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Modelling Road Safety Trends and Predicting Road Fatalities in Australia

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Introduction

Road safety is a social, economic and public health issue worldwide. Traffic accidents cause at least 500,000 deaths every year. They will kill or disable more people than war, tuberculosis or HIV by 2020. In Australia, road accidents have claimed 160,670 lives since 1925 (FORS, 1998). This death toll surpasses the aggregate Australians killed (89,850 deaths) in the four major wars (WW1, WW2, Korea, Vietnam). Since the age distribution of road accident victims is tilted towards the young, the reduction in length of life and hence loss of productivity is substantial compared with the more frequent causes of death such as cancer and diseases which are mostly associated with old age. The economic costs of road trauma have been estimated as $AUD 6,135 million in 1993, about 1.6 percent of Gross Domestic Product and $350 per head per year (BTCE, 1994).

Road safety has been an ongoing concern to all Australians. The National Road Safety Action Plan prepared by the Federal Office of Road Safety (FORS, 1996) sets specific goals to reduce road fatalities to 10 deaths for every 100,000 people per year by the year 2001, with similar reductions in serious injuries. A number of road safety strategies and initiatives have been developed and introduced by Federal and State Governments as well as Local Governments. These initiatives not only contribute to improved road safety and a dramatic decline of road fatalities but also stimulate research designated to evaluate their effectiveness. Models have been constructed to explore historical patterns of road accidents (Graham and Taylor, 1994; Navin et al, 1996; Oppe, 1991a,b; etc.), and to forecast road accidents (Vulcan, 1997; Broughton, 1988). The venture into the future has exposed many weaknesses of such models.

Road safety can be defined by many indicators. The absolute number of fatalities, hospitalisations, injuries, property damage and financial loss have all been used to indicate the size of the road safety problem. The number of fatalities can be regarded as the product of the number of kilometres travelled or vehicle stock (i.e. mobility) and probability of sustaining an injury or fatality per unit travel (i.e. exposure to risk). Rates such as deaths per vehicle-kilometre travelled, deaths per vehicle and deaths per capita are prevalent in road safety models. These standardised rates make road safety comparable between different entities such as Countries, States and cities. Three corresponding technical terms, defined as traffic hazard – fatalities/vehicle, personal hazard – fatalities/person and motorisation – vehicles/person, were first used by Trinca et al (1988), Navin et al (1996) also developed relationships among them.

This paper develops models to explain levels of road safety in Australia between 1925 and 1997 and to apply them to predict road fatalities over the next 20 years. The paper is organised into 6 sections. In section 2 road safety models are briefly reviewed and Smeed's Law is implemented. Relationships among traffic hazard, personal hazard and motorisation are explored in section 3. Two models are constructed in section 4. In section 5, road fatalities are predicted by applying these models, given projections of population vehicle growth. The conclusions are presented in the last section.

Models Of Road Safety Trends

Models of road safety have existed since the 1940's (Smeed 1949). Hakkert and McGann (1996) divided road safety models into three broad groups: macro-models, meso-models and micro-models. Macro-models investigate road safety at a highly aggregated level, using national or statewide data. The classical example is Smeed's law (Smeed 1949), which links national road fatalities to the number of motor-vehicles and population. During the 1990's, a new series of macro-models were introduced. The major contributors include Oppe (1991a, b) and Koornstra (1992). The changes over time in the number of fatalities or casualties are described as the net product of the travel risk per unit of travel and travel exposure. The long-term shape of the risk curve is found to follow an exponentially declining pattern. Graham and Taylor (1994) used Oppe's model to obtain estimates of the predicted number of fatalities for NSW in the year 2000 as part of the NSW Road Safety 2000 program. Wong-Toi (1994) calibrated the Oppe model using New Zealand and Australian data, and showed that the exponential model could reproduce fatalities with reasonable accuracy.

