TRAFFIC FATALITIES AND INJURIES: ARE REDUCTIONS THE RESULT OF 'IMPROVEMENTS' IN HIGHWAY DESIGN STANDARDS?

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Abstract

A cross-sectional time series database of U.S. data on fatalities and injuries is analysed using a fixed effects negative binomial regression. Data from 50 states over 14 years is used to examine the effect of various highway improvements on both fatalities and injuries. These include the total lane miles of capacity, total average number of lanes by functional road category (interstates, arterials, and collectors), lane widths and the relative balance of the various road categories within each state. Results strongly refute the hypothesis that engineering design improvements have been beneficial for reducing total fatalities and injuries. While controlling for other effects it is found that demographic changes in age cohorts, increased seatbelt use, and increases in medical technology have accounted for a large share of overall reductions in fatalities. These results have major implications for the cost benefit analysis of highway projects and for new Federal planning regulations that require safety to be considered as a planning factor.

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, then many drivers will travel 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.

Micro-scale analysis of specific safety improvements may show that various crash types can be reduced by road improvements. This type of analysis will not, however, show what the system-wide effects[1] on total fatalities and injuries may be, nor will it necessarily control for other effects and changes that occur simultaneously, such as demographic changes or increased seatbelt usage. This paper analyzes 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 number of lanes

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[1] System-wide effects are defined to include interactions between the road infrastructure, the vehicle, and the behavior of the driver.

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 effects 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 has also been suggested by other recent research using aggregate safety data, which is reviewed in the next section.

Having found this counter-intuitive result other factors that may have led to the observed decreases in total traffic-related fatalities are analyzed. Changes in demographics, measured by changes in age cohorts are found to have the largest effect, primarily fewer young people and more elderly people. Improvements in medical technology, measured using a proxy of white infant mortality rates is found to also be highly significant. Increased seatbelt usage also has had a major effect on reducing fatalities.

The paper is organized as follows. A brief review of relevant literature on behavioral aspects of safety and some previous empirical analysis that supports the counter-intuitive hypothesis is presented. Trends in the data are then examined. This is followed by the estimation of several models and a discussion of the results. Conclusions and implications for transport and safety policy are then discussed.

Literature Review and Theoretical Background

Much of the research in highway safety and the relationship to infrastructure has focussed on specific design elements and attempts to quantify their accident reduction potential (Transportation Research Board, 1987; McGee et al, 1995). Much of this previous research has focussed on calculating "accident reduction factors" associated with "improvements" in specific design elements. 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 which is crucial information needed for cost benefit analysis.

Vogt and Bared (1998) evaluate changes in design parameters for two lane rural roads using data from the Highway Safety Information System. Using a population of highway segments for two states (Washington and Minnesota) they derive detailed statistical models linking design elements to both total crashes and more serious crashes involving a fatality or injury (however, not disaggregating between these two). The results of their modelling support the conventional engineering hypothesis. For example, they find that increasing lane widths and less horizontal curvature reduces total crashes. While using time-series data they do not appear to control for time in their model, nor other factors that may change over time.

They acknowledge the limitations of their model and that various key variables may be omitted. The lack of controlling for time series effects, as well as cross-sectional effects, is likely to bias the results of this study.

In an analysis of system-wide safety effects, Boyle and Wright (1984) hypothesized that safety treatments of accident ‘blackspots’ may result in increased accidents at other locations. They analyze data for London that suggests some increase in accidents, though a total reduction still appears to occur. They speculate that this effect may be due to drivers encountering fewer ‘near miss’ situations within the previous blackspot location. This could result in a reduction in cautionary behavior and consequently an increase in accidents in locations near the previous blackspot that would not be measured in a traditional safety study. This type of behavioral reaction implies that drivers now perceive their risk level to be less than it was previously. Most studies of specific behavioral treatments fail to catch the system-wide effects such as those studied by Boyle and Wright (1984).

More recently, aggregate data analysis has allowed other factors in addition to infrastructure related factors to be analysed. Fridstrom & Ingebrigsten (1991) estimate a model using monthly data on traffic accidents for 18 counties in Norway. They find that extensions and improvements to the national road network do not have the expected effect of improving safety. They also find that more congested roads leads to fewer casualties. This study controlled for many different causal factors that also contribute to crashes. Karlaftis & Tarko (1998) analyze county level data from the state of Indiana and find that increased road mileage leads to increased accidents. Both these studies use aggregate cross-sectional time-series data and a negative binomial regression as is done in the analysis presented here.

Milton & Mannering (1998) find similar results using data from the State of Washington. While they find that average annual daily traffic leads to an increase in accidents, they also find that when the percent of this traffic at the peak increases, then accidents decrease (i.e., congestion leads to reduced accidents).

Milton & Mannering (1998) also examine various geometric design elements. They find that increasing the number of lanes on a given road segment, leads to more accidents and that in Eastern Washington, narrower "substandard" lane widths (of less than 3.5 metres or 11.5 ft) reduce accident frequency. They also found that horizontal curvature does not by itself increase accidents but was dependent upon whether large straight sections preceded the curves. While this latter result supports the hypothesis that reducing horizontal curvature reduces accidents, it does suggest that roads with extensive curvature may not necessarily be less safe than straighter roads. Milton & Mannering (1998) do not control for any time series or demographic effects in their study.

Shankar et al. (1995) estimated a series of negative binomial regression models in a study of the Interstate 91 corridor in Washington state. They found that when curves are spaced further apart (i.e., fewer curves per mile) more severe overturn accidents increase. 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; though the presence of snowfall tended to increase accidents on those segments with curves of lower design speeds. Shankar et al. (1995) found that those accidents attributable to curves of lower design speeds tended to be less severe than those associated with curves of higher design speeds.

Abdel-Aty & Radwan (2000) found that 'improvements' in geometric design variables reduce accidents. These included the degree of horizontal curvature and shoulder, lane and median widths. They estimated a negative binomial regression model with road segment data from an arterial highway in Florida. One problem with this study (other than the lack of control for time and demographic effects) is that it does not control for repeated observations (that is, multiple sampling of accidents from each segment). Shankar et al. (1995) do control for this by including section-specific constants in their models. This could perhaps account for the very different results shown by these two studies.

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.

Council & Stewart (1999) analysed the safety effects of converting two lane rural roads to either four lane divided roads or four lane undivided roads. They found some significant reduction in accidents for the conversion to divided roads but less significant results for undivided roads. They consider their research preliminary and inconclusive; however, it does suggest that while specific improvements such as separating lanes (or installing medians) may be relatively effective, merely adding more lanes is not. Hadi et al. (1995) analysed specific road improvements such as increasing shoulder and lane widths and found some effectiveness for these treatments. 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.

Increased congestion levels have often been assumed to lead to increased risk for drivers. This would imply that infrastructure changes or capacity increases that reduce congestion and increase flow would lead to reductions in risk. For example, wider lanes are acknowledged to lead to increases in vehicle speeds and hence are effectively adding capacity (Transportation Research Board, 1987). Zhou & Sisiopiku (1997) analyze a specific highway link in Michigan and find that the relationship between the volume/capacity ratio and accidents follows a U-shaped curve; initially as the ratio increases, accidents decrease, then turn up again at higher congestion levels. More importantly, fatal accidents were found to decrease consistently with higher congestion levels. This is not a surprising result since speeds will be lower under congested conditions. One would expect more minor vehicle interactions (i.e., fender benders) under congested conditions, but fewer fatalities. Ivan et al. (2000) in a study of link-segments in Connecticut found that single-vehicle crash rates are highest when volume-capacity ratios are low, but found no significance for multi-vehicle crashes.

Shefer & Rietveld (1997) argue that the benefits of congestion reduction must be off-set by higher accident costs. They present some empirical data to support their hypothesis, but do not control for other factors. Currently, most justifications for highway projects assume lower accident costs with decreasing congestion.

