

A SIMULATION BASED APPROACH TO ASSESS THE SAFETY PERFORMANCE OF ROAD LOCATIONS

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ABSTRACT

This paper outlines the development of a simulation modelling approach to assess the safety performance of roads. Statistical analysis, numerical modelling using Newtonian Mechanics, and micro simulation models have been used by researchers to assess roads safety performance. In this research a combination of these three methods is utilised to improve the assessment of safety at road locations compared to previous works. Micro simulation forms the basis of the framework while statistical models and numerical models using Newtonian Mechanics are the other models utilised and imbedded into the micro simulation model. The input into the micro simulation model is general traffic conditions and its output is a measure of safety performance of roads. The framework consists of two main parts. The first is the estimation of the number and severity of conflicts from general traffic flow inputs. The second part is an estimation of the expected injury severity of individuals, involving in the conflict, should the simulated conflict lead to a crash. The Australian Crash In-Depth Study (ANCIS) data base is used to estimate the statistical and numerical model parameters. The modelling framework is applied to an intersection in Melbourne, Australia and its associated safety performance results are interpreted.

Keywords: kinetic energy, injury severity score, safety evaluation, micro-simulation

RESEARCH BACKGROUND

Safety in the transport system is the consequence of an interaction between the driver, the vehicle and the road environment (Ogden, 1996). According to the literature of road safety evaluation, three modelling approaches which have been used to assess the safety

performance of roads are numerical analysis using Newtonian Mechanics, statistical analysis and micro simulation.

Considerable research has been directed at modelling vehicles and the severity of collisions between vehicles and other objects. **Newtonian mechanics**, which duplicates the physical dynamics of a crash, has been used to develop numerical models to explore the relationship between crash characteristics and severity (Wood and Simms, 2002; Buzeman et al., 1998; Wood, 1997; Evans, 1994; Jokschi, 1993; and Evans and Frick, 1993)

Other Researchers have used **statistical models** to explore the relationship of the number and severity of crashes with the main factors affecting safety. Early statistical models focused on traffic flow in particular directions and determined the level of conflict (Golob et al., 1988; Turner et al., 1998). Chin and Quddus (2003), Abdel-Aty and Keller (2005), Yan et al.(2005) and Wang and Abdel-Aty (2008) improved crash statistical analysis and used regression and/or ordered probit models for analysing driver injury severity level at intersections.

Different explanatory variables have been used to model the number and severity of crashes using statistical models. Lord et al. (2005), Kim et al. (2007) and Li et al.(2008) considered the road and environmental factors to develop models to investigate crash number or occurrence. Other researchers (Wong et al., 2007, Quddus et al., 2009, Das and Abdel-Aty, 2010) analysed the relationship between the road and environmental factors and the severity of crashes. Christoforou et al. (2010), Helai et al. (2008) and Das et al. (2009) considered the human and vehicle characteristics to be combined with environmental characteristics to estimate the severity of crashes.

A more recent approach used to replicate crash outcomes uses traffic **micro simulation analysis** (Davis, 2007). The previous approaches have tended to use crash data as the basis of analysis. The lack of such data, its slowness in being collected and the difficulty in observing some accident situations, encouraged researchers to look at other methods. One such approach grew out of the conflict analysis literature and considered surrogate safety measures for indicting the safety of facilities (Laureshyn et al., 2010; Guido et al., 2010; Archer and Young, 2009; Caliendo et al., 2007; Douglas and Head, 2003; Katamine, 2000; Hauer and Garder, 1986) A traffic conflict has been defined as ‘ *An observable situation in which two or more road users approach each other in time and space to such an extent that there is risk of collision if their movement remains unchanged*’ (Amundsen et al., 1977). Hyden (1987) defined uniform severity level and uniform severity zones for measuring the severity level of the conflicts regarding time-to-accident and conflict speed. Hyden (1996) defined different conflict levels according to different required braking rates (RBR) (or Deceleration Rate).

Recently, Archer and Young (2010), Cunto and Saccomanno (2008), and Douglas et al. (2008) have made significant steps forward in incorporating the traffic conflict approach into traffic simulation models in order to estimate the number and type of crashes. Archer and Young (2010) studied the application of surrogate safety measures for intersection safety assessment and their application in micro-simulation modelling. They used a probability approach for developing a gap acceptance model for unsignalised T intersections in order to determine the number and severity of conflicts. Cunto and Saccomanno (2008) developed a methodology for intersection safety evaluation using micro-simulation. They defined a crash potential index to assess the safety performance of intersection. Further research, which considers simulation based safety evaluation, was undertaken by the Douglas et al. (2008).

They developed Surrogate Safety Assessment Model (SSAM) for assessing the safety performance of different types of intersections. The SSAM model can determine the number and severity of conflicts in each conflict point at an intersection.

In summary, three modelling approaches have been used to investigate the level of safety of roads. Newtonian Mechanics has been used to investigate detailed crash analysis. Statistical models have been utilised to explore the relationship of crash outcome with road and environmental characteristics. Simulation models have been used to estimate the number and severity of conflicts using surrogate safety measures. The preceding approaches enhance the understanding of safety evaluation; however, road safety assessment could be improved through linking conflict outcome and crash outcome together.

In this paper a method is introduced to assess the safety performance of road network by linking the three preceding approaches. In the method, the number and severity of conflicts is measured using a micro simulation model. Then a combination of Newtonian Mechanics and statistical models is incorporated into the micro simulation model to estimate the potential injury severity of simulated conflicts. The developed framework improves the simulation based safety performance assessment by considering the risk of crash severity for different conflicts.

The following sections of this paper outline a proposed theory to assess the safety performance of roads. A computational example, showing the entire proposed approach, is then provided. The paper closes with discussion of results and conclusion.

METHODOLOGY

In this section, the simulation modelling framework developed to assess the safety performance of road locations is described (see Figure 1). The modelling framework includes two main parts.

The first part of the framework is to estimate the number and severity of conflicts using micro-simulation model. Input into this part of the framework is the geometry and traffic characteristics of the road system. After generating individual vehicle movement the conflicts can be determined using probabilistic human behaviour models such as lane changing, car following, gap acceptance and stop or go decision at the onset of amber (Archer and Young, 2009; Cunto and Saccomanno, 2008; Archer, 2005). Archer (2005), Archer and Young (2009) and Cunto and Saccomanno (2008) used different simulation based human behaviour models to determine the number and severity of conflicts. Archer (2005) developed a binary logistic regression model to model the gap acceptance behaviour of the vehicles at intersections. The explanatory variable of this model was the time gap between two vehicles. Archer and Young (2009) utilised a binary logistic regression model to predict the stop or go decision of the drivers at the onset of amber. The dependent variables of this model are the speed of the vehicle and the distance of the vehicle from the stop line. Cunto and Saccomanno (2008) used variables of the car following and the lane changing models in VISSIM model to calibrate and validate a proposed simulated crash potential index (CPI). These relationships were used in this model to generate conflicting situations.