The second type of model that has become prevalent in road safety trend analysis is the meso-model. Meso-models are multivariate-regression models that define the number of fatalities or casualties as the dependent variable. The independent variables represent a wide range of socioeconomic activities and behaviours related to volume of traffic, travel speeds, as well as the demographics of road users such as young drivers, to capture the propensity for high risk-taking. Other social variables such as murder and suicide rate are included, however, the most important explanatory effects associated with safety trends are economic, such as personal income, the unemployment rate, number of automobiles manufactured and gross national product. Micro-models introduce more explanatory variables and seek detailed relationships between the number of accidents and road safety. For example, five quantitative relationships that combine geometric features of two-lane rural highways to explain accident rates have been reported by the U.S. Transportation Research Board (TRB, 1987). These models express the accident rate as a function of average daily traffic volume, width of road lane, width of paved shoulder, width of unpaved shoulder, median roadside hazard rating, terrain factor, width of bridge, the length and degree of curvature of road horizontal line. Navin and Appeadu (1995) concluded that these models are a step in the right direction in a study of the applicability of these models to the highways of British Columbia.

Smeed (1949) presented a formula for the estimation of road accidents based on 1938 data for 20 countries including 16 European countries, USA, Canada, Australia and New Zealand. Smeed's formula can be expressed as:

$$(\frac{F}{V}) = 0.0003(\frac{V}{P})^{-2/3} \quad (1)$$

where:
F = number of road fatalities;
V = number of registered vehicles;
P = population.

The formula, used to evaluate national road safety performance, became known as Smeed's Law. Newstead et al (1995) demonstrated that Smeed's Law applied reasonably well to Victoria provided it was modified by additional factors to represent effects related to specific countermeasures. Adams (1987) considered Smeed's Law as a national learning curve and illustrated the robustness of the Law by applying it to a number of countries. Minter (1987) showed that Smeed's Law is a double-logarithmic model analogous to Wright's learning curve model, which measures performance time declining with the cumulative number of repetitions (as a measure of experience). Fieldwick (1987) applied Smeed's Law to develop fatalities and casualties models with the addition of speed limits. Smeed's Law has its critics. Broughton (1988) and Andreassen (1985) showed that each country has a specific set of constants in Smeed's Law. Broughton concluded that the relationship detected by Smeed amongst data from 1938 has no general validity. British data between 1926 and 1985 contain no trace of this relation. As a starting point, the current paper applies Smeed's Law to establish the road fatality trend in Australia, using data on road fatalities, registered motor vehicles and population (FORS, 1998) from 1925 to 1997.

From model (1), it can be inferred that Smeed's Law predicted an increasing trend in road fatalities. The observed data on road fatalities in Australia suggests that this is not the situation. (Figure 1). From 1925, the year that records of Australian road crash deaths commenced, to 1970 when the road toll reached its peak of 3,798, there has been an increasing trend of Australian road fatalities. Since then, the trend has reversed. By 1997, only 1,764 fatalities were observed, less than half of those in 1970. The turnaround of the trend in Australian road fatalities is especially evident when compared with the increases of vehicle ownership and population. Whereas there were 7.96 road fatalities per 10,000 registered vehicles and 30.4 fatalities per 100,000 of population in 1970, these rates have decreased to 1.58 and 9.7 respectively. Because of the discrepancy of observed road tolls and modelled fatality trend given by Smeed's Law, we explore a more general model (equation 2) of the Cobb-Douglas form.

$$F = aV^b P^c \quad (2)$$

where F is the number of road fatalities, V is the number of registered vehicles (in 1,000's), and P is population (in 1,000,000's); *a, b* and *c* are constants to be estimated. To estimate this model, it is expressed in double logarithmic form (equation 3).

$$log\ (F) = a + b*log\ (V) + c * log\ (P) \quad (3)$$

This General Linear Model (GLM) can be estimated using Ordinary Least Squares (OLS) regression. The estimated results are shown in Table 1.

Table 1 Estimated Results For Model (3), Australia 1925-1997

	Coefficients	t-Value	Significance
Constant	3.410	15.862	0.000
No. of Vehicles	1.867	10.820	0.000
Population Size	-4.481	-0.761	0.000

(R^2 = 0.856)

This double logarithmic model explains 85.6% of the variances in road fatalities. Registered vehicles and population size are both statistically significant. We can reject the null hypothesis of no effect of registered vehicles and population size on fatalities at the 5% level. The negative coefficient on population size is not consistent with our prior expectation, due to multicollinearity. (Pearson product-moment of registered vehicles and population size is 0.990. Correlation is significant at the 0.01 level). Alternative models are given in equations (4), (5) and (6) and results given in Tables (2), (3) and (4).

$$log\ (F) = a + b*log\ (V) \quad (4)$$

Table 2 Estimated Results For Model (4), Australia 1925-1997

	Coefficients	t-Value	Significance
Constant	4.726	21.379	0.000
No. of Vehicles	0.365	13.103	0.000