Theoretically, the results of these studies are not surprising despite the absence of these type of considerations in risk reduction strategies and cost benefit analysis. To a large extent the idea that both increased capacity and infrastructure improvements may lead to increased risk is not inconsistent with the theory of risk compensation as formulated by Peltzman (1975). This theory states that reductions in the risk of driving will be off-set by changes in driver behavior. Peltzman analysed the impact of automobile safety regulations in the U.S. and concluded that they were virtually ineffective at decreasing fatalities. As postulated by Peltzman, “driving intensity” increases in response to safer vehicles – or alternatively, drivers take additional risks knowing that their vehicles are safer and therefore the severity of a crash, should it occur, is reduced. An alternative formulation would be that "safer" roads result in increased mobility as well as faster speeds and less attentive driving, resulting in less than expected reductions in risk.

Peltzman's hypothesis and methodology has undergone extensive debate in the safety literature. Evans (1986), Graham and Garber (1984), Joksch (1976a, b) and Robertson (1977a, b; 1981) all conducted similar studies that tended to refute the risk compensation hypothesis, generally by specifying different functional forms for the estimated model. Other research, using different data and techniques has tended to support the hypothesis, including Zlatoper (1984), McCarthy (1986), Conybeare (1980), Singh and Thayer (1992) and Traynor (1993). In addition, Wilde (1982) specified a similar theory of risk homeostasis based upon the literature in behavioral psychology.

If one considers risk compensation from an economic perspective one can consider drivers as consumers of a bundle of goods, one of which is safety. Peltzman assumed that increased consumption of safety led to increased risk taking. However, it is more plausible that drivers also consume increased mobility – that is, increased driving and longer distance driving. This increase in exposure results in increased risk taking similar to Peltzman's hypothesis that the "driving intensity" of individuals increases.

Figure 1 illustrates potential behavioral effects graphically. If one assumes that individuals (and society) decide upon explicit trade-offs between risk and mobility then the isoquant shown in the figure illustrates this choice for a given level of technology. The technology represents safety devices in vehicles (e.g. air bags) and the existing road infrastructure. Movement along a given isoquant represents the trade-off that an individual makes in selecting a given bundle of safety and mobility.

The more safety one desires, the less mobility one will have and vice-versa. Point A represents a given consumers choice where the demand curve is tangent to the isoquant of production. If it is now possible to provide more mobility at the same level of safety, for example through some technological improvement such as construction of the interstate highway system or larger lane widths, then the isoquant shifts outward. The new choice along the curve will depend, however, on the shape of the demand curves. As can be seen in the graph, if point B is chosen, then one achieves both safety and mobility improvements. Point C, however, while providing greater mobility improvements actually results in a reduction in safety (the alternative, not shown, is also possible which would be less mobility and more safety). This graph could also be extended into a third dimension which would represent Peltzman's "driving intensity," one component of which might be more aggressive driving, such as increased tail-gating, which would be a complement to increased mobility.

The models estimated in this paper do not analyze the full spectrum of infrastructure "improvements" hypothesized to improve safety. Four explicit variables are analysed, the increase in total lane miles, changes in average number of lanes by functional category, changes in lane widths, and increases in the fraction of total lanes for each functional road type. Capturing the interactions between road categories is important. Chu (1999) shows how shifts to interstates may have resulted in significant reductions in fatalities, though the increase in capacity may have generated significantly more travel (Noland, 2001).

No literature appears to have analysed the impact of medical technology improvements on fatalities and injuries. Lave (1985) used hospitals per square mile to attempt to account for access to medical services (in the event of a crash). This would serve to control for rural areas being less accessible to fast medical care for emergencies. He found this variable to be significant, though his analysis suffers from not controlling for either cross-sectional or time-series effects.

The model developed below uses white infant mortality rates as a proxy for medical technology. This does not appear to have been studied within the safety literature. However, there is a strand of literature that hypothesized that high aggression levels in society lead to increased traffic fatalities. To examine this hypothesis Sivak (1983) correlated homicide rates and fatality rates from other accidents with vehicle fatality rates. This was done using one year of data at the state level, thus it does not control for either cross-sectional or time-series effects. Nevertheless, Sivak (1983) found a correlation between homicide fatality rates and traffic fatality rates. He also found a correlation with fatality rates from other accidents. It is possible that these correlations are merely driven by underlying differences in medical technology between states.

It is clear from a review of the relevant safety literature that most analyses have not controlled for time-series and cross-sectional effects. The two exceptions are Fridstrom & Ingebrigsten (1991) and Karlaftis & Tarko (1998) who found results that question whether new infrastructure (represented by new lane miles) leads to reduced fatalities. Yet many of the other studies, such as Milton & Mannering (1998) have results suggesting that conventional engineering wisdom may be suspect. The large literature on risk compensation also suggests counter-intuitive results but has not focussed on road design variables. In general, none of these studies have highlighted their unexpected results, but taken as a whole, certainly suggest that conventional hypotheses that road "improvements" improve safety should be reevaluated. The analyses presented below evaluates these issues, but first the next section discusses the data used, various trends in the data, and the estimation methodology used.

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). Total fatalities and total injuries by state was collected. The fatality data was available for every state over the 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. Figure 2 shows trends in total US traffic fatalities and injuries between 1967 and 1995. Total fatalities have generally been decreasing over this time period while total injuries have shown an upward trend. If measured per vehicle miles of travel (VMT), both fatalities and injuries have decreased significantly over time.

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 1996, are described in Table 1. In general, these 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 a small decrease 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 5.75% and the percent of arterial lane miles growing by 8.73%. This has been at the expense of the percent of collector lane miles which have shrunk by 3.26%. 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 shrunk by 48.59% while arterials with lane widths of 12 ft or greater have increased by 10.33%. Some 67% of arterials already had 12 ft or greater lane widths in 1985 and this fraction increased to 74% by 1995. 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 seatbelt usage, by state, were used to control for the effects of increased seatbelt use. This data was only available since 1990. The analyses also attempts to control for seatbelt effects by including dummy variables for those states with either primary or secondary seatbelt 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 occurrence of traffic crashes and the resulting injuries and fatalities are poisson distributed. Ordinary least squares regression is inappropriate for count data since it is not normally distributed. In addition, count data is inherently non-negative. The use of a poisson regression will, however, suffer from over-dispersion in the error term due to the inequality of the mean and variance within the data. This is easily corrected by using a negative binomial regression (Karlaftis & Tarko, 1998).

The use of cross-sectional time-series data in this analysis introduces the problem of heterogeneity in the data. These are unobserved factors that might be associated with a given cross-section (or state in the data used here) or time period. Not accounting for heterogeneity can lead to biased coefficient estimates. A technique to account for this was developed by Hausman et al. (1984) and has been described as a negative binomial fixed effects model. The Stata software package (Stata Corp., 1999) provides a procedure for implementing this estimation method which is used in the analysis below.

The model can be written as,

$$\ln l_{it} = k_i + b' x_{it}, \qquad i = 1,...N, \qquad t = 1,\ldots T_i$$

The parameter k_i is a vector representing the effect of excluded variables for each cross-sectional unit; N represents the number of cross-sectional units, and T_i is the time period. The vector of parameters to be estimated is b while x_{it} is the matrix of independent variables. Hausman et al. (1984) provide further details on the model used. The independent variables are further specified logarithmically in the models that follow.

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. Other variables known to effect crashes are also included, specifically age cohorts, per capita income, state population, and VMT. VMT and population can not be included in the same model due to being highly collinear. Separate models for each are therefore estimated.

Table 2 has results for models estimated controlling for state population while Table 3 has similar models but with vehicle miles of travel (VMT) substituted for population. The results are quite robust across both model specifications. The discussion that follows focuses on Table 2 for brevity, but could equally apply to the results in Table 3. The dependent variables are indicated on the top row of each column; these are the total deaths (DEATHS) and total injuries (INJURED) from traffic-related crashes.

