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TRAFFIC FATALITIES AND INJURIES: THE EFFECT OF CHANGES IN INFRASTRUCTURE AND OTHER TRENDS

Robert B. Noland
Alan M. Voorhees Transportation Center
Edward J. Bloustein School of Planning and Public Policy
Rutgers University, New Brunswick, NJ
rnoland@rutgers.edu

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Abstract

An analysis of how various road infrastructure improvements affect traffic-related fatalities and injuries is conducted while controlling for other factors known to affect overall safety. The road infrastructure elements analysed include total lane miles, the fraction of lane miles in different road categories (interstates, arterial, and collector roads), the average number of lanes for each road category, and lane widths for arterials and collector roads. Other variables that are controlled for in the study include total population, population age cohorts, per capita income, per capita alcohol consumption, seat-belt legislation (and seat-belt usage), and a proxy variable that represents underlying changes in medical technology. The data used is a cross-sectional time series database of U.S. states and is analysed using a fixed effects negative binomial regression that accounts for heterogeneity in the data. Data from all 50 states over 14 years is used. Results strongly refute the hypothesis that infrastructure improvements have been effective at reducing total fatalities and injuries. While controlling for other effects it is found that demographic changes in age cohorts, increased seat-belt use, reduced alcohol consumption and increases in medical technology have accounted for a large share of overall reductions in fatalities.

Key words: Transport safety, Infrastructure, Engineering design, Medical Technology, Seat-belt usage

Introduction

The upgrading of road infrastructure has normally been seen as a technique for reducing fatalities and injuries associated with traffic crashes. Historical trends would tend to support this viewpoint as fatalities per mile travelled have declined substantially over the last 30-40 years in the U.S. This has coincided with the construction of the Interstate highway system and changes in engineering standards that have resulted in roads that generally have fewer curves, fewer roadside hazards, and both wider travel lanes and more travel lanes.

Conventional traffic engineering would not question the assumption that “safer” and newer roads reduce fatalities. However, this type of approach tends to ignore behavioral reactions to safety improvements that may off-set fatality reduction goals. For example, if a two lane road is expanded to four lanes this could potentially reduce the risk of head-on collisions but may also result in many drivers travelling at higher speeds, potentially leading to no gains in safety. Of course, increased speeds allow increased mobility benefits even if the costs associated with crashes are not reduced.

This paper uses aggregate state-wide data on fatalities and injuries to determine whether road infrastructure has been beneficial in reducing fatalities and injuries. Several variables are used to define road infrastructure. These are total lane miles, the average number of lanes for alternative road classes, the lane widths for alternative road classes, and the fractional percent of each road class within a given state. Changes in horizontal curvature, shoulder widths, the separation of lanes with medians, and the presence of roadside hazards, are not examined. However, one would expect new lane miles constructed over time to have fewer of these characteristics than older infrastructure. Thus the lane mile variable serves as a proxy to represent these “improvements” in road design. Cross-sectional time-series data is used in a fixed effect negative binomial regression analysis to analyze the impact of these infrastructure variables. This technique controls for unmeasured variables that may also be affecting the dependent variable.

The underlying engineering hypothesis is that road infrastructure "improvements" will reduce both fatalities and injuries. However, it is not found that this hypothesis can be supported. Results actually tend to suggest the counter-intuitive hypothesis that these type of road "safety improvements" actually lead to statistically significant, though small, increases in total fatalities and injuries, all else equal. This result, while considered surprising, is not inconsistent with other literature using aggregate safety data (see Noland, 2001, for a comprehensive review).

Having found this result other factors that may have led to the observed decreases in total traffic-related fatalities are analysed. Changes in demographics, measured by changes in age cohorts are found to have a large effect, due primarily to fewer young people and more elderly people. Improvements in medical technology, measured using white infant mortality rates as a proxy variable, is found to be statistically significant. Increased seat-belt usage and reduced alcohol consumption also has had a major effect on reducing fatalities.

The paper is organized as follows. A brief review of relevant literature is presented. Trends in the data are then examined. This is followed by the estimation of several models and a discussion of the results followed by conclusions.

Literature Review

Much of the research in highway safety and the relationship to infrastructure (or geometric design) has focussed on specific design elements and attempts to quantify their accident reduction potential (Transportation Research Board, 1987; McGee et al, 1995). The Transportation Research Board (1987) evaluated much of the existing literature and modelling efforts to develop accident reduction factors. Various gaps in knowledge were identified but the report generally concluded that new and better design standards were leading to safety improvements.

The National Cooperative Highway Research Program (McGee et al., 1995) attempted to fill some of the identified gaps in knowledge and produced a number of new modelling results. All these models, however, do not control for other effects and do not consider system-wide impacts. Many also fail to distinguish between the severity of different crash types.

One problem with much of the early work in this area was inadequate statistical modelling. Miaou & Lum (1993) discuss many of these statistical issues and conclude that either a poisson or negative binomial regression possesses more desirable statistical properties for estimating these type of models. In particular, the negative binomial distribution accounts for overdispersion in the data and overcomes the limitations of the poisson distribution which assumes the mean is equal to the variance.

The literature contains many studies that suggest that infrastructure improvements increase the level and severity of road crashes. Fridstrom & Ingebrigsten (1991) and Karlaftis & Tarko (1998) find that network extensions increase crashes and fatalities. Milton & Mannering (1998) find similar results for increased number of lanes and that narrower lane widths reduce accident frequency. Vitaliano and Held (1991) also find that more lanes leads to more crashes, though they use only cross-sectional data in their analyses. Sawalha & Sayed (2001) also find an association between the number of lanes and increased crashes on arterials. Shankar et al. (1995) found that when curves are spaced further apart (i.e., fewer curves per mile) there is an increase in more severe overturning accidents and that curves with lower design speeds reduce the severity of accidents. This same study also found that highway segments that have curves with lower design speeds result in fewer accidents relative to those with higher design speeds. Ivan et al. (2000) using data from Connecticut found that link segments with larger shoulder widths have more single-vehicle crashes, but do not explore this result in detail. A study by Porter & England (2000) found that red-light running was more likely at intersections with more lanes, this could imply that the likelihood of a crash at these intersections may be greater.