(R^2 = 0.703)

$$log\ (F) = a + b * log\ (P) \quad (5)$$

Table 3 Estimated Results For Model (5), Australia 1925-1997

	Coefficients	t-Value	Significance
Constant	4.726	21.379	0.000
Population Size	0.365	13.103	0.000

$R^2 = 0.622$

$$log\ (F) = a + b*log\ (V/P) \quad (6)$$

Table 4 Estimated Results For Model (6), Australia 1925-1997

	Coefficients	t-Value	Significance
Constant	4.496	20.592	0.000
No. of Vehicles/Population Size	0.562	14.328	0.000

$R^2 = 0.739$

Figure 1 shows the observed and estimated road fatalities from 1925 to 1997. It intuitively illustrates that Smeed's Law is not consistent with road safety trends in Australia. Although population and number of vehicles are important influences on the incidence of road fatalities, they are not the only ones. Other potentially eligible influences include the total length of a country's roads, the percentage of private cars in the fleets, the population age distribution and the economic conditions.

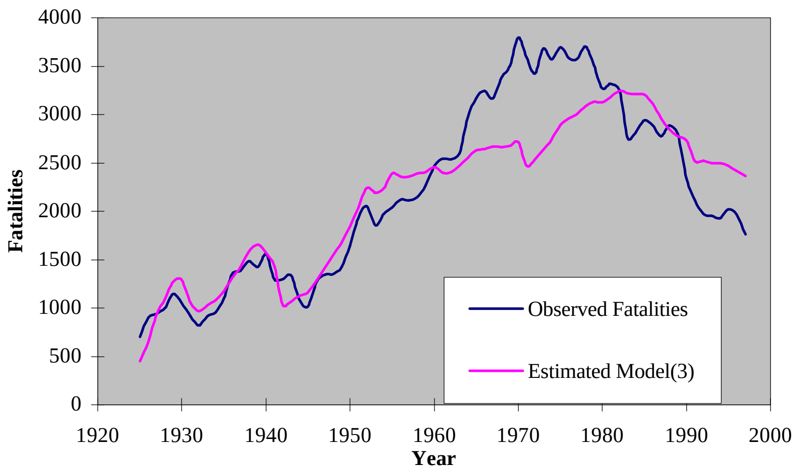


Figure 1: Observed and Estimated Road Fatalities, Australia 1925-1997

Fundamental Relationships In Road Safety Data

The starting point for a search for additional influence on road fatalities is a look at what has been occurring historically. We begin with the fatality trend. The use of standardised variables, (e.g. death per capita, per vehicle, or per vehicle-mile travelled (VMT)) is prevalent in government statistics, road safety programs and accident modelling. Trinca et al (1988) introduced three notions of traffic hazard, personal hazard and motorisation. Traffic hazard is the deaths per vehicle or per VMT. It recognises the importance of the number of vehicles to the occurrence of accidents that are the result of the confluence of vehicles, movement and driver. Personal hazard measures road fatalities per capita. Measuring the number of deaths per 100,000 people is a widely accepted way of looking at the number of deaths, taking into account the size of the resident population. Road accidents might be expected to rise with an increase in population, ceteris paribus. The number of deaths per 100,000 is also a standard measure of public health risk used internationally in relation to death due to disease and injury. Motorisation defines the level of vehicle ownership by resident population. In road safety research, it can be regarded as the ratio of personal hazard and traffic hazard. Navin (1996) noticed that there exists a fundamental relationship between traffic hazard, personal hazard and motorisation. He discovered two extremes in a study of Canadian road fatalities between 1949 and 1991. The first occurs during early motorisation, which has a high traffic hazard and low and increasing personal hazard. The second is in full motorisation, characterised by a moderate and falling traffic hazard and decreasing personal safety. Between these extremes, there is a maximum value of fatalities per capita.