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[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.

Models A and B contain all the relevant infrastructure variables. In models C and D, the lane width variables are dropped to test the robustness of the model without these variables. Models E and F include ethanol consumption as an independent variable while dropping population due to the high correlation between these two variables (and likewise with VMT). Models G and H, which we discuss further below, contain seatbelt usage as an independent variable and are estimated only for the years 1990-1997.

Total lane miles are found to be highly significant across models A – F for both total fatalities and injuries.[3] The coefficient values are relatively robust, though in models E and F the lane mile coefficient is reduced in value. This is due to a relatively high and coincidental correlation between lane miles and ethanol consumption. Model G, based on a smaller data set, does not give a significant result on the lane mile variable.

No significant effect is found for increases in the average amount of interstate lanes on fatalities. This is an important result that refutes the assumption that more lanes necessarily reduces fatalities. Of more importance, adding interstate lanes is found to increase total injuries. Model G shows this variable to be significant with respect to total fatalities over the shorter time span of 1990-1997. It is unclear why this result occurs.

Increases in the average number of arterial lanes is found to be significant in increasing total fatalities and total injuries while increases in the average number of collector lanes does not affect injuries but results in increased fatalities. It appears that having large arterials and collectors with multiple lanes increases fatalities while this does not happen for interstates. This may be due to cross-traffic, turning movements, and other roadside distractions that would not be present on an interstate. However, multiple lane interstates clearly have safety problems that result in more traffic related injuries.

The percent of lane miles by each road category shows that those states with more lane miles of interstate (relative to other categories) have a statistically significant reduction in injuries. This is consistent with the hypothesis that interstate highways are safer, relative to other road categories (probably due to access controls). However, there is not statistically significant reduction in fatalities when a state has proportionally more interstate lane miles. States with a larger share of arterial lane miles in their networks have more fatalities and injuries, while those with more collectors have more injuries. This result tends to support conventional engineering wisdom that interstate highways are safer but is confounded by the positive coefficient on the average number of interstate lanes increasing total injuries.

Those states with more arterials with lane widths of 9 ft or less have fewer traffic injuries; the coefficient on this variable is not significant for the fatality models, though it is positive. The coefficients for arterials with lane widths of 10 ft are all negative and significant, while those for arterials with lane widths of 11 ft are all insignificant. 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 no statistical significance and for 11 ft lane widths there is a negative

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[3] Given that the conventional engineering hypothesis assumes that added (or new) lane miles should reduce fatalities and injuries we can use a one-tailed test to reject this hypothesis. Therefore our 95% confidence interval is equivalent to a test statistic of 1.65.

and significant effect. The coefficient for lane widths of 12 ft or greater on collectors is significant and positive for fatalities but insignificant for injuries.

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 moderate (but not large) correlation 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 4 these coefficient values and their test statistic are shown (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. As more arterial and collector lane widths are increased up to 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.

These results are quite stunning as it is general practice to improve the safety of roads by increasing lane widths. Clearly these results suggest that drivers must react to increased lane widths, which can increase driver comfort, by reducing their caution, increasing their speeds and therefore off-setting expected safety benefits.

Table 5 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. The one result consistent with engineering hypotheses is that arterial roads are generally less safe than controlled access facilities (interstates). This analysis found significant injury reduction benefits from controlled access facilities compared to more fatalities and injuries due to arterial roads.

Other variables are included in the regressions primarily to control for other effects. However, these variables also show some interesting results and help explain the observed trends in total traffic related fatalities and injureis. States with higher per capita income tend to have higher fatalities and injuries. Larger population does not seem to conclusively lead to more fatalities (model C shows a significant effect, while A does not), but does lead to fewer injuries. Increased VMT (Table 3) is significant in increasing fatalities and in decreasing 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 as one would expect, 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.[4]

Models E and F in Table 1 replace the population variable with a variable for total ethanol consumption. These variables are highly correlated with each other and thus cannot be included in the same model. Other variables, with some minor exceptions are quite robust. Lane miles is also relatively correlated with ethanol consumption and shows a reduced value in both the fatality and injury model. Ethanol consumption is, not surprisingly, highly significant in the fatality model, but not in the injury model.

Two different sets of variables are included to capture effects from seatbelt use. The first is the inclusion of a dummy variable representing whether a state has either a primary seatbelt law, a secondary seatbelt law, or none at all. Primary laws allow police officers to ticket those they see who are not wearing seatbelts.

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[4] Interestingly, some preliminary analysis of impacts on pedestrian fatalities shows that states with a

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 Models A – F. Primary laws seem to reduce fatalities and injuries, while secondary laws result in an increase in fatalities. McCarthy (1999), using California data, found that enactment of a seatbelt law had no significant effect on fatalities. Both laws are found to increase seat belt usage, as shown in Table 6. Models G and H include seatbelt usage and this is found to be highly significant at decreasing fatalities, but not significant for decreasing injuries. These results are quite interesting and deserve more exploration, but are not examined further in this paper. These variables are included only to control for these effects to verify the robustness of our key variables of interest which are the infrastructure variables.

The year variable, which represents a time trend, is negative and significant for deaths. This means that over time the overall number of deaths is decreasing due to unmeasured factors not included in the regression. Injuries show an increase over time in the models controlled for VMT (Table 3). In the fatality model with seatbelt use data (Model G), however, the year variable becomes insignificant, suggesting that much of the unmeasured downward trend is picked up by increased seatbelt use. Model G, however, uses only 8 years of data and therefore it is difficult to know whether the lack of significance may also be due to a shorter time trend. The year trend is insignificant for injuries but shows a significant positive effect in the seatbelt model (Model H). The fixed effects methodology used accounts for state-specific effects that are missing in the model, such as seatbelt usage in Models A – D.

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higher fraction of elderly people have more pedestrian fatalities.

Therefore, it is likely that the change in significance levels in Models G and H are at least partly due to the shorter time trend.

This was tested by running Models A-D with data for the shorter time trend (1990-1997). Results (not shown here for brevity) indicate that the year variable is barely significant at the 90% level. The coefficient level is about –0.008, which is about midway between the values estimated with the full time trend and the seatbelt usage model. This suggests that some of the time trend is probably captured by the seatbelt coefficient, but not necessarily all of it.

Another factor that could be missing from the model are various improvements in vehicle safety over this time frame. The largest innovation that occurs within the time frame of the data is the introduction of air bags, starting about 1993. Given that airbag penetration rates within the total vehicle fleet were not yet substantial within the data set, this is unlikely to be a major influence. It may be having more of an effect within the seatbelt model with a shorter time series and airbag use could perhaps also make seatbelts more effective.

Another possibility is that 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 was not significant in the models estimated.

A better reflection of changes in medical technology is to find a good proxy for life saving capabilities. Many of these are often correlated with per capita income. For this reason, white infant mortality levels is tested, to avoid the stronger correlations that total infant mortality or expected life expectancy per state would have. This variable shows a large variation both across time and across states. Nationwide white infant mortality rates have decreased by 34%, from 9.43 to 6.18 deaths per 1000 births between 1985 and 1996. 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 4.4 to 8.4 with Hawaii and Maine having the lowest rate and Nebraska and Arkansas having the highest rates. Overall correlation with per capita income is only 0.48.

This variable is used in the models presented in Tables 7 and 8 (for population and VMT models, respectively). The logarithm of the inverse of the white infant mortality rate is used so that increasing values represent an increase in the level of medical technology. Data was available only for 1985 – 1986, 1988, 1990, and 1992-1996. 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 negative and highly significant in the fatality models, implying that increases in medical technology reduce total traffic-related fatalities. The coefficient is also significant in Model G which explicitly controls for seatbelt usage. 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, injuries would not be affected by medical technology improvements.

