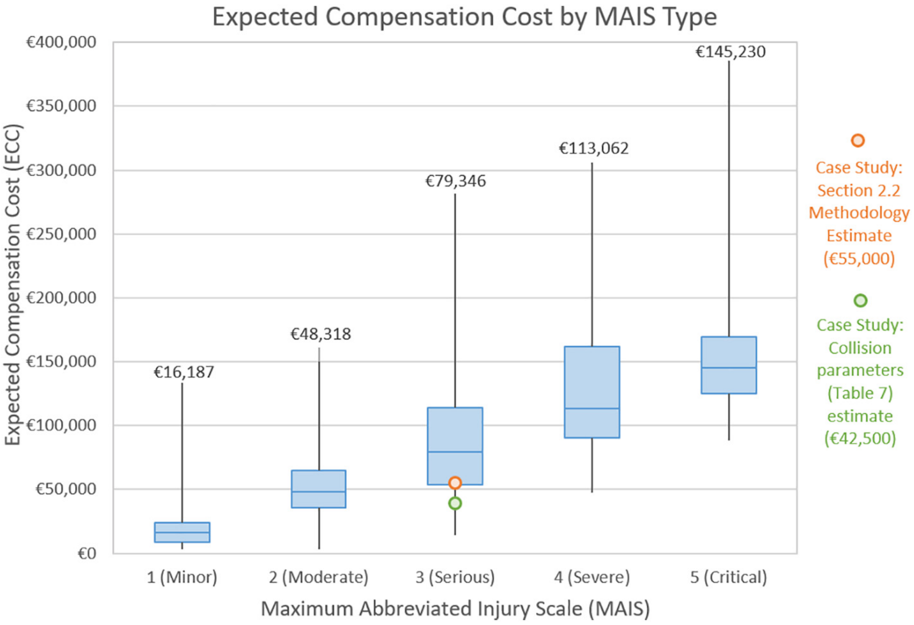

Fig. 5. A breakdown of expected compensation costs (a combination of medical costs, reduced workplace and household productivity, and loss of enjoyment of life) by the highest level of injury sustained by an MVC casualty. The highest level of injury is based on the Abbreviated Injury Scale (AIS). The median for each MAIS measure is also provided.

Furthermore, the estimates relate to delta-V plus one other variable, whereas in reality an array of different combinations is possible.

5.4. Implications of expected compensation costs (ECCs)

5.4.1. Comparison with prior estimates of economic costs

The methodology we propose in our study partially extends the economic cost approach of the U.S. Department of Transportation (2016) and Blincoe et al. (2015). The estimates provided in these reports are calculated by solely using the most severe injury suffered along the Abbreviated Injury Scale (AIS) system, whereas our study factors in both primary and secondary injuries. Blincoe et al. (2015) find that the average economic compensation due to serious-injury casualties is $135,646 in the U.S., while Schoeters et al. (2017) report serious-injury compensations ranging from €28,205 – €975,074 for European countries, with a median of €254,777. The median value for serious injuries in our sample is €79,346 (Fig. 5), which contrasts with the reported median economic cost of €225,511 for serious-to-worse injuries in Ireland in 2015 (Wijnen et al., 2017).

There is further reasoning behind the deviation between the expected court-awarded compensation and economic cost for serious injuries, as the latter figure is largely influenced by Willingness-to-Pay (WTP) estimates. WTP estimates are often used in cost-benefit analyses that measure the value that road users are willing to pay to reduce their risk of injury or death (Rizzi and Ortúzar, 2006; Hensher et al., 2009), and their societal utility has seen their use extended to economic estimates. When medical and production-loss (pecuniary) damages cannot adequately account for the non-pecuniary damages suffered in an motor vehicle collision, WTP estimates serve as a proxy for the economic damage stemming from a deceased quality of future life (Schoeters et al., 2017). Estimates of economic costs derived using the WTP methodology are typically much higher than estimates of economic damage using court-award compensation costs, due to their emphasis on accounting for non-pecuniary damages. Given the societal association with these trade-offs between costs and risk-reduction however, WTP estimates provides global information that do not correspond with individual cases of injury (Schoeters et al., 2017) and so are inadequate guidelines to follow when determining the compensation costs owed to individual occupants in MVCs. As such, it follows that our ECC-derived value of €79,346 for serious injuries contrasts significantly with the WTP-derived economic cost of €225,511 for serious-to-worse injuries in Ireland in 2015.