Figures 2 to 4 illustrate the relationships among traffic hazard, personal hazard and motorisation derived from the Australian road accident statistics between 1925 and 1997. In the early stages of motorisation, traffic hazard was high. In 1926, there were 23.1 fatalities per 10,000 registered vehicles. It rapidly decreased between 1925 and 1945, then the pace became slower, with 1.58 fatalities per 10,000 registered vehicles in 1997. Contrary to traffic hazard, in the early years of motorisation, personal hazard was relatively low (11.8 fatalities per 100,000 population) and increasing, reaching its peak in 1970 (30.4 fatalities per 100,000 population). Since then, the trend has reversed. There were 9.7 fatalities per 100,000 population in 1997, the lowest personal hazard since road safety records commenced in 1925 and the first time personal hazard was below 10.0. It is worth noting the fluctuations in personal hazard from year to year. This can be inferred that road fatalities as a stochastic phenomenon, sufficiently infrequent and sufficiently diverse, subject to wild fluctuations in a single year.

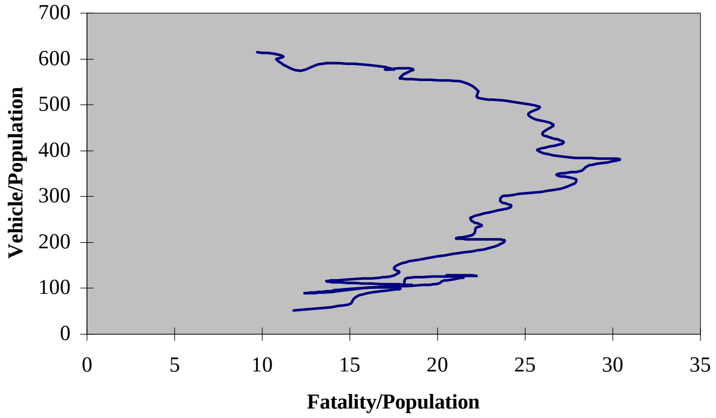


Figure 2: Relationship Between Personal Hazard and Motorization

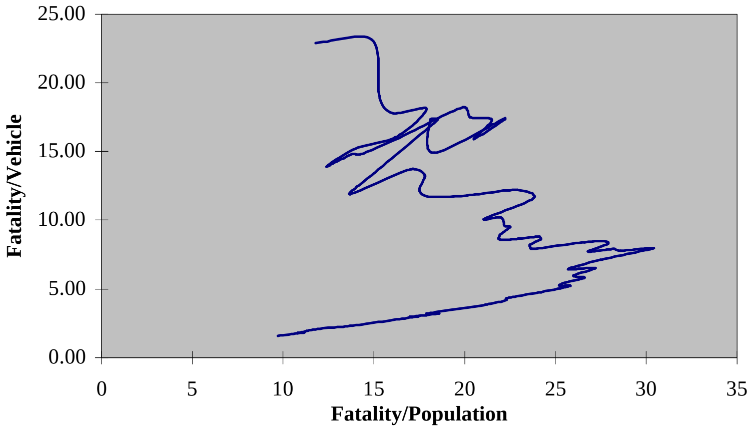


Figure 3: Relationship Between Traffic Hazard and Personal Hazard

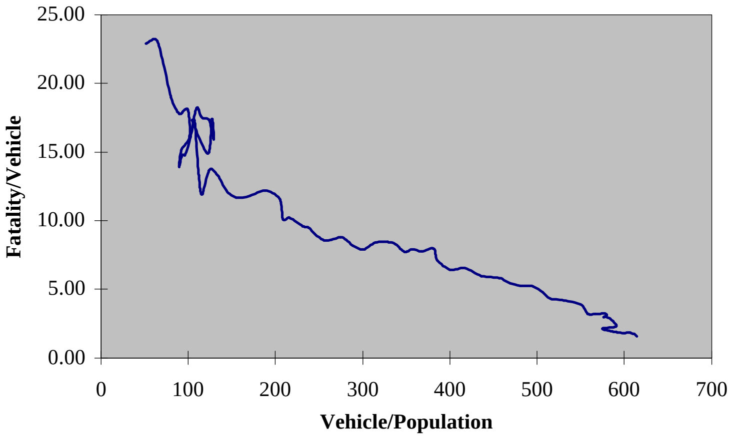


Figure 4: Relationship Between Traffic Hazard and Motorization

Notions of traffic hazard, personal hazard and motorisation are useful performance indicators, widely used in road safety models. However, we should be aware that the use of a variables such as registered vehicles and population size in both sides of a regression model will produce spurious correlation, greatly exaggerating, and in some cases, producing correlations which reality do not exist (Hakkert and McGann, 1996). An implicit assumption in using rates such as fatalities/VMT is that the relationship between vehicle kilometres of travel and fatalities is linear, which is generally not the case.

