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EFFECTS OF THE 65 MPH SPEED LIMIT ON INJURY MORBIDITY AND MORTALITY*

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Abstract—Effective December 1987 and January 1988, the maximum speed limit on rural limited access highways in Michigan was raised from 55 mph to 65 mph. This study examined the effects of the raised limit on injury morbidity and mortality. A multiple time-series design was used, comparing roads where the speed limit was raised with roads where the limit remained unchanged. Data were collected on numbers and rates of automobile crashes, injuries, and deaths from January 1978 through December 1988. Time-series intervention analyses were conducted to estimate effects associated with the speed limit change while controlling for long-term trends, seasonal cycles, and other patterns. Statistical controls were also included for major factors known to influence crash and injury rates. Results revealed significant increases in casualties on roads where the speed limit was raised, including a 19.2% increase in fatalities, a 39.8% increase in serious injuries, and a 25.4% increase in moderate injuries. Fatalities also increased on 55 mph limited access freeways, suggesting that the 65 mph limit may have spillover effects on segments of freeways where the limit was not changed. No significant changes in fatalities or injuries were found on other types of roads. The increased convenience of reduced travel time with the higher speed limit is obtained at a significant cost in terms of injury morbidity and mortality.

We measured the effects on morbidity and mortality due to motor vehicle crashes of raising the maximum speed limit from 55 mph to 65 mph on Michigan's rural interstate highways and other rural highways built to interstate standards. In April 1987, U.S. Senate Bill HR-2 was passed permitting states to raise the maximum speed limit to 65 mph on rural interstates. Michigan's governor signed Public Act 154 of 1987 on October 29, 1987, increasing speed limits on segments of Michigan's rural interstate highways from 55 to 65 mph, with no change in the minimum allowable speed of 45 mph. New speed limit signs were in place and the speed limit was officially increased to 65 mph on Michigan's rural interstate system on November 27, 1987. Furthermore, as a part of the massive budget reconciliation package passed in late December 1987, the U.S. Congress authorized a four-year demonstration project in which 20 states were permitted to increase maximum speed limits from 55 to 65 mph on *non*interstate highways built to interstate standards. Michigan chose to participate in the demonstration project, and 65 mph speed limit signs were in place and the new limit was in force on all affected sections of rural noninterstate highways by the end of January 1988.

There are two major dimensions of the expected effects of the speed limit on crash involvement: average speed and variance in speeds. Higher speeds produce greater impact forces in crashes, increasing the probability of serious injury or death. Assuming that a vehicle strikes a fixed, unmoving object (such as a bridge abutment), the kinetic energy of the occupants must be dissipated in a fraction of a second. If vehicle occupants are not wearing safety belts, this energy will be dissipated by the body against the windshield, dashboard, steering column, or against a seat-back. Since the kinetic energy increases with the square of the speed, increased speed disproportionately increases the

*This study was conducted while the senior author was at the University of Michigan Transportation Research Institute.

probability that occupants are injured. According to estimates of Giamotty and associates (1980), a crash with an impact speed of 40 mph is *twice* as likely to result in serious injury (overall AIS greater than 2) than a crash with an impact speed of 30 mph. In short, if raising the speed limit to 65 mph increases average speeds on the road, the average speed at impact in traffic crashes would likely increase, with a consequent increase in probability of serious injury or death resulting from those crashes. In addition, higher speeds reduce the time available for drivers to execute avoidance maneuvers, potentially increasing the number of crashes.

A second potential effect of raising the speed limit is increased speed variance. Speed variance refers to the distribution of speeds present on a given road in a given area. That is, how many cars are going faster or slower than the average speed? An increase in the proportion of vehicles on the road that are traveling significantly slower or faster than the average speed increases the probability of traffic crashes (Lave 1985; Garber and Gadirau 1988). Conversely, having all vehicles traveling at the same speed reduces the probability of traffic crashes. The role of changing the speed limit on speed variance is not fully understood. There is a general statistical phenomenon that the variance of a measure increases as the mean increases. Based on this common pattern, an increase in average speed resulting from raising the speed limit would also be expected to increase the variance in speeds. This is intuitively reasonable, since some drivers, who prefer driving at 55 mph, will continue to do so after the limit is raised. Other drivers will take advantage of the raised limit to increase their speeds. The result is increased speed variance, which is likely to increase the number of crashes. In short, if the 65 mph limit increases speed variance, a possible result is an increased number of traffic crashes, causing an increase in the number of motorists killed or injured.