To a large extent the idea that infrastructure improvements may lead to increased risk can be explained by behavioral responses from drivers. Many infrastructure improvements tend to make the driving task less taxing such that the driver may reduce the level of concentration needed to maintain the same level of safety. Mahalel & Szternfeld (1986) hypothesized that improved engineering standards influence driver perceptions by simplification of the driving task and an underestimation of the difficulties associated with the driving task. The net result could be an increase in accidents.

Most road improvements also allow greater speeds. This could be another underlying factor that explains the results that are found. Some of the behavioural responses discussed in the literature on risk compensation (Peltzman, 1975) and risk homeostasis (Wilde, 1982) touch on these issues, though this is clearly a controversial area.

Data, Trends, and Methodology

To analyze the relationship between road infrastructure and safety a cross-sectional time-series data base was collected for all 50 U.S. states over 14 years (from 1984 to 1997). This data was collected from the Federal Highway Administration (FHWA) Highway Statistics series (see, for example, US DOT, 1998). The fatality data was available for every state over all 14 years (for a total of 700 observations). The injury data had some omissions for some states and years giving a total of 657 observations. Total fatalities have generally been decreasing over this time period while total injuries have shown an upward trend, though when calculated as a rate per vehicle miles of travel (VMT) both have decreased over time. It should be noted that the fatality data is generally quite accurate as it is based on the National

Highway Traffic Safety Administration's (NHTSA) Fatal Accident Reporting System (FARS). The injury data tends to be less accurate and is based on NHTSA's General Estimates System (GES) which is based on a sampling of injury accidents in the US.

Data on road infrastructure included total lane miles (excluding local roads), average number of lanes by functional road category (interstates, arterials, and collectors), percent of center-line miles with a given lane width by road category, and the fractional percent of each road category in a given state (including local roads within the denominator). Interstates are controlled access highways built to the most rigorous and consistent design standards. Arterials are generally major multi-lane or intercity roads, perhaps with some controlled access, but generally not. These also tend to be major connector roads within cities and suburban areas. Collector roads are smaller scale roads that generally connect local distributor roads with arterials.

Trends in each of these variables, for the entire US, between 1985 and 1997, are displayed in Table 1. In general, these trends show that policies aimed at upgrading the design of road infrastructure have been very effective. We see that total lane miles (excluding local roads) have grown marginally over this time period. The average number of lanes on interstates and arterials has grown slightly while there has been viturally no change in the average number of lanes on collectors. In general, there are more lane miles of higher functional classification, with the percent of interstate lane miles growing by 5.65% and the percent of arterial lane miles growing by 8.62%. This has been at the expense of the percent of collector lane miles which have shrunk by 4.00%. The changes in arterial and collector lane widths have been most dramatic. The percent of arterials with lane widths of 9 ft or less has decreased by 48.33% while arterials with lane widths of 12 ft or greater have increased by 10.76%. Some 67% of arterials already had 12 ft or greater lane widths in 1985 and this fraction increased to 74% by 1997. A similar trend is apparent for collector road lane widths, with a move towards more roads with wider 11 or 12 ft lanes and fewer with 9 ft or 10 ft lanes. Obviously, a casual interpretation of these trends and those for total fatalities would suggest that as we have upgraded highway facilities, we have reduced fatalities.

In addition, estimates of seat-belt usage, by state, were used to control for the effects of increased seat-belt use. This data was only available since 1990. The effects of seat-belt use are also controlled for using dummy variables for those states with either primary or secondary seat-belt laws (described further below).

Data on total population, VMT, per capita income, alcohol consumption and population by age cohorts was also collected. These are used in the models discussed below primarily to control for other factors that are likely to affect fatalities and injuries.

The method selected to estimate the effects of these variables on total fatalities is the fixed-effects overdispersion model developed by Hausman et al. (1984).[1] This procedure uses a negative binomial distribution which has been acknowledged as the correct distribution to use for count data such as the generation of traffic-related fatalities (Karlaftis & Tarko, 1998). Hausman et al.'s (1984) method has the additional benefit of accounting for heterogeneity in the data. This is done by conditioning the joint probability of the counts for each group upon the sum of the counts for the group. This differences out the dispersion parameter for each group and allows the analyst to account for heterogeneity between groups. That is, lack of information on other factors that may influence the dependent variable does not result in biased estimates.

The number of fatalities (or injuries), y_i, for a given time period, t, is defined by the negative binomial probability mass function:

[1] See also Cameron & Trivedi (1998) for a good discussion of these models.

$$P(Y = y_i) = \frac{\Gamma\left(\frac{1}{a_i} + y_i\right)}{\Gamma\left(\frac{1}{a_i}\right) y_i!} \left(\frac{1}{1 + a_i \lambda_{it}}\right)^{\frac{1}{a_i}} \left(1 - \frac{1}{1 + a_i \lambda_{it}}\right)^{y_i}$$

where a_i is the rate of overdispersion for each group and $\Gamma(.)$ is the gamma function. In this formulation the dependent variable, λ_{it}, is defined for each group over a given time series.

The model can be written as:

$$\lambda_{it} = e^{b' x_{it}} \qquad i = 1, \ldots N \qquad t = 1, \ldots, T_i$$

The independent variables, x_{it} are defined over N cross-sectional units and over T time periods. The parameter $\boldsymbol{b}$ is estimated by maximum likelihood estimation.