Time Series Models Of Road Safety

Some authors have described road safety as a learning process. Minter (1987) showed that Smeed's Law is analogous to Wright's learning curve model, given as equation (7).

$$T_n = T_1 * n^{-b} \quad (7)$$

where:
T_n is time for n^{th} item to occur on the n^{th} repetition,
T_1 is time for the first repetition,
n is the cumulative number of repetitions, a measure of experience, and
b is a measure of the rate of reduction of time per occasion, about 0.4 for the United Kingdom.

A comparison of Smeed's road safety model with Wright's learning curve model suggests that motorisation is a measure of accumulated experience in road safety. It implies that road safety will improve, regardless of interventions and countermeasures due to the underlying learning process. However, the decrease in traffic and personal hazard is not something which happens by itself. It is reasonable to assume that improvements are associated with a wide range of safety improvement packages applied over time. Time series modelling is appropriate to allow us to incorporate the effects of these interventions.

The irregularity of historical patterns of road tolls (Figure 1) gives no knowledge of what is the trace that road safety follows. The temporal traffic hazard (Figure 5) explained in logarithmic form uncovers part of the veil. Careful scrutiny enables us to identify a linear relationship, except for some fluctuations in the 1930's and 1940's. A turning point around 1970 occurred, since then the traffic hazard decreased dramatically.

A variety of enforcements were introduced in the 1970's. From January 1, 1970, the application of Australian Design Rules for Motor Vehicle Safety specified detailed protective features such as seat belts and anchorage for child restraints, as well as improved vehicle brakes, tyres, lights and indicators. By 1973, legislation had been passed in all Australian states and Territories for the compulsory wearing of fitted seat belts in motor vehicles and for the wearing of protective helmets by motorcyclists and their pillion passengers. Legislation for driver behaviour included initiatives against drink driving through random breath testing, introduced in Victoria in 1976, and

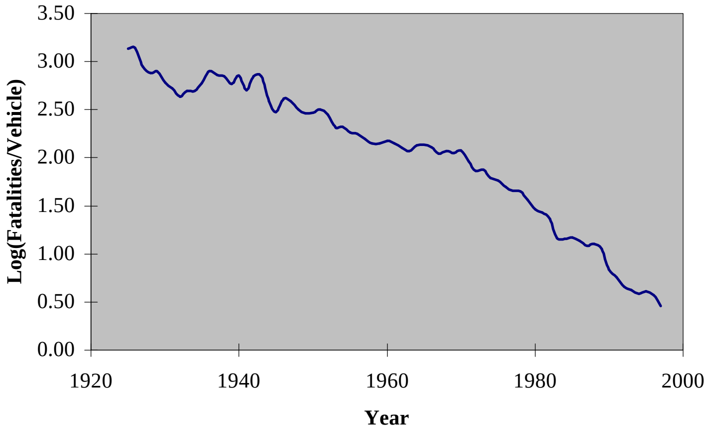


Figure 5: Time Series of Logarithm of Traffic Hazard

followed by other States and Territories. Compulsory blood testing on crash participants who attend hospital was legislated in South Australia in 1973 and later in a number of jurisdictions. Attitudinal change within the Australian population supports the view that drink driving is totally unacceptable, with a well structured system of penalties and mass public education and media campaigns. Improved roads also contribute to the decrease of road fatalities and casualties. In the treated sites of the Federal Government Black Spots program, it is estimated that persons killed in crashes have been reduced by 33%, the hospitalised by 64%, and the medically treated by 49% (BTCE, 1995). The effects of these interventions are represented by a dummy variable D in the regression model, equation(8).

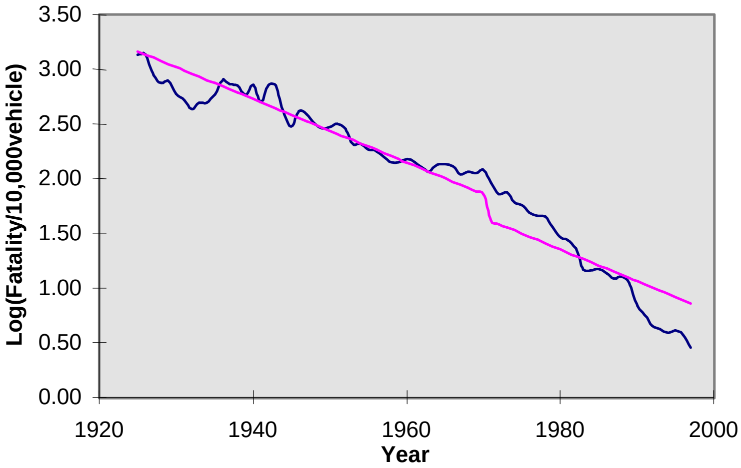
$$Log(F/V) = a + b*Y+c*D \quad (8)$$

where F is the number of road fatalities, V is the registered vehicles (in 1,000's), Y is the time trend; and D is equal to zero before 1970 and one after 1971. The results are given in Table 5.