Design speed may also influence how the speed limit change affects speed variance. Design speed is "the maximum safe speed that can be maintained over a specified section of highway when conditions are favorable such that the design features of the highway govern" (Garber and Gadirau 1988). Garber and Gadirau found that speed variance increased as the difference between the posted speed limit and the design speed of the road segment increased. Perhaps this is because drivers tend to increase their driving speed as the geometric characteristics of the roadway improve, regardless of the posted speed limit. Speed variance was found to be at a minimum on road segments where the posted speed limit was 6 to 12 mph below the design speed. If this pattern holds true across jurisdictions and across time, raising the speed limit would not increase speed variance as much as otherwise expected, and would not have as deleterious effects on injury morbidity and mortality as expected. To help isolate the effects of the raised speed limit, average speed and speed variance, we examined both numbers of traffic crashes and levels of injury severity. But we did not collect detailed information on design speed and speed variance by road segment. Therefore, our results show the effects of the raised limit on injury outcomes, but do not fully resolve questions regarding the relative contribution of changes in average speed or speed variance to observed increases in morbidity and mortality.

Several studies of the effect of the recent United States policy change permitting states to raise the speed limit from 55 to 65 mph have appeared. These reports indicate the following effects on roads with raised speed limits: 20% increase in fatal and serious-injury crashes in Texas (Brackett and Pendleton 1988), 18% increase in crashes in Alabama (Brown et al. 1989), 93% increase in the fatal crash rate in New Mexico (Gallaher et al. 1989), 15% aggregate increase in fatalities in 38 states that raised the limit (Baum et al. 1989), 14% aggregate increase in fatalities in 38 states that raised the limit (National Highway Traffic Safety Administration 1989), 15% aggregate increase in fatalities in 40 states that raised the limit (Garber and Graham 1990), and 27% aggregate increase in fatalities in 20 states that raised the limit (McKnight et al. 1989). Results are not consistent across states, and some of these findings are based on suspect analytic methods, such as use of chi-squared tests and analysis of variance techniques on serially correlated time-series data.

METHODS

Research design

Alternate explanations for observed changes in morbidity and mortality at the time of the speed limit change were controlled in three ways. First, a monthly time-series design was used to control for multi-year trends, seasonal cycles, and other regular patterns in the outcome variables. Measurement of a significant change beginning in the exact month the speed limit was raised strengthens the argument that observed differences were due to changes in speed limit.

Second, the time-series statistical models included several covariates, such as vehicle miles traveled, unemployment, and alcohol consumption, to control for their effects on deaths, injuries, and property damage. Inclusion of covariates in the time-series models further increase confidence that observed differences are a result of changes in speed limit. In addition, effects of other major policy changes known to influence injury rates, such as a compulsory safety belt law, were statistically controlled.

Third, multiple comparison time series were used to increase confidence that the raised speed limit is responsible for observed changes in morbidity and mortality. Comparisons were made between specific road segments where the speed limit was raised and roads where the limit remained unchanged. Specifically, we compared changes in the outcome measures for road segments where the limit was raised to 65 mph with (1) limited access highway road segments where the limit remained at 55 mph and (2) all other roads, where existing speed limits remained unchanged. The primary effects of the new 65 mph limit were expected only on those segments with the higher limit. While there may be some spillover effects on other road segments where the speed limit remained unchanged, any such spillover effects were expected to be small compared to the primary effects.

Data collection

Data on motor vehicle crashes from January 1978 through December 1988 were obtained from the Michigan State Police. Records were available on all traffic crashes occurring in Michigan reported to any state, county, or municipal police agency. Cases included in all time series were filtered to exclude motor vehicle crashes involving pedestrians and/or pedalcycles, since the raised speed limit is unlikely to affect the behavior of pedestrians and pedalcyclists. Each crash and injury record was stratified by whether the crash occurred on a section of limited-access highway currently posted at 65 mph, a section of limited-access highway where the speed limit remained 55 mph, or another class of road. Furthermore, we stratified outcome measures by crash configuration (single-vehicle, car-car, car-truck), vehicle damage level, and gender, age, and injury severity of crash victims.*

Covariates used in the monthly time-series models include implementation of an adult safety belt law in July 1985, estimated number of vehicle miles traveled in the state, proportion of licensed drivers under age 25, aggregate beer consumption in the state, and percentage of the labor force unemployed. Data on vehicle miles traveled and the number of licensed drivers by age and gender were obtained from the Federal Highway Administration. Monthly wholesale beer distribution figures were obtained from the U.S. Beer Institute. Data on percentage of the labor force unemployed were obtained from the Michigan Department of Management and Budget.

Finally, quarterly data on measured speeds of vehicles on the road were obtained from the Michigan Department of Transportation for the 1982–1988 period. Data are collected with pneumatic tube speed measuring devices at some locations and permanent magnetic speed loops imbedded in the pavement at other locations. Speeds are sampled

*Specific operational definitions and univariate distributions for all variables are available from the authors.

at 44 sites each year.* Approximately one-third of these sites are sampled quarterly, with the remaining sampled annually. We identified the location of each sample site and the current posted speed limit at each site to assess changes in driving speeds on the road segments where the limit was raised to 65 mph.