The year trend variable is reduced in magnitude when the medical technology proxy is included in the model. While the time trend is generally still significant, in some of the estimates it is no longer significant at the 95% level. There is less difference in the time trend for the injury models. While this indicates that there are still some other unmeasured factors that are reducing fatalities over time, accounting for medical technology effects picks up some of this effect. It is probable that the remaining unmeasured effects are due to various improvements in vehicle technology over time.

As mentioned previously, the seatbelt models (Model G) also capture much of the time trend effect. When Models A-D are estimated with the shorter time trend data and with the medical technology proxy, it is still significant. The time trend variable, however, has about the same magnitude, though it is not significant at the 95% level. This tends to suggest that medical technology improvements are picking up some of the residual time trend effect in the data, at least between 1985-1996, and most likely in the shorter time trend from 1990-1996.

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

Table 9 and Table 10 show for the population and VMT models (A and B) how 1985 fatalities and injuries would have changed with the infrastructure, demographics and medical technology levels for 1996. Medical technology improvements (as measured by the proxy) indicate that between 3767 – 4158 fewer fatalities would have occurred in 1985 if 1996 medical technology were available.

This is almost 10% of all traffic-related fatalities. If 1996 infrastructure were available in 1985, this would have resulted in between about 1995-2249 additional fatalities and 302,000 to 489,000 more injuries. Amongst the infrastructure variables, increases in lane widths to 12 foot widths seems to account for over half of the total increase in fatalities and about one-quarter of the increase in injuries. Increases in the arterial network also account for a large share of the increase in fatalities due to infrastructure ”improvements.”

Increases in per capita income account for the greatest estimated increase in fatalities and injuries. Increased seatbelt 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). Applying the estimate from Model G, using just 8 years of data to 1985 – 1996, some 15574 fatalities could have been avoided if 1996 seatbelt usage rates were occurring in 1985. The other largest influence on reducing fatalities is the reduction in the percent of people aged between 15-24 and the increase in those aged over 75. If 1996 population cohorts are applied to 1985, then in total, over 10,000 fatalities and nearly 1,000,000 injuries would have been avoided.

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 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. The review of the literature identified other studies that have found this effect, though these studies have not clearly interpreted the implications for transport and safety policy.

Other factors, primarily changes in the demographic age mix of the population, increased seatbelt usage, and improvements in medical technology are responsible for the downward trend in total fatal accidents. To date, these changes have been more than sufficient to off-set the effect of increasing per capita income and the effects of various infrastructure improvements.

The results tend to support the theory of risk compensation, in that driver behavioral changes will off-set various factors aimed at improving safety. In the results of our models, much of this may result from higher design standards allowing drivers to increase their speeds on roads and reduce their levels of caution. This allows the driver to make a trade-off between mobility and safety. It also implies that to reduce fatalities it is necessary to change driver behavior, as demonstrated by the effectiveness of increased seatbelt usage.

Traffic calming initiatives were not analysed in this study. Traffic calming safety enhancements, however, tend to lower driving speeds and require the driver to increase their attentiveness. To some extent, this could result in a behavioural effect opposite of that resulting from higher design standards. This would suggest that traffic calming, while not explicitly studied here, may be an effective infrastructure change for improving safety.

Currently the US Department of Transportation uses the Highway Economics Requirements System (HERS) to forecast future financial requirements for nationwide highway needs. This modelling system includes explicit consideration of various engineering design criteria, such as lane widths, shoulder widths, and horizontal curvature and calculates crash reduction rates based upon various engineering studies (Cambridge Systematics, 1998; US DOT, 1999). These studies provide explicit coefficient linking infrastructure improvements to crash reduction. However, they do not control for other effects as the analysis here does. It is not known how the contribution of estimated safety benefits in the current HERS model affects total forecast needs, but presumably if the current safety relationships were removed the financial need for more highway spending would be reduced.

Highway project decision making is critically linked to current assumptions about the beneficial aspects of “improved” design standards. Many projects are justified based upon their crash reduction benefits, for example, as stated in environmental impact statements. Implied in this is the decision that allowing some level of environmental damage is acceptable when safety benefits can be achieved. The Clean Air Act explicitly exempts safety related projects from the need to conform with air quality requirements as stated in state implementation plans. Obviously, if safety benefits cannot be achieved while allowing environmental degradation, this challenges a critical justification for many projects.

This is not to say that all highway projects that may decrease safety are necessarily not beneficial. Mobility improvements may still be achievable, though explicitly recognizing any safety costs would improve decision making.

While it is difficult to forecast what future trends in fatalities will occur, current demographic trends with an increase in the elderly population and fewer younger people suggest that downward trends will continue. It is even more difficult to know how much more medical technology will improve over time, but it is certainly possible that the pace of improvement may be less rapid than in the past (or alternatively it may accelerate). Increased seatbelt usage is still feasible and can still be effective at reducing future fatalities. It is likely that downward trends may continue despite increased design upgrading of highway and road infrastructure.

The modelling framework used in this paper can be expanded in several ways. First, it should be feasible to analyze various sub-categories of crash types, such as pedestrian fatalities and injuries or those involving children. In addition, it would be desirable to include data on other infrastructure elements, such as horizontal curvature and shoulder widths. This data may be available in the Highway Performance Monitoring System database. It is hoped that further analysis of these relationships will help to clarify the effects found here.

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Table 1
Trends in Highway Infrastructure Variables

	1985 value	1996 value	Percent change
Total Lane Miles (excludes local roads)	8,015,290	8,174,379	1.98%
Average Number of Interstate Lanes	4.39	4.52	2.78%
Average Number of Arterial Lanes	2.38	2.44	2.40%
Average Number of Collector Lanes	2.02	2.02	-0.04%
Percent of Lane Miles that are Interstates	2.37%	2.50%	5.75%
Percent of Lane Miles that are Arterials	10.58%	11.50%	8.73%
Percent of Lane Miles that are Collectors	20.27%	19.61%	-3.26%
Percent Arterials with 9 ft or less Lane Widths	3.06%	1.57%	-48.59%
Percent Arterials with 10 ft Lane Widths	12.87%	9.50%	-26.12%
Percent Arterials with 11 ft Lane Widths	17.01%	14.93%	-12.24%
Percent Arterials with 12 ft or greater Lane Widths	67.07%	74.00%	10.33%
Percent Collectors with 9 ft or less Lane Widths	16.21%	11.03%	-31.95%
Percent Collectors with 10 ft Lane Widths	31.60%	27.54%	-12.83%
Percent Collectors with 11 ft Lane Widths	20.25%	22.73%	12.26%
Percent Collectors with 12 ft or greater Lane Widths	31.95%	38.70%	21.13%

Table 2
Fixed Effect Negative Binomial Regressions with State Data (controlled for population)