Table 5 Estimated Results For Model(8), Australia 1925-1997

	Coefficients	t-Value	Significance
Contant	3.163	64.453	0.000
Y	-0.029	-15.956	0.000
D	-0.216	-2.701	0.009

(R^2 = 0.939)



All coefficients are statistically significant at the 5% level. The overall adjusted R square is 0.939. Figure 6 shows however that the model does not fit the safety trend, especially after 1970. The 0-1 regressor only changes the intercept of the model, and hence is inadequate in distinguishing more thresholds. It is easy to extend the model to have different slopes as well as different intercepts, to better fit the trend. The proposed model is given in equation (9).

Figure 6: Modelled and Actual Traffic Hazard

$$log(F/V) = a + b*Y + c*D + d*DY \quad (9)$$

The model is constructed by introducing one more regressor, the interaction between D and Y. The estimated results are given in Table 6.

Table 6 Estimated Results For Model (9), Australia 1925-1997

	Coefficients	t-Value	Significance
Constant	3.028	116.381	0.000
Y	-0.023	-23.320	0.000
D	1.669	12.419	0.000
DY	-0.036	-14.679	0.000

$R^2 = 0.985$

Again, all coefficients are significant at the 5% level. The overall adjusted R square is 0.985, as shown in Figures 7 and 8.

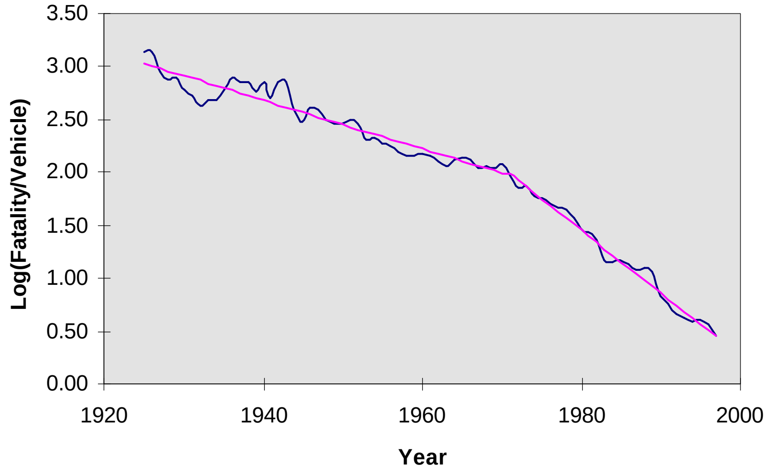


Figure 7: Modelled and Observed Traffic Hazard Trend

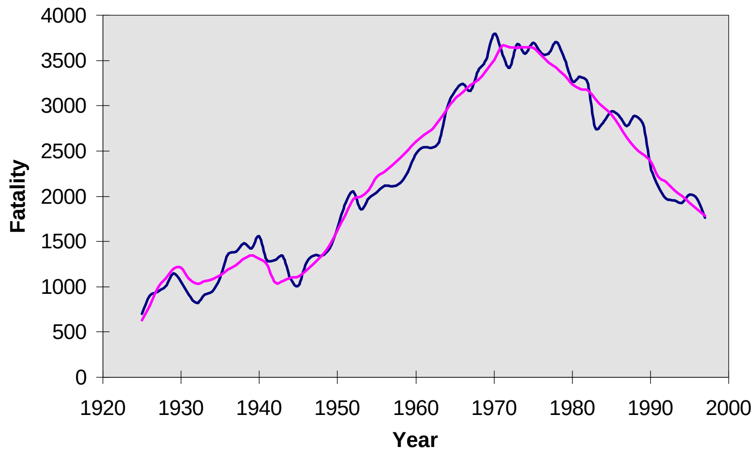


Figure 8: Modelled and Observed Fatality Trend

By incorporating one more regressor, the variable of population, equation (9) becomes equation (10). The estimated results are summarised in Table 7.