Once the conflicts have been generated their severity is studied. Conflict severity measures have been defined by several researchers. Hyden (1987) defined uniform severity level and uniform severity zones for measuring the severity level of the conflicts regarding time-to-

accident and conflict speed. Hyden (1996) defined different conflict levels according to different required braking rates (RBR) (or Deceleration Rate). The output of the first part of the simulation framework is the characteristics of the simulated serious conflict and the RBR.

The second part of the framework is the measurement of potential injury severity of each simulated conflict. The input to this part is the characteristics of the simulated conflict which are the output of the first part of the simulation framework. The second part of the framework consists of two main models:

- The first model is the driver reaction model. This model determines the driver reaction in conflict based on the simulated conflict characteristics. The driver reaction in a crash is important since it influences the severity of crashes. The driver reaction model determines whether the driver, involving in a conflict, takes any reaction.
- The second model is a two-step modelling approach used to estimate the potential injury severity of conflicts (Figure 2). In the first step, the expected speed change of the subject vehicle (ΔV_s) is estimated using conflict characteristics and a driver's reaction during a conflict; Newtonian Mechanics is used to estimate the kinetic energy applied to the subject vehicle according to the mass and estimated ΔV_s (Figure 3). The law of conservation of momentum is utilised to identify the crash characteristics affecting the ΔV_s (Sobhani et al., 2011). Those conflict characteristics which influence the identified crash characteristics are used as predictors of the ΔV_s model. In the second step the expected Injury Severity Score (ISS) of the conflict is measured using estimated kinetic energy of the subject vehicle and the impact type of the expected crash. Since the ISS has been shown to be a good indicator of mortality risk (Sampalis et al., 1995) of the occupant and is relatively simple to evaluate, it was chosen as the primary measure of occupant injury severity in this study. The estimation of the models outlined in the second part of the framework is explained in the following sections.

The final output of the micro simulation model is the safety level of the simulated road location. This safety level is determined using the number and severity of conflicts and the potential crash injury severity of the simulated conflicts.

DATA

To develop the models outlined above, a data set that contains the appropriate variables is required. The Australian Crash In depth Study (ANCIS) database (Logan et al., 2006) is used to develop the statistical relationship between conflict characteristics, driver reaction and crash injury severity. ANCIS is an ongoing research program in which in-depth data on a sample of passenger vehicle crashes since 2000 in Victoria and New South Wales has been collected. The occupants recruited to this study are those who have been hospitalised as a result of the crash. In that, the participants are interviewed using a structured questionnaire and the vehicle in which they were travelling is inspected and the site of the crash is visited. Medical records of the victims are examined to determine their injuries. Photographs of the vehicles involved in the crash are taken to measure the damage of the crash and a variety of crashworthiness measures evaluated. The total number of available cases in ANCIS database is 700 crashes; however, the information required for model development reduces the number of cases used in this study. The reason is that the required information of the dependent and explanatory variables is not available for all 700 crashes.