Statistical analyses

The goal of the time-series analyses was to estimate changes in the frequency of crashes, injuries, and deaths associated with raising speed limits from 55 to 65 mph. Box-Jenkins and Box-Tiao methods were employed to control for long-term trends and seasonal cycles, and to estimate changes beginning the first month the increased speed limit took effect (Box and Jenkins 1976; Box and Tiao 1975). The Box-Jenkins approach is a versatile time-series modeling strategy that can model a wide variety of trend, seasonal, and other recurring patterns.

At a conceptual level, the analytic strategy involves explaining as much of the variance in each variable as possible on the basis of its past history, before attributing any of the variance to another variable, such as the increased speed limit. The intervention-analysis approach is particularly appropriate for this study, because the objective was to identify significant changes in injury morbidity and mortality associated with the increased speed limit, independent of observed regularities in the history of each variable. Controlling for baseline trends and cycles with time-series models avoids biased standard error estimates that typically result from the use of conventional statistical procedures on time-series data, violating assumptions of independence.

After controlling for long-term trends, cycles, and other regularities with ARIMA models, we added an intervention step function for the month the speed limit was raised, to estimate the associated change in each outcome variable. We added a second intervention function to the time-series models to estimate the anticipatory effect of the policy change. Considerable debate and media coverage of the speed limit issue occurred throughout 1987, as bills were introduced, passed, and signed at the federal and state level. The resulting publicity may have resulted in a small portion of the law's effects occurring before the law actually took effect. To determine whether this was the case, we constructed a second intervention variable a priori, based on knowledge of publicity concerning the speed limit. The anticipatory effect variable had the value zero from January 1978 through December 1986 (Fig. 1). It incremented .01 per month from January through March 1987, because of publicity surrounding discussions of possible speed limit increase legislation. An additional increment of .31 was added in April to account for the sudden increase in publicity associated with the April congressional override of the president's veto of the bill raising the speed limit. An additional .02 per month increment was added for May through September, representing the Michigan discussion and debate of a proposed increase in speed limit. An increment of .52 was added in October 1987, the month Governor Blanchard signed the bill raising the speed limit. Finally, an increment of .04 was added for November 1987, such that all monthly increments summed to 1.0.

A number of covariates were included in the time-series models to account for changes in casualties due to other factors. Covariates included Michigan's compulsory safety belt use law, aggregate vehicle miles traveled, proportion of the licensed driver population under age 25, beer consumption, and unemployment. These variables are potential confounding factors because of established associations with traffic crash involvement. The safety belt law significantly reduced injury rates in Michigan (Streff et al. 1990). Aggregate vehicle miles traveled is a major index of exposure to risk of injury (Jovanis and Chang 1986). The proportion of young drivers influences injury rates because of the overrepresentation of young drivers in traffic crashes (Wagenaar 1983). A measure of alcohol consumption was included because of the substantial proportion of crashes that involve alcohol-impaired drivers (National Highway Traffic Safety Admin-

*Data on measured travel speeds are classified missing for the first quarter of 1986 and the first quarter of 1987 due to problems with the monitoring equipment.

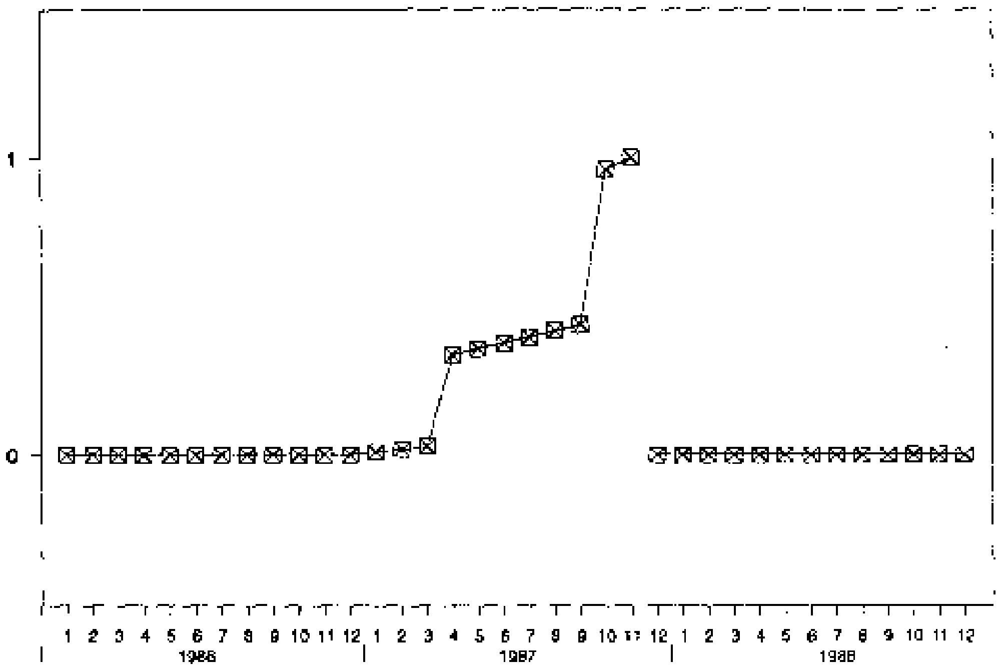

Fig. 1. Functional form of anticipatory effect variable.