$$log(F/V) = a + b*Y + c*D + d*DY + e*log(P) \quad (10)$$

Table 7 Estimated Results For Model (10), Australia 1925-1997

	Coefficients	t-Value	Significance
Constant	4.494	8.250	0.000
Y	-0.009	-1.744	0.086
D	1.851	12.738	0.000
DY	-0.038	-15.207	0.000
Log(P)	-0.845	-2.695	0.009

$R^2 = 0.986$

All variables are significant at the 5% level except the time trend variable Y, which is significant at the 10% level. Deleting the time trend Y means that variable D also should be dropped, because it is a dummy variable based on time trend. (We can still leave just DY to recognise its interaction). Then model (10) will only capture the relationship between the number of road fatalities, number of registered vehicles and population. This is another form of Smeed's Law, which is unreliable as we have shown in model (3). Model (10) is our preferred model, plotted in Figure 9.

Fatality Forecasts: Beyond 1997

Forecasting capability is a primary objective, being the basis of setting road safety targets and performance evaluation. For example, a major target of the National (Australia) Road Safety Action Plan 1996 is to reduce the national road toll to 10 deaths for every 100,000 people per year by the year 2001, with similar reductions in serious injuries (FORS,1996). Vulcan (1997) used the multiplicative model for estimating future fatalities based on expected road safety inputs. He estimated that Australian road fatalities could be reduced to 1,864 by 2001, corresponding to a fatality rate of 9.6/100,000 population. By the year 2020, the road fatalities could be reduced to about 862 which corresponds to a fatality rate of 3.4/100,000 population. Broughton (1988) also forecasted a declining trend for road accidents, fatalities and casualties in Great Britain using time series models. The basis of sound prediction is a model that fits the historic time series well and captures the major influences on road safety. This paper predicts Australian road fatalities up to the year 2020 by applying equations (9) and (10).

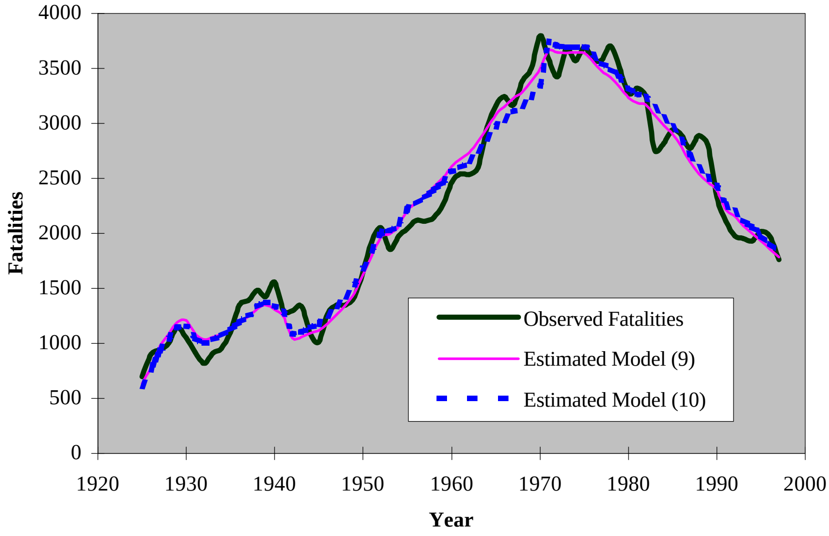


Figure 9: Observed And Estimated Fatalities

The predicted fatalities depend on a time trend, the number of registered vehicles and population size. The forecasts require input forecasts of the total number of vehicles and population size. The Australian Bureau of Statistics releases four series of population prediction models to the year 2051 (Table 8). Our task is to use these exogenous forecasts as inputs, to predict the number of vehicles before forecasting road fatalities.

Table 8 Population Prejections of Australia

Year	Series A	Series B	Series C	Series D
2000	1917.10	1917.10	1926.46	1913.40
2005	2015.44	2015.44	2041.77	2004.71
2010	2106.37	2106.37	2151.14	2087.59
2015	2190.93	2190.93	2255.15	2163.98
2020	2270.99	2270.99	2355.44	2246.86

Source: Adapted from Projections of the Population of Australia, States And Territories(322201CA,CB,CC,CD), Australian Bureau of Statistics

Three vehicle growth models (11) (12) (13) are developed using historical data on registered vehicles. All models have high goodness-of-fit with predicted results given in Table 9.