Another method, known as the random effects model, assumes that the inverse of the overdispersion parameter varies randomly between groups with a beta distribution. This method assumes that the random effects are uncorrelated with the regressors, while the fixed effect model does not make this assumption. If this assumption does not hold then the fixed effects model would provide consistent coefficient estimates while the random effects model would not. Hausman et al. (1984) show that the Hausman specification test can be used to test which model is more appropriate. For the data analyzed here it was found that the hypothesis of a fixed effects model could not be rejected in all but one case.

These statistical methods provide several advantages over previous studies. Lave (1989) criticizes the use of aggregate data in accident analysis. He compares results using statewide data for all highway types with data disaggregated by highway type and shows different results on key policy variables. His analysis, however, uses a one-year cross-section of data and hence cannot adequately control for the many other factors that may influence the model. Likewise, Loeb (1987) uses aggregate data with various socio-economic variables to analyze fatality rates. While showing several formulations that suggest robust results, the use of a one-year cross-section cannot control for heterogeneity in the data for the various states.[2] Fridstrom and Ingebrigsten (1991) point out that the key advantage of using aggregate data is that it can capture effects such as blackspot migration which could be potentially lost using disaggregate data (Boyle & Wright, 1984). Despite this, the studies of Loeb (1987) and other work criticized by Lave (1989) are probably not deficient for the use of aggregate data, but rather for the use of indadequate statistical techniques that do not account for heterogeneity and effects unmeasurable to the analyst as causal factors.

Modelling Results

A number of different models were estimated using the data described previously. The key variables of interest are the infrastructure variables and other variables that change over time. These included, age cohorts, per capita alcohol consumption, seat-belt laws (and usage), per capita income, and population. Vehicle miles of travel (VMT) was also included in models without the population variable due to their high collinearity. These results were essentially similar to the population models and are not shown for brevity.[3]

Tables 2 and 3 have results for fixed effect negative binomial models estimated controlling for state population. As mentioned previously, random effects models were also estimated but were rejected by the Hausman specification test, except in one case which is discussed below. Dependent variables are indicated for each model and were total traffic-related fatalities (DEATHS) and total traffic-related injuries (INJURED). The years of data used in the estimates are also listed. Models A and B in both Table 2 and 3 do not include proxies for medical technology improvements. These are added in models C and D. Table 3 replaces the variables for seat-belt laws with a seat-belt usage rate for each state. This data was only available from 1990 to 1997 and therefore these models contain a shorter time

[2] Loeb (1987) identifies three policy variables that may affect fatality rates. These are statewide beer consumption, whether or not the state has a vehicle inspection program, and speed. Interestingly, he finds that highway miles are not significant.
[3] See Noland (2001), a previous version of this paper that includes models with VMT.

series of data than those in Table 2. Table 4 contains a random effects negative binomial model corresponding to the fixed effects model estimated as model 3-C. This model was not rejected by the Hausman specification and is included here as a likely superior model to that of 3-C. In the following sections the results of the infrastructure variables are discussed first, followed by a discussion of demographic and trend variables, and then other key variables. The magnitude of the estimated coefficient impacts on expected fatalities and injuries is also discussed.

Infrastructure Variables

Total lane miles are found to be highly significant in the fatality models (2-A and 2-C). In models 3-A and 3-C, based on a shorter time series and controlling for seat-belt usage, total lane miles shows a small negative effect.[4] However, the random effects specification of model 3-C in Table 4, shows that the lane mile coefficient is highly significant and positive. For injuries, this variable is also significant in model B but loses significance and magnitude in model D (in both Tables 2 and 3). Initial expectations were that this variable would be significant with a negative sign, implying that additional lane miles reduce fatalities and injuries. If this variable had been found to be insignificant then this would be a strong conclusion in itself since it is generally assumed that newer lane miles, which are designed with the most recent engineering design standards will be safer. A result showing no significant effect would therefore be quite surprising. While the results are less convincing based on the shorter time series of Table 3, these results tend to suggest that additional lane miles actually increase fatalities while also having a small positive effect on injuries.

Three variables were constructed to measure the average number of lanes for the three different road classes (interstates, arterials, and collectors). This was done by dividing the total lane miles of each road class by the center line miles for that road class. This gives an overall average of the number of lanes in a given state. Results show that states with more lanes (on average) on interstates and arterials will have more injuries. No significant effect is shown for fatalities in the models in Table 2, however the models in Tables 3 and 4 do show a significant and positive effect. An increase in the number of lanes on collector roads leads to more fatalities and possibly a small (insignificant) reduction in injuries (though this effect is not picked up in the models in Tables 3 and 4).

This result again goes against conventional assumptions. Normally it is assumed that increasing highway capacity (by adding lanes) will alleviate congestion and reduce accidents. This would imply that we would expect negative coefficients on all these variables. These results suggest that this is not the case and that added lanes (on average) is probably detrimental to overall safety. Some prior research has found similar results (Vitaliano & Held, 1991; Sawalha & Sayed, 2001).

To control for the type of road infrastructure in each state, the percent of lane miles for each functional category was included in the model. In theory, one would expect that additional higher functional categories, such as interstates, would result in fewer fatalities and injuries. This seems to be the case for injuries, as Models 2-B, 2-D and 3-D have significant negative coefficients. However, no significant effect appears for the impact of more interstate lane miles on fatalities. Results are somewhat mixed for the effect of arterial and collector lane miles. The models in Table 2 suggest that more arterial lane miles results in more fatalities with model 2-A being significant and model 2-C having a positive but insignificant coefficient. Tables 3 and 4 do not have significant effects on this variable. Collector lane miles lead to more fatalities and injuries in the models of Table 2, but show no significant effect in the models of Table 3 and 4 with shorter times series. Arterial roads are

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[4] This result appears to be due to the shorter time series and not the inclusion of the seat-belt usage variable. Models specified with the seat-belt laws showed a similar negative coefficient, though with slightly lower significance.

generally considered less safe than most other road categories (primarily due to poor access control) and these results tend to support that conclusion.

