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A re-parameterisation of the Power Model of the relationship between the speed of traffic and the number of accidents and accident victims

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ABSTRACT

This paper presents a re-analysis of the Power Model of the relationship between the mean speed of traffic and road safety. Past evaluations of the model, most recently in 2009, have broadly speaking supported it. However, the most recent evaluation of the model indicated that the relationship between speed and road safety depends not only on the relative change in speed, as suggested by the Power Model, but also on initial speed. This implies that the exponent describing, for example, a 25% reduction in speed will not be the same when speed changes from 100 km/h to 75 km/h as it will when speed changes from 20 km/h to 15 km/h. This paper reports an analysis leading to a re-parameterisation of the Power Model in terms of continuously varying exponents which depend on initial speed. The re-parameterisation was accomplished by fitting exponential functions to data points in which changes in speed and accidents were sorted in groups of 10 km/h according to initial speed, starting with data points referring to the highest initial speeds. The exponential functions fitted the data extremely well and imply that the effect on accidents of a given relative change in speed is largest when initial speed is highest.

1. Background and problem

The relationship between speed and road safety has long been an important topic for research. Recent studies have attempted to model the relationship mathematically, with somewhat different results. In a recent evaluation of the so called Power Model (Nilsson, 2004) of the relationship between speed and road safety, Cameron and Elvik (2010) found that the exponents describing the effects on accidents of a given relative change in speed vary according to traffic environment. The exponents are lower for urban and residential roads than for motorways and rural roads. This suggests that the effects on accidents of a given relative change in speed depend on initial speed. Hauer and Bonneson (2006) and Hauer (2009) fitted exponential functions to the data provided in Elvik et al. (2004) describing the effects of changes in speed on fatal accidents and injury accidents.

The data provided in Elvik et al. (2004) have since been updated and expanded (Elvik, 2009). Both these reports, with references to original studies, can be downloaded free of charge from the website of the Institute of Transport Economics (www.toi.no). The most recent analyses were based on 115 studies containing a total of 526 estimates of the relationship between changes in the mean speed of traffic and changes in the number of accidents or accident victims. Analyses of the expanded data set resulted in a revision of the Power Model, as suggested by the new set of exponents listed in Table 1. The general form of the Power Model is:

$$\text{Accidents}_{\text{after}} = \text{accidents}_{\text{before}} \cdot \left(\frac{\text{speed}_{\text{after}}}{\text{speed}_{\text{before}}}\right)^{\text{exponent}} \quad (1)$$

Separate exponents are fitted for accidents at different levels of severity and for injured road users at different levels of severity. The Power Model implies that the effect on accidents of a given severity of a given relative change in speed is independent of initial speed. As an example, the Power Model predicts the same percentage change in the number of fatal accidents if speed is reduced from 100 to 75 km/h as when speed is reduced from 20 to 15 km/h (in both cases speed is reduced by 25%). This is not very plausible, as very few accidents occurring at a speed of 20 km/h are likely to be fatal.

The set of exponents proposed for the Power Model in Table 1 is consistent with the idea that the effect of a given relative change in speed depends on initial speed. Nevertheless, these exponents are at best a very crude approximation to a model in which the exponents vary continuously as a function of initial speed.

Hauer and Bonneson (2006) developed exponential functions according to which the effects of a given change in speed depend on initial speed. However, their analysis was not entirely successful. In the first place, data for residential roads was discarded and not used

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Table 1
Estimates of exponents in the Power Model. Based on Elvik (2009).

Accident or injury severity	Summary estimates of exponents by traffic environment					
	Rural roads/freeways		Urban/residential roads		All roads	
	Best estimate	95% confidence interval	Best estimate	95% confidence interval	Best estimate	95% confidence interval
Fatal accidents	4.1	(2.9, 5.3)	2.6	(0.3, 4.9)	3.5	(2.4, 4.6)
Fatalities	4.6	(4.0, 5.2)	3.0	(−0.5, 6.5)	4.3	(3.7, 4.9)
Serious injury accidents	2.6	(−2.7, 7.9)	1.5	(0.9, 2.1)	2.0	(1.4, 2.6)
Seriously injured road users	3.5	(0.5, 5.5)	2.0	(0.8, 3.2)	3.0	(2.0, 4.0)
Slight injury accidents	1.1	(0.0, 2.2)	1.0	(0.6, 1.4)	1.0	(0.7, 1.3)
Slightly injured road users	1.4	(0.5, 2.3)	1.1	(0.9, 1.3)	1.3	(1.1, 1.5)
Injury accidents – all	1.6	(0.9, 2.3)	1.2	(0.7, 1.7)	1.5	(1.2, 1.8)
Injured road users – all	2.2	(1.8, 2.6)	1.4	(0.4, 2.4)[a]	2.0	(1.6, 2.4)
Property-damage-only accidents	1.5	(0.1, 2.9)	0.8	(0.1, 1.5)	1.0	(0.5, 1.5)