The influence played by WTP is highlighted by the level of compensation due for minor injuries (Fig. 5), where non-pecuniary damages typically do not apply and so WTP estimates play a diminished role. In this case, the median economic cost of minor injuries in Ireland in 2015 was €20,860 (Wijnen et al., 2017), which aligns closely with the median expected compensation for minor injuries in our sample (€16,187). The introduction of the updated Book of Quantum guidelines in 2016 will gradually result in economic costs that more closely align with court-awarded compensation estimates, given that the updated guidelines focus on “pain, suffering and loss of enjoyment of life”, or the non-pecuniary considerations that WTP estimates consider (Personal Injuries Assessment Board, 2016).

5.4.2. Applicability and policy recommendations

The restrictive requirements for inclusion in our sample (Section 2.3.1) raised a concern that the generality of the NASS-CDS database would be lost. However, the cost breakdowns in Table 8 provide some evidence

Table 8
The proportion of claimants who settled injury claims in each cost award band between 2015 and 2018 (Central Bank of Ireland, 2019), compared with the proportion of injury claim estimates in each cost award band in our sample.

Band	Proportion of injury claims in Ireland, 2018	Proportion of injury claim (ECC) estimates in our sample
€0 – €10,000	29%	20.3%
€10,001 – €15,000	15%	12.6%
€15,001 – €30,000	29%	35.6%
€30,001 – €45,000	11%	12.8%
€45,001 – €60,000	5%	6.7%
€60,001 – €75,000	3%	3.5%
€75,001 – €100,000	3%	3.7%
>€100,000	5%	4.9%
All bands	100%	100%

that this may not be the case. Although minor collisions with injury costs less than €10,000 are under-represented in our sample (20.3%, versus 29% realised in 2018), the remaining cost bands match relatively closely with the latest Irish statistics on settled injury claims relating to MVCs (Central Bank of Ireland, 2019). This indicates that the loss of generality caused by using unweighted NASS-CDS cases is not too severe, and the expected compensation cost (ECC) estimates are at least partially representative of general injury claim cases.

Based on this evidence, it can be concluded that the methodology outlined in Section 2.2 and the estimates outlined in Table 6 provides a viable alternative perspective in to the make-up of the compensation costs attributable to MVCs. MVCs incur significant economic detriment, and this analysis highlights a number of crash characteristics that can be directly linked to increased economic costs. The results indicate that a greater number of safety features are required for backseat occupants. Backseat passengers suffered injuries associated with higher level of compensation relative to front-seat passengers, even though these incidents tend to occur at lower velocities. The results also highlighted the need for continued awareness surrounding the relative safety of seatbelts, and the increased detriment associated with alcohol-impaired driving. These issues have long-been a matter of concern for the NHTSA and other global organisations (World Health Organization, 2018), and the results found in this study serve to highlight the economic benefits of wearing seatbelts, and the economic damage associated with driving while under the influence of alcohol.

Furthermore, the results in Table 6 highlight the need for an increased proliferation of safety-enabled vehicles that can adapt to, and rectify, hazardous events that would otherwise result in MVCs. We find significant positive associations between compensation estimates and head-on or side-impact collisions. Vehicles equipped with advanced driver assistance systems (ADASs) have previously been shown to reduce the frequency and severity of these collision types in reconstructed incidents (Scanlon et al., 2015, Ranfagni et al., 2017, Scanlon et al., 2017, Bareiss et al., 2019). A higher market penetration of ADAS-enabled vehicles can mitigate the occurrence of collision types that significantly increase the level of economic detriment. Finally, the results indicate that biomechanical data (age, weight, height, gender) can be used to aid corporate or state insurance bodies in assessing the expected economic damage incurred from an MVC. Potential improvements can be made in the administrative costs associated with insurance pay outs – for example, by optimising the level of claims reserve required.