istration 1988). Wholesale beer distribution was selected as the measure of alcohol consumption in preference to total absolute alcohol from all beverages (beer, wine, and distilled spirits) because the majority of impaired drivers are impaired as a result of beer consumption (Berger and Snortum 1985). Furthermore, previous research has documented the relationship between wholesale beer distribution and the number of traffic crashes (at lags of zero to two months) (Wagenaar 1984a). Finally, the unemployment

Table 1. Effects of increase in maximum speed limit: Results from time-series models with anticipatory and implementation effects

	Estimate	Standard error	Percent change	90% Confidence Interval	
				Low	High
Fatalities					
65 MPH highways					
ARIMA (0, 0, 5) (0, 1, 1)$_{12}$ $R^2 = 0.03$					
Anticipatory effect	0.2881	0.2998			
Implementation effect	0.1754	0.1094	19.2	−0.5	42.7
55 limited access highways					
ARIMA (0, 0, 0) (0, 1, 1)$_{12}$ $R^2 = 0.17$					
Anticipatory effect	0.3021	0.3025			
Implementation effect	0.3251*	0.1454	38.4	9.0	75.8
All other roads					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$ $R^2 = 0.72$					
Anticipatory effect	0.0719	0.1278			
Implementation effect	0.0750	0.1085	7.8	−9.8	28.9
Serious injuries					
65 MPH highways					
ARIMA (0, 0, 0) (0, 1, 1)$_{12}$ $R^2 = 0.46$					
Anticipatory effect	0.4937*	0.1424			
Implementation effect	0.3353*	0.0581	39.8	27.1	53.9
55 limited access highways					
ARIMA (0, 1, 8) (0, 1, 1)$_{12}$ $R^2 = 0.31$					

Table 1. (Continued)

	Estimate	Standard error	Percent change	90% Confidence Interval	
				Low	High
Anticipatory effect	0.2742	0.1719			
Implementation effect	0.0292	0.1566	3.0	20.4	33.2
All other roads					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$ $R^2 = 0.89$					
Anticipatory effect	0.0659	0.0861			
Implementation effect	0.0851	0.0874	8.9	5.7	25.7
Moderate injuries					
65 MPH highways					
ARIMA (0, 0, 7) (0, 1, 1)$_{12}$ $R^2 = 0.50$					
Anticipatory effect	0.2191*	0.1232			
Implementation effect	0.2266*	0.0609	25.4	13.5	38.6
55 limited access highways					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$ R^2 0.38					
Anticipatory effect	0.0412	0.1477			
Implementation effect	0.0254	0.1339	2.5	21.5	21.1
All other roads					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$ $R^2 = 0.88$					
Anticipatory effect	0.0526	0.0709			
Implementation effect	0.0294	0.0731	3.0	−8.7	16.1
Minor injuries					
65 mph highways					
ARIMA (0, 0, 7) (0, 1, 1)$_{12}$ R 0.66					
Anticipatory effect	0.2197	0.1735			
Implementation effect	0.0892	0.0955	9.3	6.6	27.9
55 limited access highways					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$ $R^2 = 0.57$					
Anticipatory effect	0.1188	0.1608			
Implementation effect	0.0715	0.1472	7.4	−15.7	36.8
All other roads					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$ $R^2 = 0.77$					
Anticipatory effect	0.0626	0.0857			
Implementation effect	0.0510	0.0853	5.2	−8.5	21.1
Property damage only crashes					
65 mph highways					
ARIMA (0, 0, 1) (0, 1, 1)$_{12}$ $R^2 = 0.82$					
Anticipatory effect	0.1479	0.1235			
Implementation effect	0.1491*	0.0618	16.1	4.9	28.5
55 limited access highways					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$ R^2 0.80					
Anticipatory effect	0.1284	0.1686			
Implementation effect	0.1090	0.1690	11.5	−15.5	47.3
All other roads					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$ $R^2 = 0.83$					
Anticipatory effect	0.1081	0.1233			
Implementation effect	0.1147	0.1304	12.2	−9.5	39.0

*Statistically significant at $p < .05$, one-tailed test.

rate was included (with lags of zero to four months) because previous research has shown its relationship with motor vehicle crash involvement (Joksch 1984; Partyka 1984; Wagenaar 1984b; Evans and Graham 1988; Wagenaar and Streff 1989).