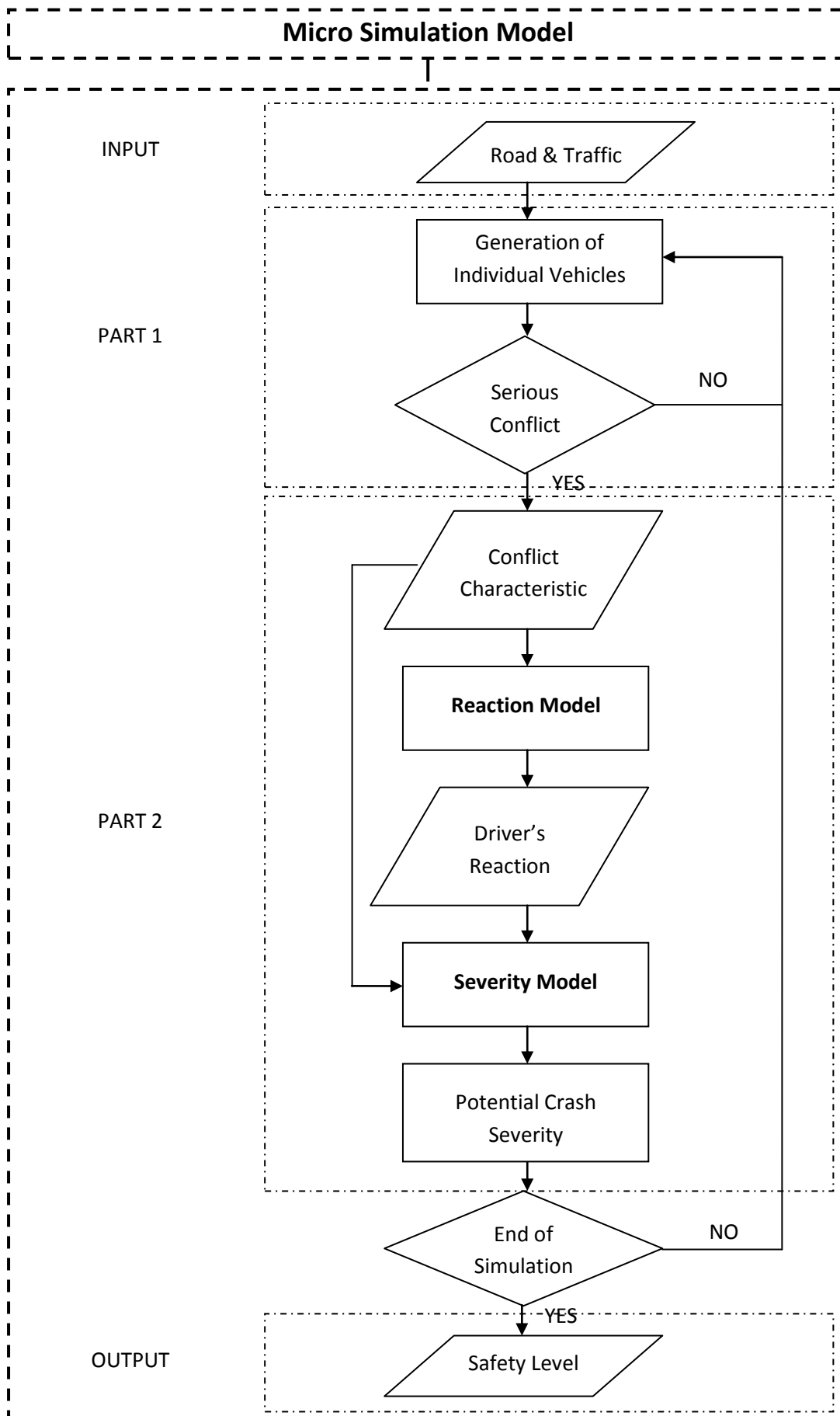
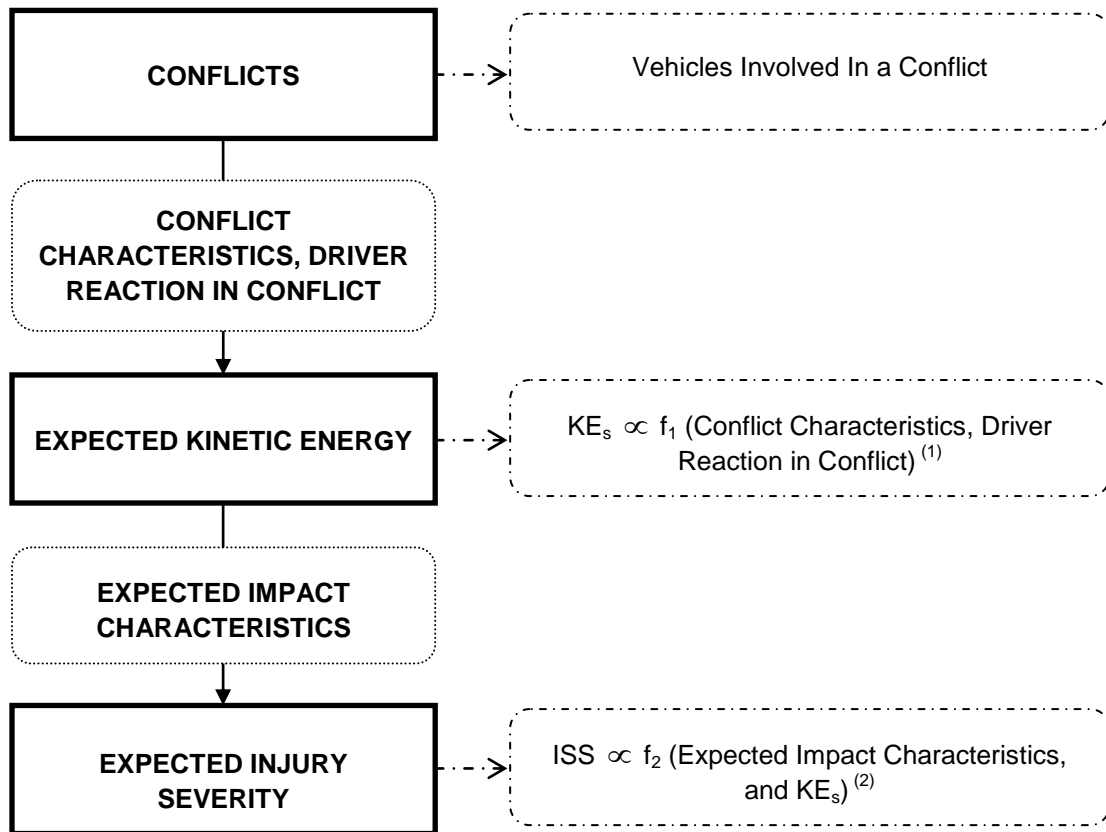


Figure 1: Flowchart of the developed framework



- (1) f_1 is the mathematical model presenting the expected kinetic energy transferred to the subject vehicle in crash according to conflict characteristics and driver reaction in conflict.
- (2) f_2 is the mathematical model presenting the expected ISS of the crash according to expected impact characteristics and kinetic energy transferred to the subject vehicle.

Figure 2: Modelling process of the crash severity

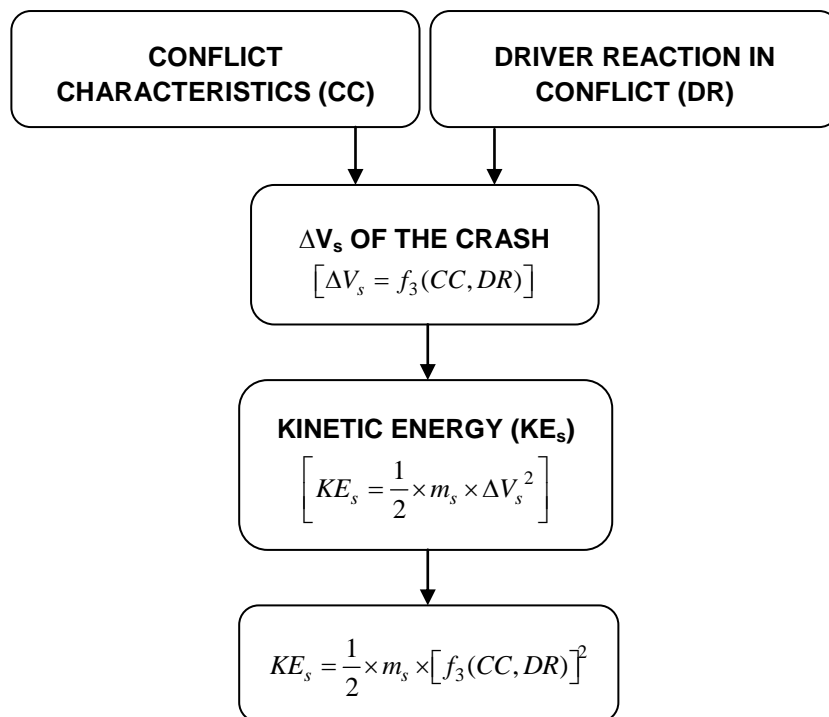


Figure 3: Kinetic Energy modelling process

MODEL ESTIMATION

Figures 1, 2 and 3 introduce the various levels of modelling used in this paper. This section estimates the parameters in the driver reaction, ΔV_s and ISS models.

Both nonlinear regression modelling and different generalised linear modelling (GLM) techniques (Agresti, 2002) were examined while developing the Driver reaction, ΔV_s and ISS models. Generalised linear regression models which have continuous output variables fitted better than nonlinear regression models for ΔV_s and ISS models.