Aggregate State Data	Dependent Variable			
	DEATHS	INJURED	DEATHS	INJURED
	(A)	(B)	(C)	(D)
Years of data	1984-1997	1984-1997	1984-1997	1984-1997
Log(total lane miles)	0.403	0.661	0.378	0.675
	(3.632)	(4.914)	(3.585)	(4.833)
Log(average number of interstate lanes)	-0.030	2.486	-0.172	2.203
	(-0.116)	(6.186)	(-0.673)	(5.252)
Log(average number of arterial lanes)	0.208	0.531	0.309	0.808
	(1.829)	(2.215)	(2.836)	(3.125)
Log(average number of collector lanes)	1.281	-0.751	1.339	-0.028
	(3.226)	(-0.775)	(3.249)	(-0.025)
Log(percent interstate lane miles)	0.099	**-0.224**	0.045	**-0.386**
	(1.112)	**(-1.781)**	(0.511)	**(-2.945)**
Log(percent arterial lane miles)	0.181	**0.277**	0.208	0.474
	(2.301)	**(2.066)**	(2.715)	(3.368)
Log(percent collector lane miles)	0.088	0.332	0.072	**0.326**
	(1.207)	(3.603)	(0.981)	**(3.459)**
Log(per capita income)	1.267	1.053	1.270	1.097
	(11.536)	(5.398)	(11.615)	(5.301)
Log(population)	0.029	-0.503	0.151	-0.586
	(0.314)	(-4.760)	(1.825)	(-5.552)
Log(percent population aged 15-24)	0.680	0.639	0.682	0.626
	(9.609)	(5.649)	(9.992)	(5.196)
Log(percent population over age 75)	-0.651	-0.732	-0.604	-0.621
	(-7.517)	(-5.847)	(-7.287)	(-4.543)
Year	-0.012	**0.008**	-0.013	**0.013**
	(-4.312)	**(1.829)**	(-4.860)	**(2.761)**
Log(percent arterials with lane widths of 9 ft. or less)	0.007	-0.022	-	-
	(1.461)	(-2.819)		
Log(percent arterials with lane widths of 10 ft.)	-0.020	-0.031	-	-
	(-2.066)	(-2.362)		
Log(percent arterials with lane widths of 11 ft.)	0.001	-0.017	-	-
	(0.100)	(-1.067)		
Log(percent arterials with lane widths of 12 ft. or greater)	-0.013	**0.096**	-	-
	(-0.233)	**(0.896)**		
Log(percent collectors with lane widths of 9 ft. or less)	-0.021	-0.031	-	-
	(-2.806)	(-2.805)		
Log(percent collectors with lane widths of 10 ft.)	0.029	-0.013	-	-
	(1.603)	(-0.432)		
Log(percent collectors with lane widths of 11 ft.)	-0.028	-0.048	-	-
	(-2.971)	(-3.804)		
Log(percent collectors with lane widths of 12 ft. or greater)	0.064	0.015	-	-
	(2.367)	(0.263)		
Primary Seatbelt Law	-0.060	**-0.050**	-0.054	-0.051
	(-3.966)	**(-1.618)**	(-3.627)	(-1.568)
Secondary Seatbelt Law	0.022	0.015	0.028	0.012
	(2.181)	(0.777)	(2.750)	(0.580)
Constant	11.501	-27.952	11.569	-36.307
	(2.339)	(-3.406)	(2.490)	(-4.409)
N	700	657	700	657
Log likelihood	-3307.06	-6026.78	-3321.85	-6060.95

Test statistic is in parentheses

Table 2 (continued)
Fixed Effect Negative Binomial Regressions with State Data (controlled for population)

Aggregate State Data	Dependent Variable			
	DEATHS	INJURED	DEATHS	INJURED
	(E)	(F)	(G)	(H)
Years of data	1984-1997	1984-1997	1990-1997	1990-1997
Log(total lane miles)	0.190 (1.933)	0.441 (3.679)	-0.228 (-0.995)	0.895 (3.284)
Log(average number of interstate lanes)	-0.192 (-0.791)	2.129 (5.424)	1.334 (3.259)	2.308 (3.143)
Log(average number of arterial lanes)	0.146 (1.332)	0.505 (2.090)	0.389 (2.193)	0.702 (1.350)
Log(average number of collector lanes)	1.157 (2.961)	-0.512 (-0.522)	0.033 (0.060)	0.511 (0.353)
Log(percent interstate lane miles)	0.069 (0.800)	**-0.321** **(-2.652)**	-0.008 (-0.049)	-0.104 (-0.356)
Log(percent arterial lane miles)	0.076 (1.072)	0.122 (0.960)	-0.075 (-0.676)	0.307 (1.403)
Log(percent collector lane miles)	0.047 (0.711)	0.287 (3.048)	-0.047 (-0.509)	0.159 (1.638)
Log(total ethanol consumed)	0.326 (5.236)	**-0.319** **(-3.165)**	-	-
Log(per capita income)	1.094 (9.870)	1.160 (5.441)	1.130 (6.037)	-0.684 (1.814)
Log(population)	-	-	0.167 (1.008)	-0.949 (-4.315)
Log(percent population aged 15-24)	0.546 (7.282)	0.720 (5.941)	0.885 (5.920)	0.963 (3.607)
Log(percent population over age 75)	-0.566 (-6.476)	-0.732 (-5.643)	-0.494 (-2.393)	-0.797 (-2.549)
Year	-0.009 (-3.328)	0.005 (0.708)	-0.004 (-0.803)	0.024 (2.727)
Log(percent arterials with lane widths of 9 ft. or less)	0.007 (1.530)	-0.019 (-2.468)	0.008 (1.317)	-0.022 (-2.499)
Log(percent arterials with lane widths of 10 ft.)	-0.018 (-1.789)	-0.037 (-2.762)	-0.009 (-0.635)	0.012 (0.614)
Log(percent arterials with lane widths of 11 ft.)	-0.005 (-0.393)	-0.0012 (-0.736)	-0.010 (-0.620)	0.003 (0.144)
Log(percent arterials with lane widths of 12 ft. or greater)	-0.029 (-0.518)	**0.095** **(0.867)**	-0.152 (-1.219)	0.081 (0.277)
Log(percent collectors with lane widths of 9 ft. or less)	-0.016 (-2.190)	-0.030 (-2.538)	-0.016 (-1.438)	-0.004 (-0.237)
Log(percent collectors with lane widths of 10 ft.)	0.025 (1.400)	-0.026 (-0.852)	0.009 (0.314)	-0.112 (-2.229)
Log(percent collectors with lane widths of 11 ft.)	-0.020 (-2.166)	-0.046 (-3.498)	-0.008 (-0.704)	-0.048 (-3.117)
Log(percent collectors with lane widths of 12 ft. or greater)	0.055 (2.141)	0.061 (1.084)	0.129 (2.853)	0.161 (1.377)
Primary Seatbelt Law	-0.046 (-3.208)	-0.059 (-1.880)	-	-
Secondary Seatbelt Law	0.020 (2.001)	0.016 (0.802)	-	-
Log(percent seatbelt usage)	-	-	-0.134 (-4.627)	-0.036 (-0.701)
Constant	7.528 (1.535)	-21.481 (-2.549)	1.283 (0.152)	-51.475 (-3.147)
N	700	657	400	378
Log likelihood	-3294.40	-6033.08	-1678.00	-3245.00

Table 3
Fixed Effect Negative Binomial Regressions with State Data (controlled for VMT)