RESULTS

Results clearly revealed significant increases in crash-induced injuries on road segments where the maximum speed limit increased from 55 mph to 65 mph (Table 1,

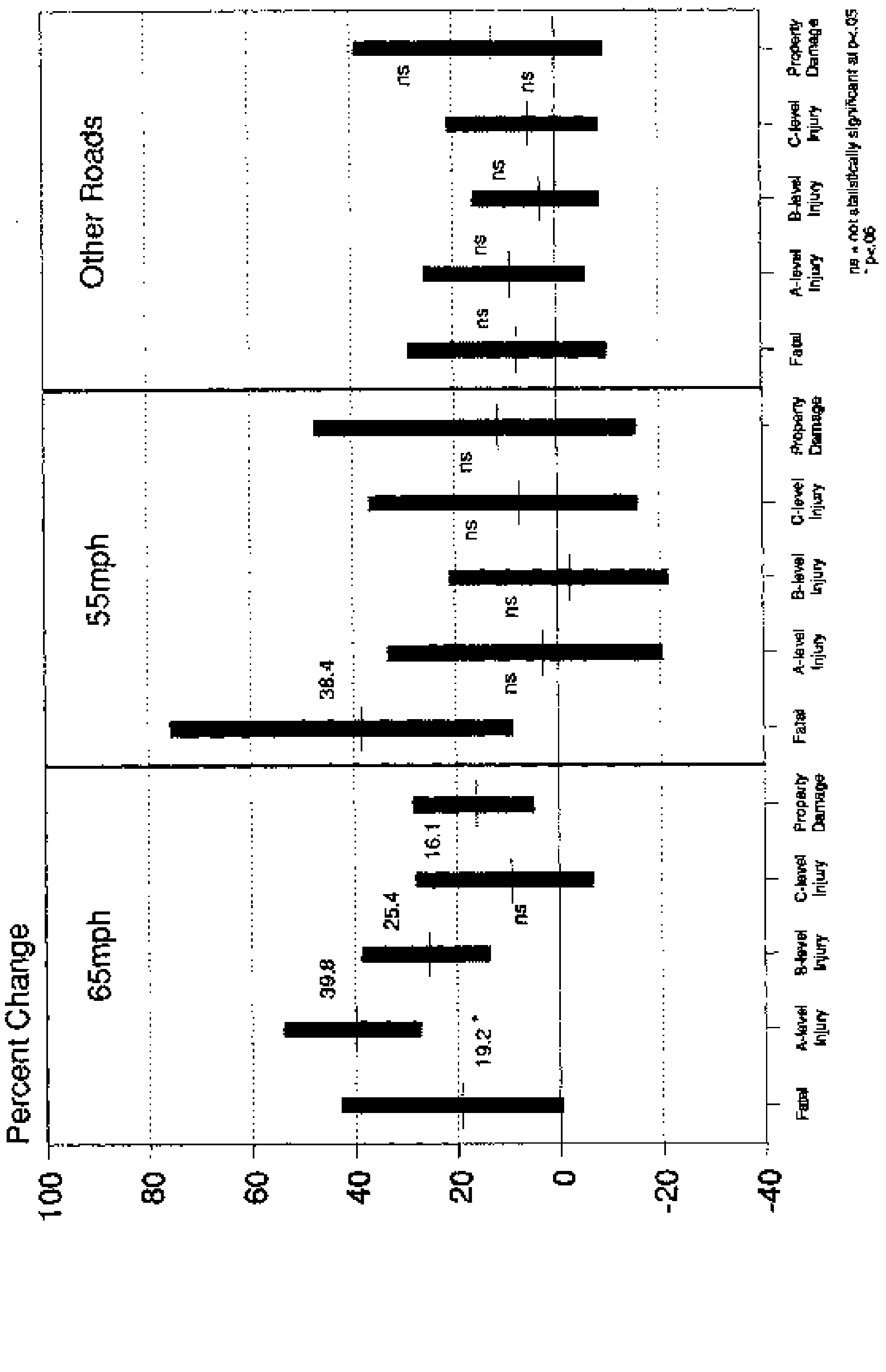

Fig. 2. Effects of increase in maximum speed limit by injury severity.