6. Conclusion

Our research offers a novel approach to quantify the severity of a motor vehicle collision. The strength of our research lies in the creation of a compensation cost system that offers a granular view on the compensation owed to individual casualties of motor vehicle collisions. Prior estimates focus solely on the most severe injury suffered, whereas we propose the use of estimates that include both primary and secondary injuries. Estimates from the ECC system are generated using standardised guidelines, mitigating the critique that compensation judgments can be subjective and highly variable. The estimates cover typical economic compensation considerations (medical expenses, workplace productivity, and household productivity) and punitive considerations (“loss of enjoyment of life” is a factor in the award amount). Specific utility for our methodology can be found in the motor insurance industry, as expected compensation estimates may decrease the uncertainty within actuarial estimates and mitigate litigation risk.

The findings of our study indicate that much of the severity of an MVC is attributed to the change in a vehicle's speed pre- and post-crash (delta-V). However, a number of other factors highly influence compensation estimates. Biomechanical indicators (Age, Weight, Height, Gender) and specific collision types (single vehicle collisions, head-on collisions, and vehicles struck in intersecting path collisions) largely alter the level of compensation owed to injured occupants. Alcohol-impaired driving is also shown to increase the economic detriment of MVCs, while wearing a seatbelt is shown to decrease the economic damage of MVCs. Both results are in accordance with prior economic studies.

Furthermore, the mediation approach unveiled relationships that would have otherwise gone unnoticed. Backseat occupants and females suffer injuries that result in higher levels of compensation, on average. However, these relationships are offset by negative associations with crash velocities. The implication of this is that excluding delta-V from our analysis would have resulted in these factors having only a marginal effect on compensation estimates. Rather than ruling out significant relationships, this indicates that there are two significant relationships involved – backseat passengers and females are associated with higher ECCs, but they tend to be involved in incidents with lower delta-Vs.

We note some limitations in the data examined. For an MVC to be considered in our dataset, at least one vehicle must be towed from the crash site. As such, the sample is slightly biased toward more serious incidents. Additionally, we only include 11.5% of available cases, in order to ensure the inclusion of accurate and complete data. This may bias the data in our sample even further. However, comparisons to latest injury claim estimates show that the loss of generality is not too severe. In addition, our fixed parameter approach can be improved by considering random parameters, considering that different levels of crash factors may have differing distributional effects on occupants. Random parameters may also account for unobserved heterogeneity, or the ‘unknown unknowns’ that exist among the inherent randomness of MVCs. Further research may also consider additional factors that can influence the expected compensation owed to MVC casualties, such as the safety rating of the vehicle and the presence of advanced safety features in the vehicle. The health profile of the occupant prior to the incident is also not available for this study, which may affect compensation pay outs.

Nevertheless, our research indicates that it is feasible to determine an appropriate estimate of compensation to be awarded solely based on collision factors. The results highlight the importance of existing safety policies (increased use of seatbelts, and eliminating alcohol-impaired driving) and lend additional support to the proliferation of advanced-safety vehicles that can mitigate the effect of detrimental crash types. Combining a fully developed ECC system with other severity-measure models may also offer a more holistic view of MVC risk and can mitigate litigation risk, as well as opening an avenue to link crash research with insurance and underwriting research.

Author contributions

DS planned and led the drafting of the manuscript in conjunction with LR and FM. DS coded the injuries, conceptualised the study and undertook the analysis. LR contributed to the design of the study. All authors were involved in the interpretations of the findings and editing of the manuscript.

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Appendix A

The tables below offer a breakdown of the relationships in Table 4. For mediation to be established, relationships must exist, or theorised to exist, between the three focal points in the mediation environment, i.e. the relationships between crash factors and delta-V, the relationships between crash factors on ECCs, and the relationship between delta-V and ECC. Table A3 represents the total effects in Table 5 – the effects of crash factors on ECC when delta-V is excluded from the model.

A.1. Direct relationship between delta-V and ECC

Table A1

Linear regression: bias-corrected, unstandardised maximum likelihood bootstrap estimates describing the relationship between delta-V and expected compensation cost (ECC).[a, b]

	Expected compensation cost (ECC) (Ln)			
	Estimate	Standard error	90% CI	Sig.
Intercept	7.848	0.112	[7.667, 8.037]	< 0.001[a]
delta-V (Ln)	0.659	0.035	[0.600, 717]	< 0.001[a]

[a] Indicates 1% significance level,

[b] Indicates 5% significance level.