Driver Reaction Model

The development of the driver reaction before crash model is outlined in this sub-section. This model represents the first model in the second part of the framework (see Figure 1). The driver reaction considered in this study is a binary output variable. Binary Logistic Regression and Binary Probit Models (BPM) were examined to estimate driver reaction before crash. The BPM fitted well; therefore, this model is adopted in this study to estimate driver reaction before crash. BPM is a type of GLM in which the random component is normal distribution and the link function is Probit function. The mathematical equation of the BPM is:

$$P_n(j) = \phi(a_0 + \sum_{i=1}^n a_i x_i) \quad (1)$$

$$P_n(J) = 1 - P_n(j) \quad (2)$$

where:

$P_n(j)$: Dependent variable.

i : Subscribe showing the number of independent variables.

j : The first level of the dependent variable.

J : The second level of the dependent variable (The reference level).

x_i : Independent variable.

a_0 : Intercept

a_i : Coefficient calculated for each of the independent variables.

ϕ : Denote the standardised cumulative density function (CDF) of normal distribution.

Level J is the reference level of the dependent variable. In the Equations (1) and (2), a_0 and a_i are calculated in calibration process of the BPM.

The ANCIS database was used to develop this model. The dependent variable of this model is the probability of driver reaction. The driver reactions are “no reaction” and “reaction”. The preceding variables are the levels of the dependent variable in the BPM. The “reaction” level is considered as the reference level (level J). The explanatory variables considered for the model are summarised in Table 1. The levels of the definition for classifying accidents (DCA) used in ANCIS are shown in Figure 4.

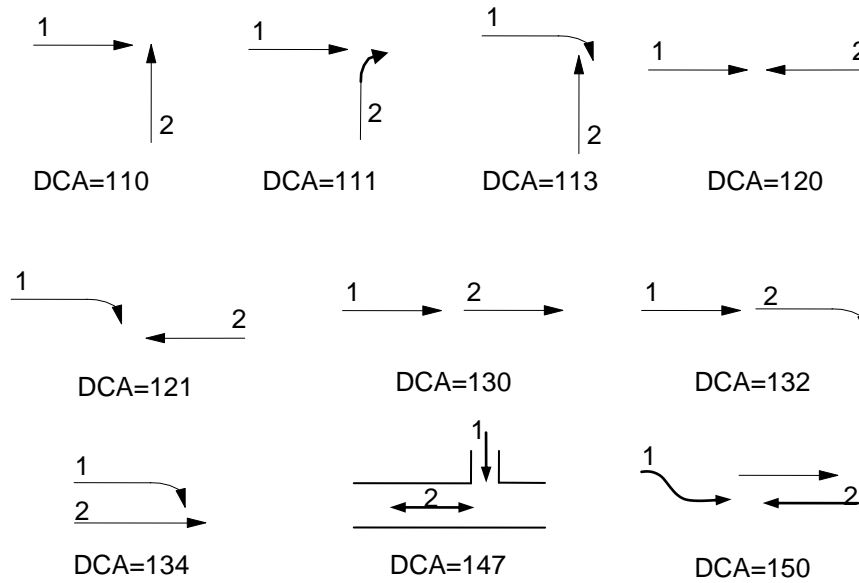


Figure 4: Crash configurations used (from definitions for classifying accidents)

The model calibration process is undertaken using 150 crashes. The goodness of fit of the model was tested using Omnibus test comparing the performance of the fitted model and the “Null” model. The contribution of each of the explanatory variables to the model was tested using a Wald statistic with 5% level of significance. The results of the model fit show a well-fitted model based on the Omnibus test ($\text{sig} < 0.001$) and Wald statistic ($\text{sig} < 0.001$ for speed limit at the scene of the crash; $\text{sig} = 0.002$ for the interaction of the weather condition, DCA and gender).

The variables which were significant in the model are the speed limit at the scene of the crash, and the combination of “Definitions for Classifying Accidents (DCA)”, “weather condition” and “gender”.

Table 2 shows that accordance to the model parameters when the speed limit at the scene of the crash increases the probability of “no-reaction” behaviour is decreased. This value gives an estimation of average speed of the vehicles moving on the road.

Table 2 further shows that the clear weather condition is significant according to the model calibration results. The DCA of a crash shows the crash type. In general the interaction of “weather condition”, “DCA” and “gender” has positive impact on “no-reaction” behaviour. However, this influence is different for different interaction levels of type of crash and gender. The probability of “no-reaction” for side crashes is more than right turn against, head-on and right near crashes. This is reasonable as side crashes usually happen at intersections and it is harder to see the other vehicle in a side crash. For frontal crash the probability of reaction is more than other crashes. This is predictable as both drivers can generally see each other more easily in a frontal crash.

The model variables and parameters are described in Table 2.

Table 1: Variables considered for developing the model

dependent variable	Independent variable	Description	Defined levels
Driver Behaviour (2 levels: 1= Reaction; 2=No-reaction)	I ₁	Speed limit at the scene of the crash (km/h)	Numerical
	I ₂	Weather condition	2 levels: 0= weather is not clear; 1= weather is clear.
	I ₃	Definitions for Classifying Accidents (DCA)	5 levels: 1= Side crashes (110); 2= right near crashes (113); 3= head on crashes (120); 4= right through crashes (121); 5= other crashes.
	I ₄	Gender	2 levels: 0= female; 1= male.

Table 2: Binary Probit model parameters

Level of The Dependent variable* (<i>j</i>)	Independent variable (<i>x_i</i>)	Parameters (<i>a_i</i>)	Significance Level (Wald Statistic)	S.E.
No-Reaction	I ₁	-0.031	< 0.001	0.0077
	I ₂ (1) ** * I ₃ (1) * I ₄ (0)	3.431	< 0.001	0.9155
	I ₂ (1) * I ₃ (1) * I ₄ (1)	2.413	0.002	0.7751
	I ₂ (1) * I ₃ (2) * I ₄ (0)	2.088	0.050	1.0257
	I ₂ (1) * I ₃ (3) * I ₄ (0)	1.783	0.015	0.7333
	I ₂ (1) * I ₃ (3) * I ₄ (1)	2.113	0.002	0.6874
	I ₂ (1) * I ₃ (4) * I ₄ (0)	2.310	0.001	0.6705
	I ₂ (1) * I ₃ (5) * I ₄ (0)	2.680	< 0.001	0.6428
	I ₂ (1) * I ₃ (5) * I ₄ (1)	3.089	< 0.001	0.7307

The model presented in Table 2 is used to find the probability of “no-reaction” behaviour in a crash situation. A cut off value of 50% is defined to indicate the marginal value that if the probability exceeded that value, the “no reaction” behaviour occurs. The final result of BPM is used as an independent variable in the ΔV_s model presented in Figure 3.