Increasing the lane widths of roads is normally seen as a strategy for reducing accidents. Those states with more arterials with lane widths of 9 ft or less have fewer traffic injuries, as is shown by the statistical significance of the coefficient in models 2-B and 3-B and the negative sign in models 2-D and 3-D. The coefficient on this variable is generally not significant for the fatality models with the exception of the model in Table 4. The coefficients for arterials with lane widths of 10 ft are all negative and often significant in Table 2 for both injuries and fatalities. The coefficients for arterials with lane widths of 11 ft are also negative and significant (in Table 2). The coefficient for arterial lane widths of 12 ft or greater is also not significant for either injuries or fatalities.

For collector lane widths we see a similar, but slightly different pattern. The coefficient for collectors with lane widths of 9 ft or less are negative and significant indicating that smaller lane widths reduce both fatalities and injuries. For 10 ft lane widths there is generally no statistical significance, though in Table 3 the coefficients on the injury models are negative and significant. For 11 ft lane widths there is also generally a negative and significant effect. The coefficient for lane widths of 12 ft or greater on collectors is positive and in some cases significant for fatalities (Table 3).

The data on the lane width variables was also analysed by including only one of the corresponding variables in each model. This was done due to correlations between some of the lane width variables. Generally, the correlations between these variables were about 0.50 with only 3 of the 28 correlations exceeding 0.70. In Table 5 these coefficient values and their test statistic are shown for 20 different models (other coefficients had similar values to those in Tables 2 and 3 and are omitted for brevity). The pattern in the coefficients for both the fatality and injury models is quite clear. When there are more arterial and collector lane widths of 12 ft or more, traffic fatalities and injuries increase. The coefficients for 12 foot or greater lane widths are the only estimates that are positive and significant. Estimates for coefficients of smaller lane widths are either significantly negative or insignificant. The coefficient for a variable representing the percent of lane widths (for each road class) of less than or equal to 11 ft is also estimated. This is negative and significant in all cases except for injuries on collector roads. While it is not clear from these results whether there is some optimal "safest" lane width, there does seem to be evidence that lane widths of over 11 ft do not contribute to a safer road environment.

These results are quite surprising as it is general practice to improve the safety of roads by increasing lane widths. One possible behavioral response is that drivers increase their speed when lanes are wider and off-set any safety benefit from increased lane space. Another possibility is the hypothesis of Mahalel & Szternfeld (1986) that drivers may feel safer and reduce cautionary behavior.

Table 6 summarizes the conventional engineering wisdom on how highway engineering "improvements" affect safety and are compared with the results derived here. As can be seen, it is in general, not possible to support the engineering hypotheses. One result consistent with the engineering hypotheses is that arterial roads are generally less safe than controlled access facilities (interstates). This analysis found statistically significant injury reduction benefits from controlled access facilities compared to more fatalities and injuries due to arterial roads.

Demographic and Trend Variables

Other variables are included in the regressions to control for other effects known to have an impact on traffic-related fatalities and injuries. These variables provide interesting results and help explain the observed trends in total traffic related fatalities and injuries.

States with higher per capita income tend to have higher fatalities and injuries as shown by the large statistically significant positive coefficients on this variable. This result is somewhat counterintuitive as normally wealthier areas seek to avoid riskier activities. However, this effect has been found in other aggregate studies (Hakim et al., 1991). Larger population does not seem to conclusively lead to more fatalities or injuries.

Most importantly it was found that changes in age cohorts has a large significant effect on both fatalities and injuries. The percent of the population between 15 and 24 years of age increases both fatalities and injuries since drivers in this age group are well known for being involved in more crashes. However, increases in the percent of the population over age 75 leads to fewer fatalities and injuries, which is a surprising result.

The year variable, which represents a time trend, is negative and significant for fatalities in model 2-A. It is not significant for injuries in model 2-B. This is an important result, as it indicates that other factors, not included in the regression analyses are playing a role in reducing total fatalities. Inclusion of the medical technology variables (discussed further below) eliminates the significance of the time trend variable in model 2-C, suggesting that improvements in medical technology is playing a role in reducing traffic-related fatalities. Inclusion of the seat-belt usage variable in models 3-A and 3-C has the same effect of eliminating the significance of the time trend.[5] It is possible that other variables, not included in this study may also play a role over time, such as marginal improvements in the design of vehicles.[6]

Other Variables

Two different sets of variables are included to capture effects from seat-belt use. The first is the inclusion of a dummy variable representing whether a state has either a primary

[5] The shorter time trend also seems to have an effect as the year variable is also not significant when the seat-belt usage variable is not included.
[6] The introduction of airbags in the 1990's may also have an effect, though within the time series of the data, this would have represented a small fraction of the total fleet.

seat-belt law, a secondary seat-belt law, or none at all. Primary laws allow police officers to ticket those they see who are not wearing seat-belts. Secondary laws only allow tickets to be given if drivers have committed some other moving violation. Most states have secondary laws while a few have recently enacted primary laws. These variables are included in the models of Table 2. Primary laws have the expected effect of reducing both fatalities and injuries, while secondary laws unexpectedly seem to result in an increase in fatalities. However, this effect disappears in model 3-C. McCarthy (1999), using California data, found that enactment of a seat-belt law had no significant effect on fatalities.

Both laws have been found to increase seat belt usage (see Noland et al., 2001). This suggests that an alternative approach is to include measured seat-belt usage instead of the seat-belt law dummy variables in the model. As discussed previously, this was done for the models in Table 3 and 4, but data was only available for the 8 years between 1990 and 1997. Results show that seat-belt usage is statistically significant at reducing fatalities but has no effect on injuries.