A.2. Direct relationships between crash factors and delta-V

Table A2

Linear regression: bias-corrected, unstandardised maximum likelihood bootstrap estimates describing the relationship between crash factors and delta-V.

	delta-V (Ln)			
	Estimate	Standard error	90% CI	Sig.
Intercept	6.932	0.387	[6.324, 7.588]	< 0.001[a]
Environmental factors				
Dry road	*(Control)*			
Wet road	−0.010	0.037	[−0.070, 0.051]	0.804
Snowy or icy road	0.003	0.058	[−0.090, 0.099]	0.944
Daylight	*(Control)*			
Darkness	0.087	0.019	[0.057, 0.121]	< 0.001[a]
Clear conditions	*(Control)*			
Cloudy conditions	0.052	0.029	[0.004, 0.097]	0.068
Rain, snow or fog	0.008	0.044	[−0.061, 0.084]	0.826
Level ground	*(Control)*			
Uphill	0.008	0.025	[−0.032, 0.049]	0.744
Downhill	0.051	0.024	[0.013, 0.093]	0.026[b]
No controls/other	*(Control)*			
Traffic signals	0.026	0.020	[−0.007, 0.058]	0.188
Stop yield signs	0.050	0.036	[−0.010, 0.108]	0.171
Other regulation signs	−0.058	0.071	[−0.168, 0.066]	0.436
Crash factors				
Single vehicle collision	0.145	0.038	[0.081, 0.204]	< 0.001[a]
Rear-end collision	*(Control)*			
Head-on collision	0.301	0.038	[0.235, 0.358]	< 0.001[a]
Turning across path	−0.059	0.025	[−0.102, −0.018]	0.02[b]
Intersecting path – striking vehicle	−0.085	0.033	[−0.143, −0.034]	0.014[b]
Intersecting path – struck vehicle	−0.216	0.036	[−0.275, −0.156]	< 0.001[a]
Backing up	−0.307	0.159	[−0.695, −0.098]	0.002[a]
Current vehicle age	−0.003	0.003	[−0.007, 0.002]	0.311
Vehicle weight (Ln)	−0.462	0.050	[−0.547, −0.384]	< 0.001[a]
Automobile	*(Control)*			
SUV	0.043	0.024	[0.002, 0.082]	0.079
Light trucks and vans	0.054	0.033	[−0.003, 0.107]	0.116
No avoidance manoeuvre	*(Control)*			
Brake to avoid	−0.087	0.019	[−0.118, −0.056]	< 0.001[a]
Accelerate/swerve to avoid	−0.103	0.030	[−0.153, −0.054]	< 0.001[a]
Occupant characteristics				
Age (Ln)	−0.032	0.016	[−0.060, −0.007]	0.039[b]
Weight	0	0	[−0.001, 0]	0.523
Gender	−0.078	0.020	[−0.110, −0.045]	< 0.001[a]
Height	−0.001	0.001	[−0.002, 0.001]	0.447
In-vehicle dynamics				
Driver DUI	0.201	0.049	[0.121, 0.281]	< 0.001[a]
Seatbelt used	−0.058	0.023	[−0.095, −0.020]	0.009[a]
Seat at front track position	0.118	0.047	[0.037, 0.194]	0.012[b]
Seat in front – mid position	0.020	0.029	[−0.027, 0.070]	0.486
Seat in mid/non-adjustable	*(Control)*			
Seat in mid – rear position	−0.039	0.023	[−0.075, 0]	0.103

(continued on next page)

Table A2 (*continued*)

	delta-V (Ln)			
	Estimate	Standard error	90% CI	Sig.
Seat at rear track position	−0.050	0.023	[−0.088, −0.013]	0.025[b]
Multiple airbags deployed in vehicle	0.123	0.025	[0.080, 0.163]	<0.001[a]
Occupant in driver seat	*(Control)*			
Occupant in passenger seat	−0.016	0.021	[−0.049, 0.019]	0.487
Occupants in backseat	−0.109	0.036	[−0.166, −0.049]	0.004[a]

[a] Indicates 1% significance level,

[b] Indicates 5% significance level.