ΔV_s Model

Various modelling functions with continuous outcome (dependent variable) such as linear regression models, non-linear regression models and generalized linear regression models were examined to estimate ΔV_s of the crash. The model estimation is carried out based on 138 data crashes. The Log-Gamma regression model, which is a type of generalized linear regression models (GLRM), provided the best fit for predicting the ΔV_s of the subject vehicle in the crash and is adopted in this study. In this model the random component of the dependent variable is estimated using a Gamma distribution. The Log function is selected as the link function of the model. The mathematical expression of the model is shown below:

$$f_3 : Y = EXP(\beta_0 + \sum_{i=1}^i \beta_i \times x'_i) \quad (3)$$

Where:

Y : Dependent variable

i : Subscribe showing the number of independent variables

x'_i : Independent variable

β_0 : Constant

β : Coefficient of the independent variable

β_0 and β are calculated in calibration process of the model.

The conflict characteristics, considered as independent variables, are indicated based on the crash characteristics affecting the value of ΔV_s (Sobhani et al., 2011). The conflict characteristics considered to estimate expected ΔV_s for each conflict is given in Table 3.

Different levels of DCA are shown in Figure 4.

The significance of the conflict characteristics was determined using statistical analysis. The variables included in the model, their parameter estimates, and the significance of the parameters (5% level) are summarised in Table 4.

The variables which are significant for the model are m_b/m_s and the interaction between driver reaction and definitions for classifying accidents (DCA).

The Omnibus test and likelihood ratio Chi-Square test statistics were used to examine the significance of each independent variable in the model. The results of the fitness of the model show a well fitted model based on the Omnibus test (sig<0.001) and likelihood ratio Chi-Square test (sig<0.001 for interaction of driver reaction and DCA; sig=0.027 for the mass ratio).

The mathematical equation of the kinetic energy of crash is:

$$f_1 : KE_s = \frac{1}{2} \times m_s \times (EXP(\sum_{i=1}^i \beta_i \times x'_i))^2 \quad (4)$$

Where:

β_i and x_i are the parameters and independent variables of the ΔV_s model respectively (see Table 4). KE_s is the kinetic energy transferred to the subject vehicle.

Table 3: Variables considered for developing the model

dependent variable	Independent variable	Description	Defined levels
ΔV_s	P ₁	Speed limit at the scene of the crash (km/h)	Numerical
	P ₂	Driver reaction	2 levels: 1= reaction; 2= no reaction.
	P ₃	Definitions for Classifying Accidents (DCA)	10 levels: 1= Side crash (110); 2= Right far crash (111); 3= right near crash (113); 4= head on crash (120); 5= right through crash (121); 6= Rear end crash (130); 7= Right rear crash (132); 8= Lane change right crash (134); 9= Emerging from driveway-lane crash (147); 10= Head on (overtaking) crash (150).
	P ₄	Mass ratio (Mass of bullet vehicle over mass of target vehicle)	Numerical

Table 4: Characteristics included in the ΔV_s model

Dependent variable (Y)	Independent variable (X_i')	Average Value (Numerical)	Proportion of crashes involving interaction (P ₂ ()*P ₃ ()) (Categorical)	Significance level	Parameters (β_i) ($\beta_0 = 0$)	S.E.
ΔV_s of The Subject Vehicle	P ₂ (1)*P ₃ (1)*		4.9 (%)	< 0.001	3.168	0.2737
	P ₂ (2)*P ₃ (1)		14.8 (%)	< 0.001	3.110	0.1693
	P ₂ (2)*P ₃ (2)		1.6 (%)	< 0.001	3.469	0.3349
	P ₂ (2)*P ₃ (3)		4.9 (%)	< 0.001	3.109	0.2417
	P ₂ (1)*P ₃ (4)		8.2 (%)	< 0.001	3.576	0.2041
	P ₂ (2)*P ₃ (4)		31.1 (%)	< 0.001	3.520	0.2252
	P ₂ (1)*P ₃ (5)		8.2 (%)	< 0.001	3.369	0.2261
	P ₂ (2)*P ₃ (5)		6.6 (%)	< 0.001	3.371	0.2326
	P ₂ (1)*P ₃ (6)		6.6 (%)	< 0.001	3.161	0.2209
	P ₂ (2)*P ₃ (6)		3.3 (%)	< 0.001	3.602	0.3110
	P ₂ (2)*P ₃ (7)		1.6 (%)	< 0.001	2.342	0.5588
	P ₂ (1)*P ₃ (8)		1.6 (%)	< 0.001	2.719	0.3272
	P ₂ (2)*P ₃ (9)		3.4 (%)	< 0.001	2.315	0.4345
	P ₂ (1)*P ₃ (10)		1.6 (%)	< 0.001	3.554	0.3357
P ₂ (2)*P ₃ (10)		1.6 (%)	< 0.001	3.709	0.3414	
	P ₄	1.1521		0.021	0.347	0.1508

The estimated parameters of ΔV_s model show that the ratio of mass of bullet vehicle over mass of target vehicle influences the ΔV_s in a positive way. This is logical since this parameter has a positive correlation with ΔV_s according to the law of conservation of momentum (Sobhani et al., 2011).

Table 4 shows that there are 15 different interactions between the DCA and human behaviour. This interactive variable is very important since these variables influence vehicles situation before and after the crash. Therefore the value of ΔV_s is affected by these parameters. The estimated parameters of the model show that the ΔV_s for the crashes with DCA levels 7, 8 and 9 are lower than other type of crashes. This is reasonable as these levels of DCA are related to rear-end, sideswipes and “Emerging from driveway-lane” crashes which are generally less severe than other types of crashes. Also, the parameter estimation of the model shows that there is not a large difference among the other estimated parameters associated with interaction of different levels of the preceding variable. Thus, the interactions which have more frequency in the data have more effect on the model. The ANCIS data base shows that the proportion of frontal crashes, side crashes and right turn against crashes are more than other cases. These are among the most severe type of crashes in the road network (Abdel-Aty and Keller, 2005).