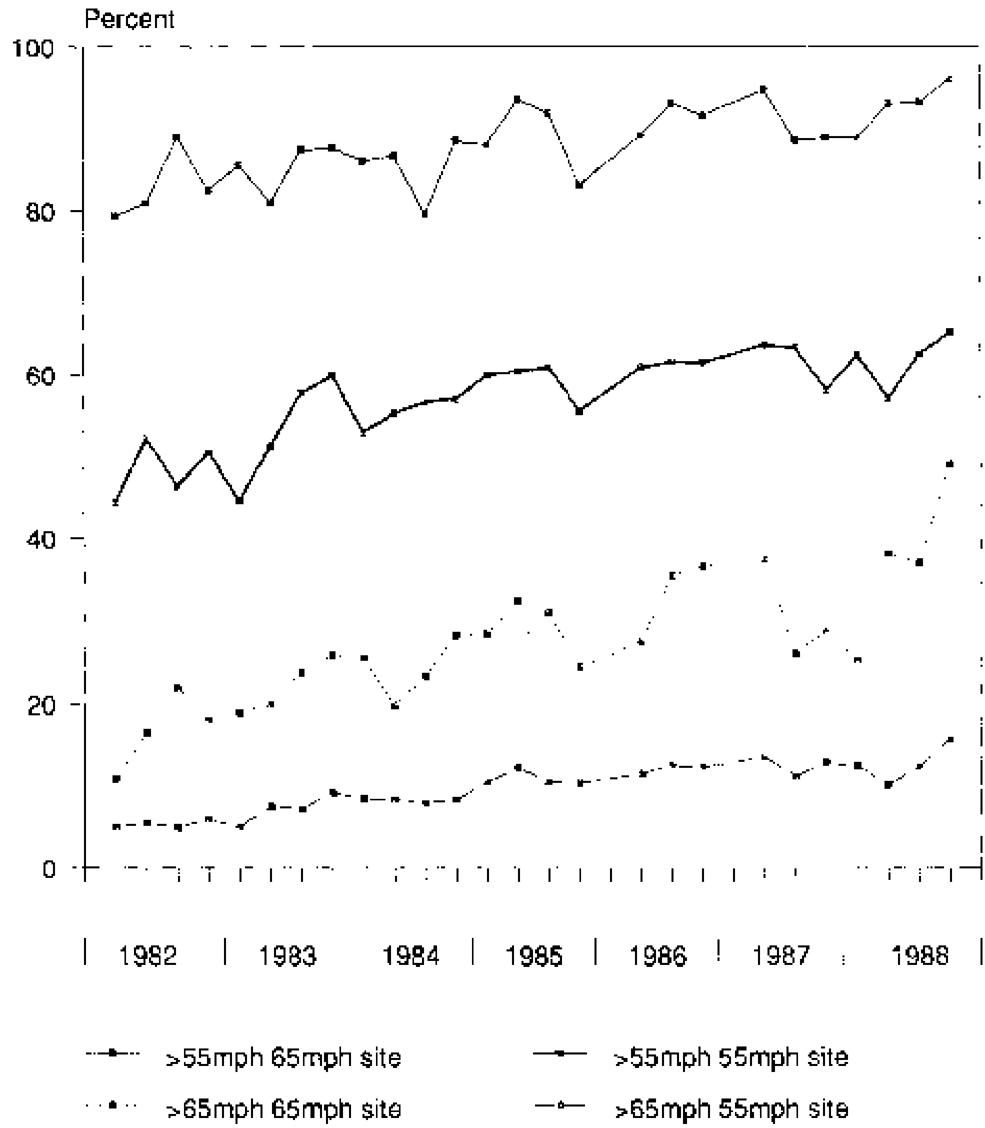

Fig. 3. Travel speeds measured at 55 sites throughout Michigan: 1982–1988.

Figure 2). Effects attributable to the increased speed limit include a 39.8% ($p < .05$) increase in serious (A-level) injuries and a 25.4% ($p < .05$) increase in moderate (B-level) injuries on road segments with the 65 mph limit. The number of minor (C-level) injuries did not change significantly. The number of vehicles involved in property-damage-only crashes increased 16.1% ($p < .05$) after the limit was increased. Finally, the number of deaths on freeways with the 65 mph limit increased 19.2% ($p < .06$) and fatalities on limited access freeways posted at 55 mph increased 38.4% ($p < .05$).

We believe these results reflect increased morbidity, mortality, and property damage causally attributable to the policy raising the speed limit for two reasons. First, the increases began immediately after the signs for the higher speed limit were posted. Second, with the notable exception of fatalities on limited access highways that remained at 55 mph, the increases were only found on those specific road segments where the posted speed limit was changed. However, it is important to notice the size of the confidence intervals shown in Fig. 2 and the size of the standard errors in Tables 1 through 4. Specific pairwise comparisons between two particular road class/injury severity estimates are in most cases not statistically significant. For example, our results do not demonstrate that the raised speed limit increased A-level injuries significantly more than it increased B-level injuries. The reason for the relatively large standard errors

Table 2. Effects of increase in maximum speed limit: Results from time-series models with implementation effect only