A.3. Direct relationships between crash factors and ECC, excluding delta-V

Table A3

Linear Regression: Bias-corrected, unstandardised Maximum Likelihood bootstrap estimates describing the relationship between crash factors and expected compensation costs (ECCs) after excluding delta-V from the model.

	Expected compensation cost (ECC) (Ln)			
	Estimate	Standard error	90% CI	Sig.
Intercept	10.740	0.797	[9.437, 12.071]	<0.001[a]
Environmental factors				
Dry road	*(Control)*			
Wet road	−0.092	0.073	[−0.212, 0.029]	0.212
Snowy or icy road	−0.252	0.116	[−0.438, −0.057]	0.033[b]
Daylight	*(Control)*			
Darkness	0.030	0.038	[−0.031, 0.092]	0.436
Clear conditions	*(Control)*			
Cloudy conditions	0.134	0.054	[0.047, 0.225]	0.013[b]
Rain, snow or fog	0.107	0.085	[−0.029, 0.252]	0.197
Level ground	*(Control)*			
Uphill	0.015	0.049	[−0.065, 0.096]	0.758
Downhill	0.053	0.049	[−0.028, 0.135]	0.272
No controls/other	*(Control)*			
Traffic signals	0.039	0.039	[−0.026, 0.103]	0.320
Stop yield signs	0.053	0.069	[−0.060, 0.165]	0.447
Other regulation signs	0.071	0.130	[−0.143, 0.288]	0.593
Crash factors				
Single vehicle collision	0.483	0.069	[0.368, 0.594]	<0.001[a]
Rear-end	*(Control)*			
Head-on collision	0.593	0.071	[0.470, 0.708]	0.001[a]
Turning across path	0.049	0.050	[−0.036, 0.129]	0.365
Intersecting path – striking vehicle	−0.084	0.064	[−0.186, 0.024]	0.203
Intersecting path – struck vehicle	0.182	0.064	[0.077, 0.286]	0.003[a]
Backing up	−0.079	0.223	[−0.368, 0.428]	0.786
Current vehicle age	−0.010	0.005	[−0.019, −0.001]	0.053
Vehicle weight (Ln)	−0.121	0.105	[−0.294, 0.051]	0.251
Automobile	*(Control)*			
SUV	−0.069	0.049	[−0.146, 0.013]	0.169
Light trucks and vans	−0.130	0.063	[−0.234, −0.025]	0.031[b]
No avoidance manoeuvre	*(Control)*			
Brake to avoid	−0.107	0.039	[−0.171, −0.041]	0.008[a]
Accelerate/swerve to avoid	−0.038	0.057	[−0.135, 0.053]	0.486
Occupant characteristics				
Age (Ln)	0.219	0.034	[0.162, 0.276]	<0.001[a]
Weight	0.002	0.001	[0, 0.003]	0.048[b]
Gender	0.030	0.038	[−0.033, 0.093]	0.425
Height	−0.004	0.001	[−0.006, −0.001]	0.009[a]
In-vehicle dynamics				
Driver DUI	0.316	0.093	[0.160, 0.465]	0.001[a]
Seatbelt used	−0.300	0.044	[−0.370, −0.225]	<0.001[a]
Seat at Front track position	0.085	0.084	[−0.057, 0.219]	0.333
Seat in front – mid position	0.027	0.059	[−0.076, 0.121]	0.654
Seat in mid/non-adjustable	*(Control)*			
Seat in mid – rear position	−0.043	0.044	[−0.114, 0.034]	0.345
Seat at rear track position	−0.042	0.046	[−0.117, 0.033]	0.366
Multiple airbags deployed in vehicle	0.305	0.051	[0.224, 0.390]	<0.001[a]
Occupant in driver seat	*(Control)*			
Occupant in passenger seat	−0.015	0.044	[−0.087, 0.057]	0.710
Occupants in backseat	0.108	0.077	[−0.010, 0.240]	0.136

[a] Indicates 1% significance level,

[b] Indicates 5% significance level.

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