ISS Model:

The second step in the modelling process of the crash severity (Figure 2) is the relationship between the ISS of the crash and the kinetic energy of the crash. Table 5 shows the independent variables of this model. The independent variables of this model are the energy of the crash and the crash impact type. Occupant characteristics such as airbags, the restraint use and the age of occupant are the other parameters which could be included in ISS model. The model developed in this study is incorporated in micro simulation model. Therefore, the explanatory variables selected for ISS model included those variables that could easily and accurately be delivered as the output of simulation models. Simulation models are developed based on probability distribution functions. The data related to the probability distributions of fastening seat belt, presence of airbag and age of the drivers is difficult to accurately collect from the simulation model. The ISS model including all the preceding variables was explained in Sobhani et al. (2011).

A multiple linear regression technique is utilised to predict the Injury Severity Score (ISS) of the crash. In this type of model it is assumed that there is a linear relationship between dependent and independent variables (Ross, 2010). The following equation presents the mathematical equation of the model:

$$f_2 : Y' = \sum_{i=1}^i (\alpha_0 + \alpha_i \times x_i^n) \quad (5)$$

Y' : Dependent variable

α_0 : Intercept

i : Subscribe representing the number of independent variables

α_i : Coefficient of each independent variable which should be calibrated

x_i^n : Independent variable

The model characteristics are summarised in Table 6.

Table 5: Crash characteristics considered for ISS model

Model	Independent variable	Description	Defined levels
ISS	KE _s	Kinetic Energy Applied to Subject Vehicle	Numerical
	I ₅	Near side/ Far side/Front/Rear Impact	5 levels: (1=struck on near side; 2= struck on far side; 3= none; 4= front; 5= rear)

Table 6: Characteristics of ISS model

Dependent Variable (DV)	Independent Variable (IV)	Significance Level	Parameters (α_i)	R Squared
ISS	KE	0.038	2.487x 10 ⁻⁵	0.6
	I ₅ (1)*	0.000	10.745	
	I ₅ (2)	0.009	8.017	
	I ₅ (4)	0.001	8.251	

* The number in the bracket shows the level of the variable.

The results of parameter estimate of the model show that the KE_s affect the ISS positively. This is reasonable since a part of this kinetic energy transfers to human body and cause injuries and fatalities (Corben et al., 2004; Elvik, 2004).

Definitions of different impact types are shown in Figure 5. As it can be seen from Table 6, the crash severity of the struck on near side cases is higher than struck on far side and frontal cases. This is logical since in struck on far side and frontal impact types a larger amount of kinetic energy is absorbed by the vehicle body structure than the struck on near side impact type.

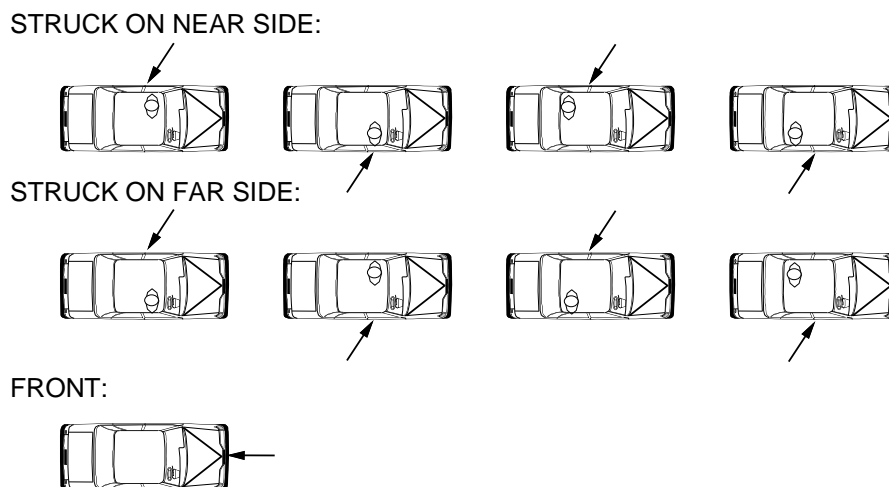


Figure 5: Definitions of impact type of the crash

APPLICATION OF THE METHODOLOGY

The previous sections have outlined the simulation based approach developed to assess the safety performance of road locations. In this section, a case study of the methodology is presented. The four leg unsignalised intersection between Victoria Road and Burke Road, Camberwell, Melbourne, Australia (Figure 6) was chosen for the case study. The type of the intersection is a cross intersection controlled by stop sign in the approaches from Victoria Road. Information associated with the geometric design, the traffic volume and the origin destination matrix of intersection were collected from the site. In this discussion the crash taken into consideration is the side crash occurring between the vehicles giving way from Victoria Road (West to East) and the vehicles driving along Burke Road (South to North). In this side crash the vehicles from Victoria Road are considered as subject vehicles.

Micro Simulation Model

VISSIM traffic simulation model is used to model traffic movements in the intersection. The driver reaction model and the severity model are incorporated in the VISSIM simulation model using VISSIM COM Interface. The model was calibrated to represent the flow at the intersection and the level of conflict calculated using the required braking rate for severe conflicts. Estimates of the level of conflict are calculated using the required braking rate (Archer and Young, 2010). According to the definitions proposed by Hyden (1996), a RBR of more than $-4 \text{ (m/s}^2\text{)}$ was considered as a serious conflict.



Figure 6: Intersection layout

The criteria used for measuring the safety level of the intersections are: the number of serious conflicts, the average expected kinetic energy of the subject vehicle (KE_s), calculated for each conflict, using the ΔV_s model and the average potential ISS, calculated for each conflict, using the ISS model. The average of expected KE_s and the average of expected ISS are calculated for all the vehicles which have the possibility of being a subject vehicle in a crash. These are the vehicles in Victoria Road.

If a vehicle is not involved in a serious conflict the magnitude of the expected KE_s and the expected ISS is zero. To compare the safety of the road movements the average KE_s and ISS can be calculated. This can be done in two ways. Equations 6 and 7 present the average expected KE_s and the average expected ISS for all the minor approach vehicles simulated in the studies.

$$AVKE_s = \frac{\sum_{i=1}^{n_{con}} KE_s}{V} \quad (6)$$

$$AVISS = \frac{\sum_{i=1}^{n_{con}} ISS}{V} \quad (7)$$

Where:

$AVKE_s$: The average expected KE_s

$AVISS$: The average expected ISS

KE_s : Expected kinetic energy of the subject vehicle

ISS : Expected injury severity score of the subject vehicle

n_{con} : The number of serious conflicts

V : Total number of vehicles in Victoria Road during the simulation time

The average of expected KE_s and the average of expected ISS can also be calculated for the subject vehicles that are involved in a serious conflict. Equations 8 and 9 show these formulas.

$$AKE_s = \frac{\sum_{i=1}^{n_{con}} KE_s}{n_{con}} \quad (8)$$

$$AISS = \frac{\sum_{i=1}^{n_{con}} ISS}{n_{con}} \quad (9)$$

Where:

AKE_s : The average expected KE_s for serious conflicts

$AISS$: The average expected ISS for serious conflicts

Micro Simulation Results

The VISSIM simulation model was run for a three hours simulation period and for three different minor traffic flows (20 veh/hr, 40 veh/hr and 80 veh/hr) on Victoria Road. This enables the safety performance of the intersection to be studied in three traffic flow situations. Other variations such as vehicle composition, traffic signal characteristics, average speed and road geometry could have potential influence on the intersection safety; however, this example is designed to demonstrate the general performance of the methodology. Three

runs of each simulation model are undertaken and the average values of the outputs used to describe the safety performance of the manoeuvre.