Alcohol consumption has also been associated with traffic fatalities (Hakim et al., 1991). To control for this effect, per capita alcohol consumption (measured as total ethanol volume consumed divided by total population) was included in the models. This has a very significant effect on total fatalities but was not significant for total injuries.

Improvements in medical technology may also be playing a significant role in reducing overall traffic-related fatalities. To examine this effect, two variables are tested. The first, is the density of hospitals within a state which may serve as a proxy for emergency response times and for the relative amount of rural areas within a state. One would expect a higher density of hospitals to result in fewer fatalities. Lave (1985) showed that this was a significant variable, with those states having a higher density of hospitals per square mile having fewer fatalities, however, he did not use time series data in his analysis. This variable had an unexpected positive coefficient in the fatality models and was statistically significantly with a negative coefficient in the injuries model. While the coefficient was not generally significant in the fatality models, it could be that this simply is an endogenous response of more hospitals being built in states with more fatal traffic accidents.

A better reflection of changes in medical technology is to find a good variable that represents life saving capabilities. Initially it was hoped that some index of change in medical technology would be readily available. However there does not appear to be a statistical measure of this type collected and certainly not at the state level. Therefore a proxy variable was needed which would be correlated with the underlying changes in medical technology over time and between states. This variable need not necessarily be linked with traffic-related mortality but would represent changes in medical technology.

For this reason, white infant mortality levels was tested. This was thought to be one of the best indicators of changes in medical technology and also exhibited large variations between states and over time. Nationwide white infant mortality rates in the US have decreased by 34%, from 9.43 to 6.18 deaths per 1000 births between 1985 and 1997. For a given year, there is a large variability between states, ranging from a minimum of 7.5 deaths per 1000 births in 1985 for the states of Hawaii and Massachusetts to a high of 12.2 deaths per 1000 births for the states of Wyoming and Delaware. In 1996 the range was 4.3 to 9.1 with New Hampshire having the lowest rate and West Viriginia having the highest rate. Overall correlation with per capita income is only 0.48. Use of total infant mortality rates, instead of just white infant mortality rates, would have had a stronger correlation with per capita income, making interpretation of the results more difficult.

Data on white infant mortality rates was available only for 1985 – 1986, 1988, 1990, and 1992-1997. Missing years were filled in with averaged values from bordering years. Tests of the model with missing years produced essentially the same results.

As can be seen, this variable is positive and highly significant in the fatality models, implying that increases in medical technology reduce total traffic-related fatalities (i.e., reduced white infant mortality represents increased medical technology). The coefficient is also significant in the models that control for seat-belt usage (Tables 3 and 4). Equally important, the variable is not at all significant in the injury models. Therefore, it appears to be picking up the ability of medical technology to reduce the incidence of fatalities in the most severe crashes; though, as one would expect, total injuries would not be affected by medical technology improvements.

The year trend variable is reduced in magnitude and loses its statistical significance when the medical technology proxy is included in the model. Accounting for medical technology effects appears to pick up much of the effect of other factors reducing fatalities over time. As noted previously, this effect is not apparent in the seat-belt usage models which appear to have also captured the time trend, though the white infant mortality variable is still statistically significant in the seat-belt models.

Magnitude of Impacts

These results show that in general, infrastructure “improvements” have led to an increase in total traffic-related fatalities, while demographic changes, reduced per capita alcohol consumption, and medical technology improvements have decreased fatalities. Increased seat-belt usage also appears to have decreased fatalities though the impact of seat-belt legislation is less clear. A relevant question is what the relative impact of changes over time have been.

Table 7 shows how 1985 fatalities and injuries would have changed by applying the elasticities estimated by the models to the 1997 levels of the variables. Table 7 also shows the 95% confidence levels associated with these estimates, though point estimates are shown for those above a 90% one-tailed confidence level.

The effects of changes in infrastructure have resulted in about 1700 more fatalities in 1997 relative to 1985. Of this, about 900 of these fatalities are associated with changes in lane widths. The estimated confidence interval for the increase in fatalities from infrastructure changes ranges from 750 to over 2700 and from about 700 to 1100 more fatalities due to lane width changes. These estimates are based on summing the positive and negative effects of the changes associated with these variables. The infrastructure changes that have most increased fatalities are added lane miles of capacity and increases in the percent of lanes miles that are arterial roads.

Increased injury levels associated with each of the variables are also shown in Table 7. Infrastructure changes have led to about 300,000 more injuries while lane width changes have accounted for about 60,000 more injuries. The largest infrastructure effect leading to increased injuries is the increase in the average number of interstate lanes (about 235,000 more injuries).

The variable with the largest impact on increased fatalities is increased per capita income (over 11,000). Increases in income have also had the largest effect on increasing injuries (over 630,000). Increased population has resulted in about 850 more fatalities.

Those factors driving down total fatalities are fewer young people aged 15-24 (reduction of about 5300), more older people aged over 75 (reduction of about 3100), less alcohol consumption (reduction of about 3200), and better medical technology as represented by the proxy of white infant mortality rates (reduction of about 2000). Hospitals per square mile has fallen over the time span of the data resulting in an increase of nearly 240,000 injuries. Calculations show that this variable has decreased fatalities, but this may be an endogenous effect, as discussed previously.

Increased seat-belt usage appears to have the greatest impact on fatality reduction based upon estimated nationwide usage of only 21% in 1985 increasing to 68% nationwide in

1996 (US DOT, 1998). This estimate is derived by applying the coefficient from the model in Table 4, using just 8 years of data to and results in about 12,600 fewer fatalities in 1996 compared to 1985.