Multinomial model:
$V = a*Y^2 + b*Y + c \quad (R^2 = 0.997)$
(11)

Logarithmic model:
$V = a * Log(Y) + b \quad (R^2 = 0.988)$
(12)

Linear Model:

$$V = a * Y + b \qquad (R^2 = 0.987) \qquad (13)$$

Table 9 Vehicle Prediction of Australia

Year	Multinomial Model	Logarithmic Model	Linear Model
2000	11652	12341	12353
2005	12225	13537	13561
2010	12631	14731	14769
2015	12870	15921	15976
2020	12941	17109	17184

Predicted road fatalities using model (9) are given in Table 10, and those using model (10) are given in Table (11).

Table 10 Predicted Road Fatalities Using Model (9)

Year	Multinomial Model	Logarithmic Model	Linear Model
2000	1529	1620	1621
2005	1195	1323	1325
2010	919	1072	1075
2015	697	862	865
2020	522	690	693

The models capture the effects of population and the number of registered vehicles on road safety. Therefore, the precision of prediction is not only dependent on the reliability of the models but also the accuracy of exogenous population projections provided as well as modelled vehicle growth. Re-calibration of the models is preferred if the growth patterns in population size and vehicles registrations are different to those in the models. These predictions are not deterministic, because the models acknowledge the contribution of various road safety programs to the declined road fatalities. The efforts to influence behaviour through education, enforcement and engineering have been and will remain the major means to reduce the road toll. The road environment has been improving through road engineering, traffic management, land use and transport planning. Improved safety features of vehicles also contribute to the decrease in accident occurrence and severity. However, these approaches might be challenged by the Risk-Homeostasis Theory (Wilde,1982; Ruppert, 1994), which suggests there exists a constant rate of accident with a given geographical, national and historical situation that can hardly be influenced by political, legal, administrative or technical measures. Every safety advantage gained by safer roads or cars will be compensated by vehicle drivers, who tend to regulate their driver behaviour according to the given level of risk-acceptance. When cars are equipped with ABS brakes, they are driven faster. Wearing a seat belt may increase the driver's subjective sense of security and cause him to take more risks when driving. More pedestrians and cyclists may fall victim to increased driver speed and carelessness. OECD (1990) research has shown that these behavioural adaptations have an effect on the safety benefits achieved through road safety programmes; however, it does not eliminate entirely the safety gains obtained. Relationships between suggested models in this paper and learning process models (Minter, 1987) are mixed and complex. The learning process model recognises that motorisation is a measure of accumulated experience with regards to road safety. As the number of vehicles grows annually, every vehicle or VMT adds a driving experience that benefits road safety. This process might also be explained by the time trend, which seems consistent with the results reported herein. On the other hand, the learning process model assumes that road safety will improve naturally and slowly, and accident rates will inevitably fall irrespective of road safety measures. The implications of behavioural adaptation and the learning process to road safety are challenging and should be the focus of ongoing research.

Table 11 Predicted Fatalities Using Model (10)

Year	Population Prediction	Vehicle Prediction		
		Multinomial Model	Log Model	Linear Model
2000	Series A	1588	1744	1746
	Series C	1581	1739	1741
	Series D	1591	1746	1748
2005	Series A	1261	1340	1399
	Series C	1247	1381	1384
	Series D	1267	1403	1405
2010	Series A	992	1156	1159
	Series C	974	1136	1139
	Series D	999	1165	1168
2015	Series A	772	955	958
	Series C	753	932	935
	Series D	780	965	968
2020	Series A	595	786	789
	Series C	577	762	766
	Series D	603	797	800

Conclusions

Road fatalities have been declining since the 1970’s and this trend is predicted to continue. Road fatalities could be reduced to somewhere between 1,529 and 1,748 in the year 2000 and between 522 and 800 in the year 2020, based on forecasts presented herein, given population projections and vehicle forecasts. Although road safety trends can be modelled with relatively high accuracy, there are still some significant factors that may be missed and some captured factors may not be statistically significant. There are fluctuations in road fatalities from year to year, but the development of road accidents tends to follow a general trend. Road fatalities can be reduced but presently not be eliminated because of its multi-causality and chance occurrence.

Acknowledgments

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