Aggregate State Data	Dependent Variable					
	DEATHS	INJURED	DEATHS	INJURED	DEATHS	INJURED
	(A)	(B)	(C)	(D)	(G)	(H)
Years of data	1984-1997	1984-1997	1984-1997	1984-1997	1990-1997	1990-1997
Log(total lane miles)	0.340	0.461	0.354	0.477	-0.175	0.313
	(3.526)	(3.546)	(3.678)	(3.412)	(-0.817)	(1.419)
Log(average number of interstate lanes)	-0.078	2.188	-0.147	1.879	1.397	1.693
	(-0.311)	(5.544)	(-0.594)	(4.540)	(3.498)	(2.523)
Log(average number of arterial lanes)	0.145	0.575	0.227	0.872	0.388	0.585
	(1.228)	(2.360)	(2.005)	(3.338)	(2.172)	(1.167)
Log(average number of collector lanes)	1.303	-1.188	1.373	-0.616	0.049	0.156
	(3.274)	(-1.231)	(3.326)	(-0.553)	(0.088)	(0.112)
Log(percent interstate lane miles)	0.081	**-0.294**	0.014	**-0.429**	0.004	-0.606
	(0.901)	**(-2.385)**	(0.161)	**(-3.266)**	(0.022)	(-2.431)
Log(percent arterial lane miles)	0.151	0.122	0.205	**0.299**	-0.050	-0.023
	(2.101)	(0.960)	(2.942)	**(2.218)**	(-0.474)	(-0.116)
Log(percent collector lane miles)	0.063	0.342	0.076	**0.335**	-0.027	0.158
	(0.927)	(3.533)	(1.114)	**(3.321)**	(-0.306)	(1.389)
Log(per capita income)	1.186	1.117	1.148	1.209	1.104	0.388
	(10.113)	(5.344)	(9.769)	(5.473)	(5.672)	(0.980)
Log(VMT)	0.132	**-0.307**	0.199	-0.396	0.097	-0.407
	(1.925)	**(-3.039)**	(2.969)	(-3.719)	(0.757)	(-2.244)
Log(percent population aged 15-24)	0.667	0.652	0.650	0.672	0.891	0.751
	(9.391)	(5.650)	(9.572)	(5.437)	(5.937)	(2.696)
Log(percent population over age 75)	-0.633	-0.708	-0.578	-0.649	-0.457	-0.922
	(-7.186)	(-5.659)	(-6.833)	(-4.823)	(-2.054)	(-3.214)
Year	-0.014	0.012	-0.016	0.020	-0.005	0.034
	(-4.728)	(2.520)	(-5.512)	(4.061)	(-0.909)	(3.640)
Log(percent arterials with lane widths of 9 ft. or less)	0.007	-0.021	-	-	0.007	-0.021
	(1.522)	(-2.712)			(1.238)	(-2.222)
Log(percent arterials with lane widths of 10 ft.)	-0.020	-0.033	-	-	-0.009	-0.000
	(-2.083)	(-2.401)			(-0.640)	(-0.009)
Log(percent arterials with lane widths of 11 ft.)	0.003	-0.021	-	-	-0.009	-0.011
	(0.281)	(-1.316)			(-0.555)	(-0.498)
Log(percent arterials with lane widths of 12 ft. or greater)	-0.012	**0.084**	-	-	-0.151	0.137
	(-0.202)	**(0.765)**			(-1.204)	(0.455)
Log(percent collectors with lane widths of 9 ft. or less)	-0.021	-0.026	-	-	-0.017	0.003
	(-2.872)	(-2.287)			(-1.574)	(0.165)
Log(percent collectors with lane widths of 10 ft.)	0.028	-0.024	-	-	0.005	-0.117
	(1.514)	(-0.792)			(0.172)	(-2.280)
Log(percent collectors with lane widths of 11 ft.)	-0.027	-0.042	-	-	-0.008	-0.046
	(-2.906)	(-3.383)			(-0.745)	(-3.063)
Log(percent collectors with lane widths of 12 ft. or greater)	0.059	0.066	-	-	0.117	0.232
	(2.219)	(1.184)			(2.576)	(1.951)
Primary Seatbelt Law	-0.055	**-0.064**	-0.049	**-0.064**	-	-
	(-3.677)	**(-2.084)**	(-3.344)	**(-1.951)**		
Secondary Seatbelt Law	0.020	0.022	0.023	0.022	-	-
	(1.949)	(1.101)	(2.252)	(1.047)		
Log(percent seatbelt usage)	-	-	-	-	-0.133	-0.045
					(-4.607)	(-0.768)
Constant	16.548	-38.157	19.098	-53.205	5.135	-73.854
	(2.959)	(-4.173)	(3.609)	(-6.012)	(0.461)	(-4.246)
N	700	657	700	657	400	378
Log likelihood	-3305.28	-6033.55	-3319.18	-6069.13	-1678.20	-3252.31

Test statistic is in parentheses

Table 4
Coefficients on Lane Width Variables when Modelled Individually in Population Model

	Fatality Models	Injury Models
Percent Arterials with 9 ft or less Lane Widths	0.001 (0.103)	-0.035 (-4.130)
Percent Arterials with 10 ft Lane Widths	-0.029 (-2.758)	-0.063 (-3.988)
Percent Arterials with 11 ft Lane Widths	-0.025 (-2.252)	-0.064 (-4.026)
Percent Arterials with 12 ft or greater Lane Widths	0.091 (1.647)	0.310 (2.769)
Percent Collectors with 9 ft or less Lane Widths	-0.018 (-2.524)	-0.039 (-3.255)
Percent Collectors with 10 ft Lane Widths	0.007 (0.426)	-0.031 (-1.021)
Percent Collectors with 11 ft Lane Widths	-0.027 (-3.255)	-0.073 (-6.392)
Percent Collectors with 12 ft or greater Lane Widths	0.060 (2.606)	0.110 (2.232)

Test statistic is in parentheses

Table 5
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	+	*	+	weak -
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 6
Seatbelt Usage, fixed effects regression

	Percent seatbelt usage
Years of data	1990-1997
Primary Seatbelt Law	0.072 (2.855)
Secondary Seatbelt Law	0.112 (8.127)
Year	0.017 (11.540)
Constant	-32.974 (-11.396)
N	400
R-Sq	0.517

Test statistic is in parentheses

Table 7

Fixed Effect Negative Binomial Regressions with State Data (controlled for population), with Medical Technology variables

Aggregate State Data	Dependent Variable			
	DEATHS	INJURED	DEATHS	INJURED
	(A)	(B)	(C)	(D)
Years of data	1985-1996	1985-1996	1985-1996	1985-1996
Log(total lane miles)	0.435 (3.517)	0.743 (4.764)	0.411 (3.430)	0.826 (5.348)
Log(average number of interstate lanes)	-0.077 (-0.268)	2.681 (5.961)	-0.128 (-0.450)	2.543 (5.400)
Log(average number of arterial lanes)	0.119 (0.974)	**0.335** **(1.297)**	0.230 (1.987)	0.565 (2.021)
Log(average number of collector lanes)	1.813 (3.278)	0.174 (0.152)	1.569 (2.817)	0.196 (0.147)
Log(percent interstate lane miles)	0.095 (0.957)	***-0.155*** ***(-1.068)***	0.067 (0.683)	**-0.302** **(-2.042)**
Log(percent arterial lane miles)	0.196 (2.220)	0.360 (2.382)	0.219 (2.549)	0.582 (3.781)
Log(percent collector lane miles)	0.128 (1.581)	0.360 (3.464)	0.105 (1.285)	0.403 (3.777)
Log(per capita income)	1.222 (9.775)	0.785 (3.409)	1.228 (9.827)	0.844 (3.463)
Log(population)	0.129 (1.209)	-0.575 (-4.670)	0.227 (2.350)	-0.724 (-6.298)
Log(percent population aged 15-24)	0.638 (7.692)	0.786 (5.976)	0.649 (8.104)	0.762 (5.538)
Log(percent population over age 75)	-0.689 (-6.959)	-0.797 (-5.637)	-0.679 (-7.287)	-0.773 (-5.140)
Year	-0.007 (-1.852)	0.015 (2.540)	-0.006 (-1.746)	**0.019** **(3.266)**
Log(percent arterials with lane widths of 9 ft. or less)	0.009 (1.618)	-0.023 (-2.731)	-	-
Log(percent arterials with lane widths of 10 ft.)	-0.026 (-2.335)	-0.040 (-2.486)	-	-
Log(percent arterials with lane widths of 11 ft.)	-0.002 (-0.133)	0.005 (0.277)	-	-
Log(percent arterials with lane widths of 12 ft. or greater)	0.008 (0.125)	**0.147** **(1.143)**	-	-
Log(percent collectors with lane widths of 9 ft. or less)	-0.018 (-2.193)	-0.033 (-2.743)	-	-
Log(percent collectors with lane widths of 10 ft.)	0.002 (0.11)	-0.059 (-1.696)	-	-
Log(percent collectors with lane widths of 11 ft.)	-0.025 (-2.511)	-0.054 (-4.138)	-	-
Log(percent collectors with lane widths of 12 ft. or greater)	0.066 (2.108)	-0.035 (-0.514)	-	-
Primary Seatbelt Law	-0.043 (-2.471)	-0.059 (-1.581)	-0.035 (-2.017)	**-0.064** **(-1.643)**
Secondary Seatbelt Law	0.004 (0.368)	0.009 (0.451)	0.010 (0.954)	0.005 (0.211)
Log(inverse of white infant mortality rate)	-0.181 (-3.431)	0.007 (0.994)	-0.192 (-3.603)	0.058 (0.751)
Log(hospitals per square mile)	0.002 (0.769)	***0.008*** ***(1.350)***	0.002 (0.649)	0.006 (0.985)
Constant	-1.712 (-0.259)	-38.073 (-3.530)	-3.919 (-0.599)	-45.440 (-4.222)
N	597	558	597	558
Log likelihood	-2757.64	-5024.79	-2771.57	-5053.70