These results suggest that changes in absolute levels of fatalities and injuries are most sensitive to demographic and behavioral variables. Infrastructure changes have had a small positive effect on fatalities and injuries but this has been dwarfed by the large reductions from other changes over time. Clearly, these results suggest that not controlling for factors that change over time could lead to misleading results on how infrastructure change may affect traffic safety.

Conclusions

The results of this analysis suggest that changes in highway infrastructure that have occurred between 1984 and 1997 have not reduced traffic fatalities and injuries and have even had the effect of increasing total fatalities and injuries. This conclusion conflicts with conventional engineering wisdom on the safety benefits of "improving" highway facilities and achieving higher standards of design (Transportation Research Board, 1987). While not all explicit highway design improvements were analysed, the fact that adding new and higher design standard lane miles leads to increased fatalities and injuries suggests that new "improved" design standards are not achieving safety benefits. This result is consistent with much of the literature in this area as discussed in Noland (2001) and briefly reviewed here. Other factors, primarily changes in the demographic age mix of the population, increased seat-belt usage, reduced per capita alcohol consumption, and improvements in medical technology are responsible for the downward trend in total fatal accidents.

A key conclusion is that when analyzing the safety effects of infrastructure change it is necessary to control for changes in exogenous factors and other policy initiatives aimed at reducing accidents. Previous research has generally consisted of cross-sectional datasets that have not captured changes over time. In cases where safety effects have been analysed before and after some infrastructure change it is often necessary to collect several years of before and after accident data to have sufficient numbers for statistical analyses. Again, these type of analyses could suffer from not picking up changes in other factors over time. Many studies also tend to aggregate fatalities and injuries, due mainly to the low probability of fatalities occurring on any specific segment under study. This may lead to erroneous conclusions if infrastructure changes have a different impact on fatal outcomes than on injuries. Finally, newer statistical methods are now available that more appropriately account for the random processes that generate accidents, meaning that there may be erroneous results in some of the older work examining these issues within the safety literature.

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Table 1
Trends in Highway Infrastructure Variables

	1985 value	1997 value	Percent change
Total Lane Miles (excludes local roads)	8,015,290	8,235,037	2.74%
Average Number of Interstate Lanes	4.340	4.457	2.71%
Average Number of Arterial Lanes	2.433	2.508	3.09%
Average Number of Collector Lanes	2.024	2.026	0.08%
Percent of Lane Miles that are Interstates	2.36%	2.49%	5.65%
Percent of Lane Miles that are Arterials	10.60%	11.51%	8.62%
Percent of Lane Miles that are Collectors	20.32%	19.51%	-4.00%
Percent Arterials with 9 ft or less Lane Widths	3.06%	1.58%	-48.33%
Percent Arterials with 10 ft Lane Widths	12.87%	9.22%	-28.34%
Percent Arterials with 11 ft Lane Widths	17.01%	14.91%	-12.32%
Percent Arterials with 12 ft or greater Lane Widths	67.07%	74.29%	10.76%
Percent Collectors with 9 ft or less Lane Widths	16.21%	10.74%	-33.71%
Percent Collectors with 10 ft Lane Widths	31.60%	27.01%	-14.54%
Percent Collectors with 11 ft Lane Widths	20.25%	23.01%	13.64%
Percent Collectors with 12 ft or greater Lane Widths	31.95%	39.24%	22.83%

Table 2
Fixed Effect Negative Binomial Model

Aggregate State Data	(A)		(B)		(C)		(D)	
Dependent Variable	DEATHS		INJURED		DEATHS		INJURED	
Years of data	1984-1997		1984-1997		1985-1997		1985-1997	
	Coef.	T-Stat	Coef.	T-Stat	Coef.	T-Stat	Coef.	T-Stat
Infrastructure Variables								
Log(total lane miles)	0.355	3.16	0.624	4.55	0.378	2.83	0.183	1.17
Log(average number of interstate lanes)	0.173	0.69	2.524	6.23	0.253	0.96	2.843	6.87
Log(average number of arterial lanes)	0.101	0.91	0.506	2.09	0.101	0.84	0.494	2.35
Log(average number of collector lanes)	1.036	2.61	-0.713	-0.73	1.271	2.47	-1.246	-1.41
Log(percent interstate lane miles)	0.052	0.61	-0.204	-1.60	0.061	0.66	-0.367	-2.81
Log(percent arterial lane miles)	0.152	1.92	0.238	1.70	0.132	1.47	0.103	0.74
Log(percent collector lane miles)	0.149	2.07	0.304	3.32	0.125	1.62	0.205	2.26
Log(percent arterials with lane widths of 9 ft. or less)	0.007	1.44	-0.021	-2.68	0.006	1.16	-0.011	-1.48
Log(percent arterials with lane widths of 10 ft.)	-0.017	-1.60	-0.035	-2.41	-0.017	-1.52	-0.033	-2.33
Log(percent arterials with lane widths of 11 ft.)	-0.003	-0.24	-0.011	-0.67	-0.003	-0.21	0.003	0.24
Log(percent arterials with lane widths of 12 ft. or greater)	0.005	0.09	0.133	1.24	0.034	0.54	0.075	0.67
Log(percent collectors with lane widths of 9 ft. or less)	-0.022	-3.06	-0.034	-2.92	-0.022	-2.67	-0.023	-2.19
Log(percent collectors with lane widths of 10 ft.)	0.025	1.39	-0.015	-0.51	0.011	0.55	-0.008	-0.28
Log(percent collectors with lane widths of 11 ft.)	-0.023	-2.54	-0.044	-3.50	-0.024	-2.34	-0.031	-3.18
Log(percent collectors with lane widths of 12 ft. or greater)	0.033	1.21	0.008	0.14	0.048	1.59	0.027	0.42
Demographic and Trend Variables								
Log(percent population aged 15-24)	0.566	5.87	0.646	4.14	0.621	5.99	0.749	4.80
Log(percent population over age 75)	-0.322	-3.19	-0.518	-3.46	-0.366	-3.22	-0.219	-1.34
Log(per capita income)	0.955	8.05	0.953	4.27	0.877	6.71	0.730	3.13
Log(population)	0.119	1.35	-0.471	-4.26	0.148	1.40	0.045	0.31
Year	-0.010	-2.90	0.005	0.89	-0.003	-0.85	0.000	-0.02
Other Variables								
Primary Seat-belt Law	-0.047	-3.20	-0.048	-1.54	-0.039	-2.39	-0.103	-3.16
Secondary Seat-belt Law	0.022	2.27	0.013	0.67	0.006	0.54	0.011	0.54
Log(Per capita alcohol consumption)	0.490	5.67	0.103	0.65	0.417	4.52	0.147	0.95
Log(White Infant Mortality)	-	-	-	-	0.130	2.67	0.013	0.18
Log(Hospitals per Square Mile)	-	-	-	-	0.136	1.61	-0.617	-6.54
Constant	13.074	2.23	-19.746	-1.94	-0.162	-0.02	-12.784	-1.06
N	700		657		646		607	
Log likelihood	-3290.75		-6029.45		-3007.16		-5510.20	