[a] Confidence interval specified informally.

in the analyses. In the second place, analysis was not successful for property-damage-only accidents. In the third place, analysis relied on individual data points, some of which are very uncertain. In the fourth place, the functions developed are somewhat complex and the possibility of developing a more parsimonious version of them deserves to be explored. The functions developed by Hauer and Bonneson (2006) were formulated as follows:

$$\text{AMF} \quad (\text{for speed change from} \quad v \quad \text{to} \quad v^*) = e^{\alpha[v - v^* + (\beta/2)\cdot(v^2 - v^{*2})]} \tag{2}$$

AMF is the accident modification factor associated with a certain change in speed. Thus, an AMF of, for example, 0.80 corresponds to an accident reduction of 20%. Speed is stated in miles per hour. α and β are coefficients estimated by means of regression analysis. The exponential functions developed by Hauer and Bonneson fitted the data slightly better than the Power Model.

The objective of this paper is to continue analysis along the lines of Hauer and Bonneson. The Power Model will be compared to an exponential model in order to determine which model best fits the data. The next section explains the approach taken to analysis.

2. Data and methods

2.1. Data aggregation

The data base compiled by Elvik (2009) contains a total of 526 estimates of the relationship between changes in speed in changes in road safety. The largest number of estimates is found for injury accidents. Table 2 presents some summary statistics for the data.

Analysis relying on the data aggregation approach explained below was only feasible for fatal accidents, injury accidents and property-damage-only accidents. The other categories listed in Table 2 were not included in the analyses reported in this paper. Fig. 1 shows the relationship between initial speed (km/h) and estimates of the exponent in the Power Model for injury accidents. Six outlying data points were omitted to improve the readability of the figure. Each estimate of the exponent in the Power Model was defined as:

$$\text{Estimate of exponent} = \alpha = \frac{\ln(Y_1/Y_0)}{\ln(V_1/V_0)}$$

where Y_0 is the number of accidents before a change in speed, Y_1 is the number of accidents after a change in speed, V_0 is speed before the change and V_1 is speed after the change. The values of these variables were reported in each of the studies that were included in the data base (Elvik, 2009). No clear relationship can be detected between initial speed and the value of the exponent. However, Fig. 1 ignores the fact that the standard errors of the data points vary considerably; more precise data points should count for more than less precise data points. As an example, the standard error of the leftmost data point in Fig. 1 is 6.15. The best estimate of the exponent is 6.82. Hence, a 95% confidence interval ranges from −5.23 to 18.87. Other data points are more precise and should therefore carry greater weight. Since many of the data points are imprecise, a case can be made for aggregating data points to make them more precise and suitable for analysis.

In Table 3, the data for injury accidents has been placed in twelve groups according to initial speed. Each group contains estimates that refer to initial speeds in a range of 10 km/h. Eleven of these groups contain one or more estimates of the exponent in the Power Model. Thus, there were 16 estimates for initial speeds between 100 and 109.9 km/h. The mean estimate of the exponent for these 16 estimates and the standard error of the mean are also shown in Table 3. The mean estimates of the exponent were obtained by synthesising individual estimates by means of meta-analysis. Each estimate was assigned a statistical weight inversely proportional to its sampling variance and a weighted mean estimate of the exponent was developed. Technical details can be found in Elvik et al. (2004).

Even within each of the groups included in Table 3, estimates of the exponent vary considerably. Fig. 2 shows a funnel plot of the 16 estimates of the exponent referring to initial speeds between 100.0 and 109.9 km/h. The solid vertical line shows the mean estimate of the exponent (3.87). The dashed lines indicate the contours of the funnel. If the variation in the estimates of the exponent were random only, all data points ought to be located inside the contours. However, as seen in Fig. 2, many data points are located outside the contours of the funnel. Even so, one can discern a tendency for estimates with small standard errors to be clustered more closely together than estimates with large standard errors. The weighted mean estimate is close to the centre of the distribution, with seven estimates greater than the mean and nine estimates smaller than the mean.

The exponents listed in Table 3 show a tendency, albeit somewhat irregular, to become smaller as initial speed becomes lower. Thus, all exponents for initial speeds above 80 km/h are greater than 3. The majority of exponents for initial speeds from 70 km/h and below are smaller than 2. Thus, aggregating the data seems to reveal a pattern that was not readily observable in the swarm of individual data points shown in Fig. 1. The analyses have therefore been based on aggregated data as shown in Table 3.

2.2. Chaining estimates of accident modification factors

The estimates of the exponents in each of the groups in Table 3 are based on quite different changes in speed. Thus, initial speeds in the interval from 100.0 to 109.9 km/h varied between 100.0 km/h