Figure 7 shows an analysis of the relationship between the mass ratio and each of the kinetic energy and the injury severity score of the potential crashes associated with simulated serious conflicts. The mass ratio is the ratio of the mass of bullet vehicle and the mass of target vehicle involving in a simulated serious conflict. The kinetic energy is the expected kinetic energy applied to the subject vehicle if the serious conflict leads to crash. The injury severity score is the injury severity score of the individuals calculated given the conflict leads to crash. The mass ratio is the output of the part one of the simulation framework and the kinetic energy and the injury severity score are the outputs of the second part of the simulation framework (see Figure 1).

Figure 7(a) shows that a parabolic trend of mass ratio and the expected kinetic energy in the three simulated scenarios fits the data well. This relationship is consistent with the relationship of the mass ratio and the kinetic energy calculated based on the Newtonian Mechanics (see Sobhani et al. 2011).

Figures 7(b) shows the relationship of the mass ratio and the injury severity score (ISS). As can be seen from Figure 7(b) a parabolic relationship fits well for these two variables. This shows the clear relationship between the expected kinetic energy applied to the subject vehicle and the potential injury severity of individuals present in this vehicle (see Sobhani et al. 2011).

The overall performance of the model is summarised in Table 7. It shows the average number of serious conflicts, the average KE and ISS for all minor traffic vehicles (Equations 6 and 7), and the average KE and ISS for serious conflicts (Equations 7 and 8)

Table 7: The results of the model

Evaluation Measure	Traffic Flow in Minor Road		
	20 veh/hr	40 veh/hr	80 veh/hr
Average number of serious conflicts	4.2	7.1	14.3
AKE _s (Joules)	616338.7	966324.4	1091807
AISS	24.5	34.7	37.4
AVKE _s (Joules)	41089.24	56368.92	59139.55
AVISS	1.72	2.01	2.05

Table 7 shows that, the number of serious conflicts increases with increasing traffic in minor approach (Victoria Road). This is expected as the number of conflicting manoeuvres increases by increasing in-traffic flow from crossing direction.

Table 7 also shows two types of safety comparison for each of the three simulated scenarios.

The first comparison is the absolute comparison of the safety for the three simulated scenarios. AKE_s and AISS are the evaluation measures providing an absolute comparison of the scenarios. Two samples t-test with 95% confidence level was performed to compare the simulation results for the three scenarios. The statistical test results showed that there is significant difference in the average expected kinetic energy for subject vehicle (AKEs) and the average potential injury severity score (AISS), calculated for serious conflicts, between

the first and third scenarios where the minor traffic flow is 20 veh/hr and 80 veh/hr respectively. This means based on the absolute comparison the first scenario, traffic flow in minor approach is 20 veh/hr, is the safer than the third scenario, traffic flow in minor approach is 80 veh/hr, because the AKE_s and $AISS$ has the lower magnitude in this scenario.

The absolute comparison only considers the average expected kinetic energy and the average potential injury severity score for the serious conflicts. This does not include the minor vehicles crossing from the intersection who are not involved in any conflict. In the relative comparison of the safety level of three simulated scenarios all vehicles crossing the intersection are included. The average value of the expected kinetic energy and the average potential injury severity score for all the vehicles in the minor traffic flow are calculated using $AVKE_s$ and $AVISS$ equations respectively (see Equations 6 and 7). Two samples t-test with 95% confidence level was performed to compare the simulation results for the three scenarios. The results showed that there is not enough evidence to show significant difference between the results of the simulated scenarios.

As mentioned above, the main difference between the absolute and relative comparisons is the calculation method of the average value of expected KE_s and expected ISS . Given that the traffic flow of the minor road is the only variable changed in the three simulated scenarios, there would be more conflicting manoeuvres as the minor traffic flow increased. Consequently, the possibility of risky conflicts to occur is increased. That is why in absolute comparison there is a significant difference between the simulation results of the first scenario, traffic flow in minor approach is 20 veh/hr, and the third scenario where traffic flow in minor approach is 80 veh/hr. On the other hand, according to the relative comparison, the minor road vehicles crossing the intersection without involving in conflict do not take any risk; therefore, for these cases the value of $AVKE_s$ and $AVISS$ is zero. Thus, not only the number and severity of risky conflicts takes part in the final results of the safety evaluation but also it is important to consider the ratio of the increased rate of the number of serious conflicts over the increased rate of traffic flow. The composition of these two factors indicates the safety level of the simulated intersection for different scenarios. For example, consider the situation that the simulation results of the third scenario show more risky conflicts in comparison with the first scenario. Also consider that the ratio of the increased rate of the number of serious conflicts over the increased rate of traffic flow for the first and the third scenario is equal or more than one. In this situation the safety level of the third scenario is lower than the safety level of the first scenario.