	Estimate	Standard Error	Percent Change	90% Confidence Interval	
				Low	High
Fatalities					
65 mph highways					
ARIMA (0, 0, 5) (0, 1, 1)$_{12}$					
$R^2 = 0.03$					
Implementation effect	0.1699	0.1089	18.5	−0.9	41.8
55 limited access highways					
ARIMA (0, 0, 0) (0, 1, 1)$_{12}$					
$R^2 = 0.18$					
Implementation effect	0.2796*	0.1381	32.3	5.4	66.0
All other roads					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
$R^2 = 0.72$					
Implementation effect	0.0353	0.0819	3.6	−9.5	18.5
Serious injuries					
65 mph highways					
ARIMA (0, 0, 0) (0, 1, 1)$_{12}$					
$R^2 = 0.41$					
Implementation effect	0.3128*	0.0624	36.7	23.4	51.5
55 limited access highways					
ARIMA (0, 1, 8) (0, 1, 1)$_{12}$					
$R^2 = 0.30$					
Implementation effect	−0.1424	0.1094	−13.3	−27.6	3.8
All other roads					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
$R^2 = 0.89$					
Implementation effect	0.0334	0.055	3.4	−5.5	13.2
Moderate injuries					
65 mph highways					
ARIMA (0, 0, 7) (0, 1, 1)$_{12}$					
$R^2 = 0.49$					
Implementation effect	0.2028*	0.0606	22.5	10.9	35.3
55 limited access highways					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
$R^2 = 0.38$					
Implementation effect	−0.0505	0.0949	−4.9	−18.7	11.1
All other roads					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
$R^2 = 0.88$					
Implementation effect	−0.0120	0.0453	−1.2	−8.3	6.4
Minor injuries					
65 mph highways					
ARIMA (0, 0, 7) (0, 1, 1)$_{12}$					
$R^2 = 0.66$					
Implementation effect	0.0456	0.0896	4.7	9.7	21.3
55 limited access highways					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
$R^2 = 0.57$					
Implementation effect	−0.0052	0.1041	−0.5	−16.2	18.1
All other roads					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
$R^2 = 0.77$					
Implementation effect	0.0054	0.055	0.5	−8.2	10.1
Property damage only crashes					
65 mph highways					
ARIMA (0, 0, 1) (0, 1, 1)$_{12}$					
$R^2 = 0.82$					
Implementation effect	0.1254*	0.0589	13.4	2.9	24.9
55 limited access highways					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
$R^2 = 0.80$					
Implementation effect	0.0124	0.1093	1.2	−15.4	21.2
All other roads					
ARIMA (0, 1, 1) (0, 1, 1)$_{12}$					
$R^2 = 0.83$					
Implementation effect	−0.0340	0.0795	−3.3	−15.2	10.2

*Statistically significant at $p < .05$, one-tailed test.

Table 3. Differential effects of increase in maximum speed limit to 65 mph by crash configuration, vehicle damage level, gender, and age

	Estimate	Standard error	Percent change	90% confidence interval	
				Low	High
Crash configuration					
Single vehicle					
ARIMA $(0, 1, 1)(0, 1, 1)_{12}$					
$R^2 = 0.86$					
Anticipatory effect	0.1812	0.1347			
Implementation effect	0.2051*	0.1096	22.8	2.5	47.0
Car-car					
ARIMA $(0, 1, 1)(0, 1, 1)_{12}$					
$R^2 = 0.71$					
Anticipatory effect	0.1718	0.2195			
Implementation effect	0.1296	0.1966	13.8	−17.6	57.3
Car-truck					
ARIMA $(0, 1, 1)(0, 1, 1)_{12}$					
$R^2 = 0.76$					
Anticipatory effect	0.0195	0.1704			
Implementation effect	0.0096	0.1383	1.0	19.6	26.8
Vehicle damage level					
Low					
ARIMA $(0, 0, 1)(0, 1, 1)_{12}$					
$R^2 = 0.81$					
Anticipatory effect	0.0930	0.1253			
Implementation effect	0.1258*	0.0625	13.4	2.3	25.7
Medium					
ARIMA $(0, 0, 1)(0, 1, 1)_{12}$					
$R^2 = 0.81$					
Anticipatory effect	0.1167	0.1300			
Implementation effect	0.1198*	0.0643	12.7	1.4	25.3
High					
ARIMA $(0, 1, 1)(0, 1, 1)_{12}$					
$R^2 = 0.69$					
Anticipatory effect	0.2015	0.1484			
Implementation effect	0.1447	0.1156	15.6	−4.4	39.8
Gender					
Male Driver Rate					
ARIMA $(0, 0, 0)(0, 1, 1)_{12}$					
$R^2 = 0.77$					
Anticipatory effect	0.1284	0.1123			
Implementation effect	0.1193*	0.0533	12.7	3.2	23.0
Female Driver Rate					
ARIMA $(0, 0, 0)(0, 1, 1)_{12}$					
$R^2 = 0.83$					
Anticipatory effect	0.2359*	0.1211			
Implementation effect	0.1481*	0.0599	16.0	5.1	28.0
Age					
Age 15–24 rate					
ARIMA $(0, 1, 1)(0, 1, 1)_{12}$					
$R^2 = 0.77$					
Anticipatory effect	0.0961	0.2075			
Implementation effect	0.1847	0.2058	20.3	−14.3	68.7
Age 25–55 rate					
ARIMA $(0, 1, 1)(0, 1, 1)_{12}$					
$R^2 = 0.81$					
Anticipatory effect	0.2201	0.1420			
Implementation effect	0.1728	0.1070	18.9	−0.3	41.7
Age 56+ rate					
ARIMA $(0, 1, 1)(0, 1, 1)_{12}$					
$R^2 = 0.68$					
Anticipatory effect	0.2834*	0.1381			
Implementation effect	0.1757*	0.0783	19.2	4.8	35.6
Total Vehicles Crashed					
ARIMA $(0, 1, 1)(0, 1, 1)_{12}$					
$R^2 = 0.80$					
Anticipatory effect	0.1534	0.1496			
Implementation effect	0.1553	0.1241	16.8	4.8	43.3