Table 3
Fixed Effect Negative Binomial Regressions with Seat-belt Use Variable

Aggregate State Data	(A)		(B)		(C)		(D)	
Dependent Variable	DEATHS		INJURED		DEATHS		INJURED	
Years of data	1990-1997		1990-1997		1990-1997		1990-1997	
	Coef.	T-Stat	Coef.	T-Stat	Coef.	T-Stat	Coef.	T-Stat
Infrastructure Variables								
Log(total lane miles)	-0.294	-1.28	0.893	3.32	-0.401	-1.60	0.021	0.07
Log(average number of interstate lanes)	1.402	3.40	2.376	3.26	1.447	3.47	2.935	4.08
Log(average number of arterial lanes)	0.382	2.12	0.709	1.37	0.395	2.21	0.949	2.00
Log(average number of collector lanes)	0.001	0.00	0.406	0.28	-0.162	-0.29	-1.288	-1.06
Log(percent interstate lane miles)	-0.018	-0.11	-0.091	-0.32	-0.121	-0.71	-0.569	-1.98
Log(percent arterial lane miles)	-0.104	-0.93	0.243	1.10	-0.122	-1.07	0.100	0.53
Log(percent collector lane miles)	-0.033	-0.35	0.126	1.39	-0.050	-0.52	0.117	1.10
Log(percent arterials with lane widths of 9 ft. or less)	0.008	1.33	-0.020	-2.34	0.008	1.39	-0.013	-1.46
Log(percent arterials with lane widths of 10 ft.)	-0.012	-0.88	0.018	0.98	-0.019	-1.31	0.003	0.16
Log(percent arterials with lane widths of 11 ft.)	-0.008	-0.56	0.006	0.24	-0.010	-0.64	0.000	0.01
Log(percent arterials with lane widths of 12 ft. or greater)	-0.162	-1.29	0.073	0.25	-0.126	-1.02	0.018	0.07
Log(percent collectors with lane widths of 9 ft. or less)	-0.016	-1.49	-0.010	-0.60	-0.013	-1.13	-0.001	-0.04
Log(percent collectors with lane widths of 10 ft.)	0.011	0.40	-0.109	-2.15	0.016	0.56	-0.087	-1.81
Log(percent collectors with lane widths of 11 ft.)	-0.008	-0.76	-0.047	-3.01	-0.006	-0.53	-0.027	-2.44
Log(percent collectors with lane widths of 12 ft. or greater)	0.119	2.56	0.204	1.71	0.117	2.56	0.097	0.87
Demographic and Trend Variables								
Log(percent population aged 15-24)	0.819	5.43	1.149	4.04	0.759	5.00	1.000	4.22
Log(percent population over age 75)	-0.508	-2.42	-0.463	-1.18	-0.542	-2.49	-0.481	-1.62
Log(per capita income)	0.722	3.19	0.580	1.40	0.809	3.59	0.607	1.55
Log(population)	0.159	0.97	-0.976	-4.55	0.231	1.33	-0.126	-0.51
Year	0.004	0.52	0.021	1.76	0.006	0.85	0.010	0.90
Other Variables								
Log(Per capita alcohol consumption)	0.253	1.82	0.018	0.08	0.201	1.42	0.092	0.46
Log(Percent Seat-belt Use)	-0.143	-4.98	-0.029	-0.56	-0.134	-4.68	-0.039	-0.76
Log(White Infant Mortality)	-	-	-	-	0.142	2.68	-0.010	-0.12
Log(Hospitals per Square Mile)	-	-	-	-	0.102	0.85	-0.723	-5.51
Constant	-8.085	-0.70	-42.018	-1.99	-13.688	-1.18	-30.844	-1.51
N	400		378		396		374	
Log likelihood	-1682.25		-3245.30		-1662.40		-3198.85	