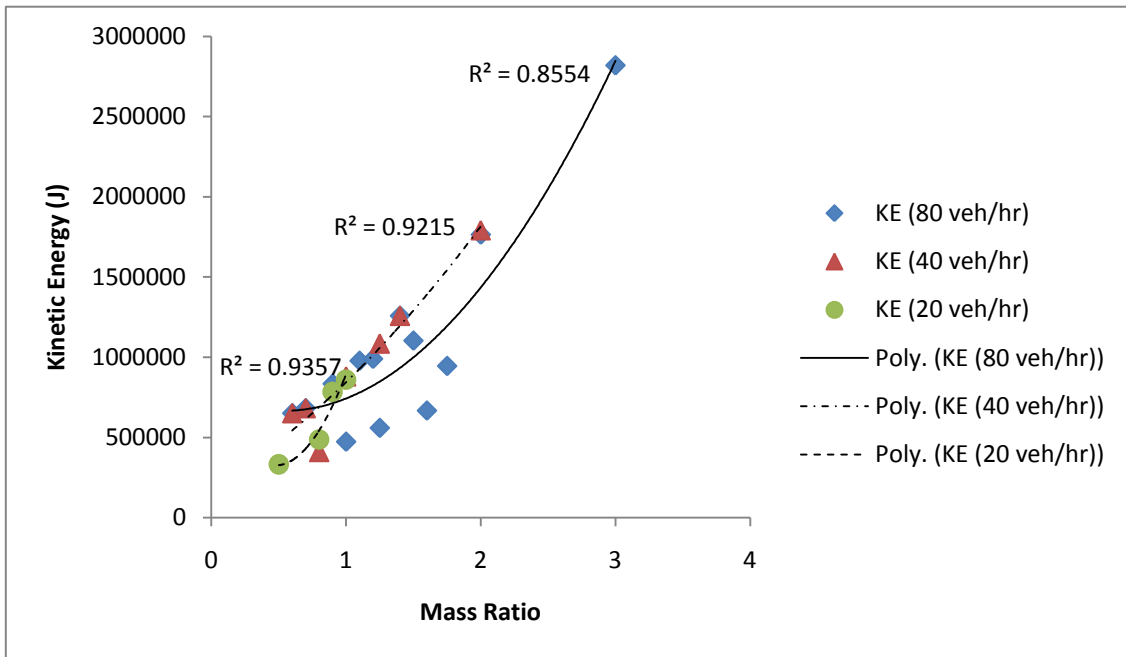
CONCLUSION

This paper explained the development of a simulation based modelling approach to assess the safety performance of road locations. The developed framework consists of two main parts.

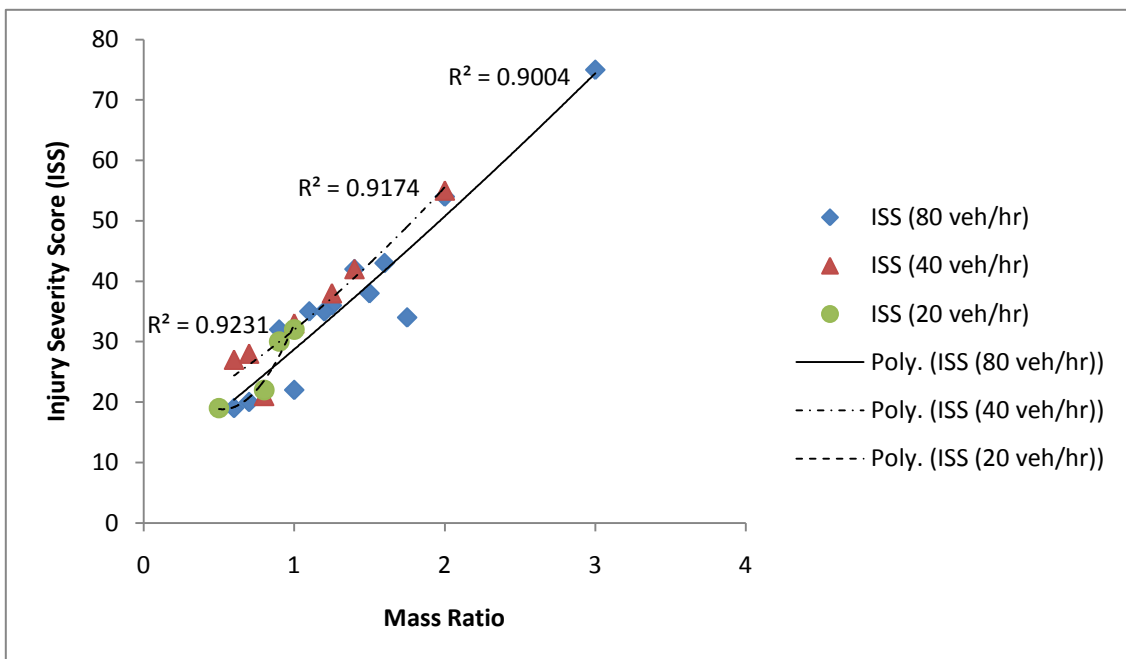
The first part of the framework is to estimate number and severity of conflicts using micro simulation model. Inputs into this part of the framework are the geometry and traffic characteristics of the road system. The output of the first part of the framework is the characteristics of the simulated serious conflict.

The second part of the framework is the measurement of potential injury severity of each simulated conflict. This part of the framework consists of two main models.

The first model is the driver reaction model. This model determines the driver reaction in conflict based on the simulated conflict characteristics.



(a) Relationship of KE_s and mass ratio



(b) Relationship of ISS and mass ratio

Figure 7: Relationship of mass ratio, KE_s and ISS

Then a two-step modelling approach was proposed to estimate the potential injury severity of conflicts. In the first step, the expected speed change of the subject vehicle (ΔV_s) was estimated using conflict characteristics and a driver's reaction during a conflict. Newtonian Mechanics was used to estimate the kinetic energy applied to the subject vehicle according to

the mass and estimated ΔV_s . The law of conservation of momentum was utilised to identify the crash characteristics affecting the ΔV_s . Those conflict characteristics which influence the identified crash characteristics were used as predictors of the ΔV_s model. In the second step expected Injury Severity Score (ISS) of the conflict was measured using estimated kinetic energy of the subject vehicle and the impact type of the expected crash.

The final output of the micro simulation model is the safety level of the simulated road location. This safety level is indicated based on the number and severity of conflicts and the potential crash injury severity of the simulated conflicts.

The developed methodology was applied to an unsignalized four-leg intersection and the final results were discussed.

The modelling approach outlined in this paper enhances the modelling process of road safety evaluation based on conflicts since it enables researchers to estimate the severity of expected crashes for each conflict using micro-simulation modelling approach. Furthermore, the developed modelling framework uses a mixture of micro-simulation, statistical and numerical analysis to link the conflicts with crash severity to provide a better assessment of road network safety. Moreover, the developed methodology has this potential to be used for assessing the safety performance of other road locations such as signalised intersections and highway/freeway segments.

However, some areas of this research require improvement in future studies. Different conflict severity levels should be considered as an important factor affecting the results of the safety evaluation. This issue was not investigated in details in this study. In terms of the transferability of the results, the model theory and the proposed safety performance measures are transferable as are the findings related to the variables included in the model. However, the data used in estimating the model parameters was collected in Australia. As such it will have certain characteristics which are peculiar to design standards, behaviour and road conditions in Australia. Estimation of the parameter values for similar models in other countries will verify the transferability of the model and improve our understanding of different conditions in different constituencies.

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