Test statistic is in parentheses

Table 7 (continued)
Fixed Effect Negative Binomial Regressions with State Data (controlled for population), with Medical Technology variables

Aggregate State Data	Dependent Variable			
	DEATHS	INJURED	DEATHS	INJURED
	(E)	(F)	(G)	(H)
Years of data	1985-1996	1985-1996	1990-1996	1990-1996
Log(total lane miles)	0.300	0.528	-0.049	1.185
	(2.675)	(3.984)	(-0.194)	(3.984)
Log(average number of interstate lanes)	-0.104	2.337	1.381	2.940
	(-0.378)	(5.358)	(3.100)	(3.262)
Log(average number of arterial lanes)	0.091	**0.347**	0.402	0.570
	(0.767)	**(1.323)**	(2.316)	(0.968)
Log(average number of collector lanes)	1.669	0.612	0.183	1.127
	(3.103)	(0.525)	(0.323)	(0.657)
Log(percent interstate lane miles)	0.062	**-0.277**	0.072	0.142
	(0.643)	**(-2.009)**	(0.394)	(0.458)
Log(percent arterial lane miles)	0.135	**0.235**	0.005	0.382
	(1.664)	**(1.617)**	(0.047)	(1.662)
Log(percent collector lane miles)	0.126	**0.298**	0.070	0.197
	(1.676)	**(2.835)**	(0.713)	(1.784)
Log(total ethanol consumed)	0.308	**-0.425**	-	-
	(4.353)	**(-3.806)**		
Log(per capita income)	1.057	0.994	1.283	0.988
	(8.298)	(3.984)	(6.598)	(2.430)
Log(population)	-	-	0.293	-1.155
			(1.533)	(-4.764)
Log(percent population aged 15-24)	0.501	0.895	0.947	1.310
	(5.628)	(6.399)	(5.518)	(4.380)
Log(percent population over age 75)	-0.605	-0.809	-0.274	-0.765
	(-5.998)	(-5.589)	(-1.148)	(-1.812)
Year	-0.003	**0.009**	-0.003	0.021
	(-0.888)	**(1.556)**	(-0.636)	(2.233)
Log(percent arterials with lane widths of 9 ft. or less)	0.008	-0.019	0.010	-0.026
	(1.562)	(-2.264)	(1.553)	(-2.813)
Log(percent arterials with lane widths of 10 ft.)	-0.025	-0.050	-0.009	0.016
	(-2.188)	(-3.209)	(-0.521)	(0.711)
Log(percent arterials with lane widths of 11 ft.)	-0.009	0.011	-0.009	0.033
	(-0.660)	(0.614)	(-0.515)	(1.257)
Log(percent arterials with lane widths of 12 ft. or greater)	-0.007	0.158	-0.068	0.108
	(-0.109)	(1.198)	(-0.528)	(0.334)
Log(percent collectors with lane widths of 9 ft. or less)	-0.015	-0.031	-0.009	-0.013
	(-1.807)	(-2.443)	(-0.734)	(-0.782)
Log(percent collectors with lane widths of 10 ft.)	0.001	**-0.067**	-0.012	-0.168
	(0.030)	**(-1.921)**	(-0.393)	(-3.166)
Log(percent collectors with lane widths of 11 ft.)	-0.020	-0.054	-0.002	-0.054
	(-2.102)	(-3.919)	(-0.128)	(-3.305)
Log(percent collectors with lane widths of 12 ft. or greater)	0.058	0.018	0.144	0.159
	(1.924)	(0.264)	(3.011)	(1.204)
Primary Seatbelt Law	-0.032	-0.069	-	-
	(-1.898)	(-1.837)		
Secondary Seatbelt Law	-0.001	0.009	-	-
	(-0.124)	(0.431)		
Log(percent seatbelt usage)	-	-	-0.159	-0.037
			(-5.206)	(-0.675)
Log(inverse of white infant mortality rate)	-0.184	-0.055	-0.147	0.043
	(-3.627)	(-0.699)	(-2.526)	(0.446)
Log(hospitals per square mile)	0.001	**0.009**	-0.001	-0.000
	(0.464)	**(1.551)**	(-0.181)	(-0.010)
Constant	-6.142	-32.405	-4.509	-48.095
	(-0.923)	(-2.937)	(-0.460)	(-2.643)
N	597	558	347	325
Log likelihood	-2749.48	-5028.50	-1405.50	-2714.21

Test statistic is in parentheses

Table 8
Fixed Effect Negative Binomial Regressions with State Data (controlled for VMT), with Medical Technology variables