Table 4
Random Effects Negative Binomial Model Corresponding to Model 3-C

Aggregate State Data	(C)	
Dependent Variable	DEATHS	
Years of data	1990-1997	
	Coef.	T-Stat
Infrastructure Variables		
Log(total lane miles)	0.431	4.48
Log(average number of interstate lanes)	0.370	1.31
Log(average number of arterial lanes)	0.519	3.11
Log(average number of collector lanes)	-0.508	-0.93
Log(percent interstate lane miles)	0.163	1.60
Log(percent arterial lane miles)	-0.018	-0.19
Log(percent collector lane miles)	0.022	0.26
Log(percent arterials with lane widths of 9 ft. or less)	0.013	2.23
Log(percent arterials with lane widths of 10 ft.)	0.004	0.26
Log(percent arterials with lane widths of 11 ft.)	0.002	0.09
Log(percent arterials with lane widths of 12 ft. or greater)	-0.136	-1.17
Log(percent collectors with lane widths of 9 ft. or less)	-0.020	-1.64
Log(percent collectors with lane widths of 10 ft.)	0.026	0.91
Log(percent collectors with lane widths of 11 ft.)	-0.001	-0.08
Log(percent collectors with lane widths of 12 ft. or greater)	0.023	0.57
Demographic and Trend Variables		
Log(percent population aged 15-24)	0.970	6.25
Log(percent population over age 75)	-0.407	-2.56
Log(per capita income)	0.403	1.92
Log(population)	0.557	6.02
Year	0.014	2.23
Other Variables		
Log(Per capita alcohol consumption)	0.322	2.71
Log(Percent Seat-belt Use)	-0.123	-4.18
Log(White Infant Mortality)	0.198	3.43
Log(Hospitals per Square Mile)	0.081	1.24
Constant	-36.217	-3.43
N	396	
Log likelihood	-2110.87	

Table 5
Coefficients on Lane Width Variables when Modelled Individually

	Fatality Models	Injury Models
Percent Arterials with Lane Widths of 9 ft or less	-0.001 (-0.24)	-0.022 (-2.99)
Percent Arterials with 10 ft Lane Widths	-0.023 (-2.25)	-0.051 (-3.94)
Percent Arterials with 11 ft Lane Widths	-0.027 (-2.60)	-0.037 (-3.28)
Percent Arterials with Lane Widths of 11 ft or less	-0.042 (-2.97)	-0.064 (-4.03)
Percent Arterials with Lane Widths of 12 ft or greater	0.093 (1.72)	0.186 (1.85)
Percent Collectors with Lane Widths of 9 ft or less	-0.023 (-2.82)	-0.033 (-3.15)
Percent Collectors with 10 ft Lane Widths	-0.007 (-0.37)	-0.017 (-0.61)
Percent Collectors with 11 ft Lane Widths	-0.025 (-2.83)	-0.039 (-4.40)
Percent Collectors with Lane Widths of 11 ft or less	-0.061 (-2.07)	-0.008 (-0.21)
Percent Collectors with Lane Widths of 12 ft or greater	0.069 (2.63)	0.091 (1.71)

Test statistic is in parentheses

Table 6
Hypothesized and Modelled Effect of Infrastructure Variables

	Fatalities		Injuries	
	Engineering Hypothesis	Results of Analysis	Engineering Hypothesis	Results of Analysis
Total Lane Miles	-	+	-	+
Average Interstate Lanes	-	*	-	+
Average Arterial Lanes	-	*	-	+
Average Collector Lanes	-	+	-	*
Percent Interstate Lane Miles	-	*	-	-
Percent Arterial Lane Miles	+	+	+	+
Percent Collector Lane Miles	*	+	*	+
Percent Arterials with 9 ft or less Lane Widths	+	*	+	-
Percent Arterials with 10 ft Lane Widths	+	-	+	-
Percent Arterials with 11 ft Lane Widths	*	*	*	*
Percent Arterials with 12 ft or greater Lane Widths	-	*	-	*
Percent Collectors with 9 ft or less Lane Widths	+	-	+	-
Percent Collectors with 10 ft Lane Widths	+	*	+	*
Percent Collectors with 11 ft Lane Widths	*	-	*	-
Percent Collectors with 12 ft or greater Lane Widths	-	+	-	*
	+ = positive and significant effect **- = negative and significant effect** *** = insignificant effect**			

Table 7
Estimated Changes in Fatalities and Injuries using Elasticity Values

Results from Models 2-C and 2-D	Fatality Elasticity	Injury Elasticity	Change in 1985 fatalities with 1997 values of each variable	95% confidence range of estimate		C 1 (
Total Lane Miles	0.378	*	474	146	803	
Average Interstate Lanes	*	2.843	*	*	*	
Average Arterial Lanes	*	0.494	*	*	*	
Average Collector Lanes	1.271	-1.246	57	12	103	
Percent Interstate Lane Miles	*	-0.367	*	*	*	
Percent Arterial Lane Miles	0.132	*	521	-175	1214	
Percent Collector Lane Miles	0.125	0.205	-229	48	-506	
Percent Arterials with 9 ft or less Lane Widths	*	-0.011	*	*	*	
Percent Arterials with 10 ft Lane Widths	-0.017	-0.033	220	513	-64	
Percent Arterials with 11 ft Lane Widths	*	*	*	*	*	
Percent Arterials with 12 ft or greater Lane Widths	*	*	*	*	*	
Percent Collectors with 9 ft or less Lane Widths	-0.022	-0.023	339	587	90	
Percent Collectors with 10 ft Lane Widths	*	*	*	*	*	
Percent Collectors with 11 ft Lane Widths	-0.024	-0.031	-150	-272	-24	
Percent Collectors with 12 ft or greater Lane Widths	0.048	*	501	-115	1109	
Total for Lane Width Variables			**910**	**713**	**1111**	
Total for Infrastructure Variables			**1733**	**744**	**2725**	
Average Per Capita Income	0.877	0.730	11228	7950	14510	
Total Population	0.148	*	851	-343	2039	
Total Percent aged 15-24	0.621	0.749	-5289	-3561	-7024	
Total Percent aged over 75	-0.366	-0.219	-3099	-4991	-1213	
Per Capita Alcohol Consumption	0.417	*	-3233	-1829	-4633	
White Infant Mortality	0.130	*	-2047	-542	-3539	
Hospitals per Square Mile	0.136	-0.617	-784	169	-1735	
Seat-belt Use (model 4-C, 3-D, based on 1996 value)	-0.123	*	-12594	-18561	-6703	

* Not significant at 90% level (one-tailed test)