Aggregate State Data	Dependent Variable					
	DEATHS	INJURED	DEATHS	INJURED	DEATHS	INJURED
	(A)	(B)	(C)	(D)	(G)	(H)
Years of data	1985-1996	1985-1996	1985-1996	1985-1996	1990-1996	1990-1996
Log(total lane miles)	0.471 (4.255)	0.529 (3.400)	0.472 (4.240)	0.644 (3.944)	0.079 (0.323)	0.584 (2.156)
Log(average number of interstate lanes)	-0.031 (-0.110)	2.410 (5.382)	-0.051 (-0.180)	2.233 (4.714)	1.520 (3.440)	2.530 (2.909)
Log(average number of arterial lanes)	0.080 (0.626)	0.428 (1.623)	0.176 (1.442)	0.683 (2.404)	0.396 (2.226)	0.480 (0.855)
Log(average number of collector lanes)	1.875 (3.362)	-0.365 (-0.332)	1.646 (2.897)	-0.501 (-0.379)	0.276 (0.479)	0.143 (0.088)
Log(percent interstate lane miles)	0.090 (0.888)	**-0.232** **(-1.623)**	0.037 (0.368)	-0.338 (-2.247)	0.121 (0.657)	-0.395 (-1.391)
Log(percent arterial lane miles)	0.223 (2.738)	0.189 (1.303)	0.274 (3.471)	0.399 (2.645)	0.053 (0.489)	0.055 (0.248)
Log(percent collector lane miles)	0.147 (1.904)	0.371 (3.401)	0.153 (1.991)	**0.437** **(3.804)**	0.105 (1.101)	0.207 (1.598)
Log(per capita income)	1.175 (8.824)	0.867 (3.541)	1.140 (8.439)	1.005 (3.860)	1.274 (6.127)	0.752 (1.728)
Log(VMT)	0.08 (1.055)	-0.349 (-2.986)	0.143 (1.927)	-0.535 (-4.389)	0.078 (0.559)	-0.577 (-2.621)
Log(percent population aged 15-24)	0.628 (7.516)	0.799 (5.855)	0.614 (7.653)	0.822 (5.666)	0.967 (5.600)	1.141 (3.462)
Log(percent population over age 75)	-0.689 (-6.927)	-0.780 (-5.500)	-0.657 (-6.971)	-0.801 (-5.348)	-0.273 (-1.065)	-1.049 (-2.747)
Year	-0.008 (-2.069)	**0.021** **(3.374)**	-0.009 (-2.392)	0.031 (4.957)	-0.004 (-0.640)	0.035 (3.361)
Log(percent arterials with lane widths of 9 ft. or less)	0.008 (1.580)	-0.022 (-2.610)	-	-	0.009 (1.328)	-0.027 (-2.456)
Log(percent arterials with lane widths of 10 ft.)	-0.026 (-2.327)	-0.047 (-2.810)	-	-	-0.009 (-0.589)	-0.007 (-0.242)
Log(percent arterials with lane widths of 11 ft.)	-0.001 (-0.090)	0.000 (0.006)	-	-	-0.007 (-0.427)	0.012 (0.492)
Log(percent arterials with lane widths of 12 ft. or greater)	0.010 (0.154)	**0.151** **(1.136)**	-	-	-0.081 (-0.626)	0.80 (0.242)
Log(percent collectors with lane widths of 9 ft. or less)	-0.021 (-2.640)	-0.026 (-2.041)	-	-	-0.012 (-0.987)	0.002 (0.106)
Log(percent collectors with lane widths of 10 ft.)	0.002 (0.096)	-0.067 (-1.895)	-	-	-0.019 (-0.612)	-0.171 (-3.139)
Log(percent collectors with lane widths of 11 ft.)	-0.027 (-2.798)	-0.048 (-3.711)	-	-	-0.005 (-0.426)	-0.051 (-3.281)
Log(percent collectors with lane widths of 12 ft. or greater)	0.057 (1.840)	0.038 (0.563)	-	-	0.134 (2.712)	0.264 (1.958)
Primary Seatbelt Law	-0.043 (-2.400)	-0.075 (-2.065)	-0.036 (-2.012)	**-0.083** **(-2.106)**	-	-
Secondary Seatbelt Law	0.003 (0.299)	0.012 (0.566)	0.008 (0.693)	0.014 (0.631)	-	-
Log(percent seatbelt usage)	-	-	-	-	-0.159 (-5.189)	-0.038 (-0.582)
Log(inverse of white infant mortality rate)	-0.164 (-3.220)	-0.056 (-0.693)	-0.160 (-3.122)	-0.005 (-0.057)	-0.127 (-2.269)	-0.023 (-0.215)
Log(hospitals per square mile)	0.002 (0.759)	0.009 (1.503)	0.002 (0.671)	0.007 (1.169)	-0.001 (-0.310)	0.002 (0.214)
Constant	2.176 (0.298)	-53.878 (-4.471)	3.940 (0.552)	-73.046 (-6.214)	-1.231 (-0.105)	-79.603 (-3.997)
N	597	558	597	558	347	325
Log likelihood	-2757.81	-5031.30	-2772.44	-5063.20	-1406.49	-2721.56

Test statistic is in parentheses

Table 9

Estimated Changes in Fatalities and Injuries using Elasticity Values from Population-based Models

Results from Models 7-A and 7-B	Fatality Elasticity	Injury Elasticity	Change in 1985 fatalities with 1996 values of each variable	Change in 1985 injuries with 1996 values of each variable
Total Lane Miles	0.435	0.743	378	50867
Average Interstate Lanes	*	2.681	*	256943
Average Arterial Lanes	0.119	*	125	*
Average Collector Lanes	1.813	*	-28	*
Percent Interstate Lane Miles	*	*	*	*
Percent Arterial Lane Miles	0.196	0.360	749	108394
Percent Collector Lane Miles	*	0.360	*	-40940
Percent Arterials with 9 ft or less Lane Widths	*	-0.023	*	38551
Percent Arterials with 10 ft Lane Widths	-0.026	-0.040	297	36041
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	-0.018	-0.033	252	36372
Percent Collectors with 10 ft Lane Widths	*	-0.059	*	26118
Percent Collectors with 11 ft Lane Widths	-0.025	-0.054	-134	-22837
Percent Collectors with 12 ft or greater Lane Widths	0.066	*	610	*
Total for Lane Width Variables			**1025**	**114245**
Total for Infrastructure Variables			**2249**	**489509**
Average Inverse White Infant Mortality	-0.181	*	-4158	*
Average Per Capita Income	1.222	0.785	10707	542071
Total Population	*	-0.575	*	*
Total Percent aged 15-24	0.638	0.786	-5258	-510561
Total Percent aged over 75	-0.689	-0.797	-4948	-451122
Seatbelt Use (model 7-G, 7-H)	-0.159	-0.037	-15574	-285634

* Not significant at 90% level

Table 10
Estimated Changes in Fatalities and Injuries using Elasticity Values from VMT-based Models

Results from Models 8-A and 8-B	Fatality Elasticity	Injury Elasticity	Change in 1985 fatalities with 1996 values of each variable	Change in 1985 injuries with 1996 values of each variable
Total Lane Miles	0.471	0.529	409	36216
Average Interstate Lanes	*	2.410	*	230970
Average Arterial Lanes	*	0.428	*	35437
Average Collector Lanes	1.875	*	-29	*
Percent Interstate Lane Miles	*	-0.232	*	-45984
Percent Arterial Lane Miles	0.223	*	852	*
Percent Collector Lane Miles	0.147	0.371	-210	-41727
Percent Arterials with 9 ft or less Lane Widths	*	-0.022	*	36874
Percent Arterials with 10 ft Lane Widths	-0.026	-0.047	297	42348
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	-0.021	-0.026	294	28657
Percent Collectors with 10 ft Lane Widths	*	-0.067	*	*
Percent Collectors with 11 ft Lane Widths	-0.027	-0.048	-145	-20299
Percent Collectors with 12 ft or greater Lane Widths	0.057	*	527	*
Total for Lane Width Variables			**973**	**87580**
Total for Infrastructure Variables			**1995**	**302492**
Average Inverse White Infant Mortality	-0.164	*	-3767	*
Average Per Capita Income	1.175	0.867	10295	598695
Total VMT	0.08	-0.349	1398	-480597
Total Percent aged 15-24	0.628	0.799	-5176	-519006
Total Percent aged over 75	-0.689	-0.780	-4948	-441499
Seatbelt Use (model 8-G, 8-H)	-0.159	-0.038	-15574	-293354

* Not significant at 90% level

Figure 1
Trade-offs Between Safety and Mobility

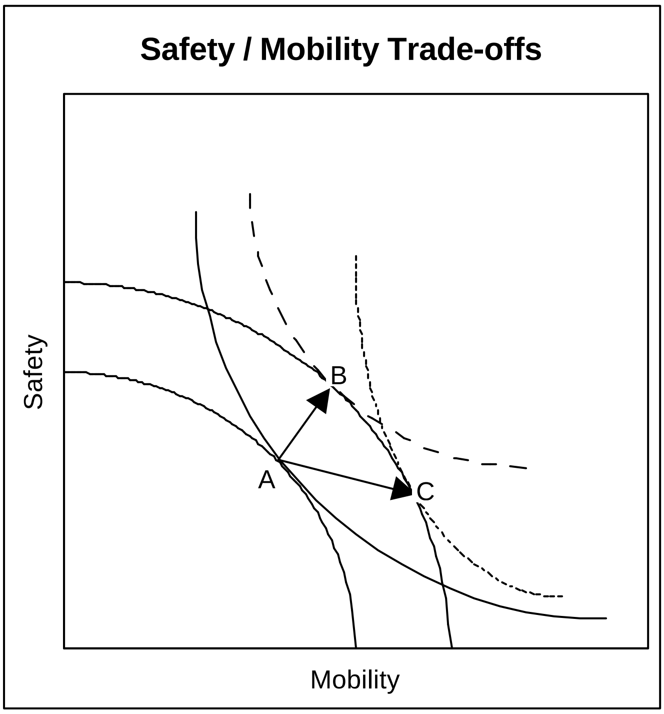

Figure 2
Trends in US Traffic Fatalities and Injuries (index = 100 in 1967)