*Statistically significant at $p < .05$, one-tailed test.

is the availability of only 12 months of data after the intervention. In time-series models, standard errors are the smallest (all else equal) if the intervention occurs in the middle of the series. Thus, when we have 10 years of postintervention data available, to complement the 10 years of baseline data used, we will be able to specify the differential effects of the increased speed limit with much greater precision.

We examined available data on travel speeds measured at 55 sites throughout the state of Michigan, to assess the effect of the new law on actual travel speeds. The proportion of motorists traveling over the posted speed limit has been increasing throughout the 1980s. In addition to this gradual upward trend, there was a noticeable further increase in travel speeds in 1988. This sudden increase in speeds occurred only at those sites where the limit was raised to 65, where the proportion of motorists exceeding 65 mph increased 21.3% from 1987 to 1988 (see the dotted line in Fig. 3). Increasing travel speeds may reflect a decline in public support and police enforcement of the 55 limit in the 1980s (U.S. House of Representatives 1985).

Although the actual posting of the new 65 mph speed limit signs occurred in late November 1987, considerable discussion and publicity regarding the pending increase in the limit occurred throughout 1987. As a result, we hypothesized that a small portion of the effect of the increased limit might have occurred before the new signs were actually posted, in anticipation of the formal change in late November and December of 1987. We tested this hypothesis by incorporating another variable in each time-series model to estimate this anticipatory effect. The anticipatory and implementation effects were then simultaneously estimated. Results revealed significant increases in serious and moderate injuries in anticipation of the speed limit change, but no significant anticipatory effects on fatalities, minor injuries, or property-damage-only crashes (Table 1). We reestimated each time-series model excluding the anticipatory effect variable to determine the effect of inclusion of this variable on the estimates of the implementation effects. Results showed virtually no differences in estimated implementation effects (Table 2). Furthermore, the models with anticipatory effects explained the same amount of variance as those without (average R^2 of models with anticipatory effect paramater was .586; average R^2 of models without anticipatory effect paramater was .582).

In addition to analyses of the speed limit effects by injury severity, we assessed differential effects of the law by crash configuration, extent of vehicle damage, gender, and age (Table 3). There were no significant differences in the size of the increase in crashes associated with the 65 mph limit across any of these groups. The increased injuries, deaths, and property damage after the 65 mph limit took effect were experienced by both males and females.

The quasi-experimental research design, including experimental series of road segments where the speed limit was raised and comparison series of road segments where the limit remained unchanged, controlled for many threats to a causal interpretation of observed increases in casualties. To provide further confidence that other major factors influencing crash outcomes could not explain observed effects, we reestimated each time-series model including a series of covariates that previous studies have demonstrated influence crash and injury rates. Results of models including covariates revealed larger estimated increases in fatalities, moderate injuries, and property-damage-only crashes associated with the 65 mph speed limit than models without these covariates (Table 4). Observed increases in casualties associated with the 65 mph speed limit cannot be attributed to other factors such as the compulsory safety belt law, changes in vehicle miles traveled, economic conditions, alcohol consumption, or changing demographics of the driver population. If anything, estimated effects without statistical controls for these factors understate the deleterious effects of the 65 mph limit on casualty outcomes.

DISCUSSION

Raising the speed limit to 65 mph was followed by increased casualties due to motor vehicle crashes. On road segments where the limit was raised, the percentage increases in injury and death were large (16% to 40%). Fortunately, the limited access highways

Table 4. Effects of increase in maximum speed limit: Results from time-series models with anticipatory effects, implementation effects, and controls for effects of covariates

		Estimate	Standard error	Percent change	90% confidence interval Low	90% confidence interval High
Fatalities						
65 mph highways						
ARIMA (0, 0, 5) (0, 1, 1)$_{12}$ $R^2 = 0.10$						
Anticipatory effect		0.8352	0.3741			
Implementation effect		0.3945	0.1705	48.4	12.1	96.4
Adult belt law		−0.4901	0.1616			
Vehicle miles traveled		0.7413	0.9104			
Unemployment rate	Lag 0	0.2749	0.5107			
	Lag 1	0.3071	0.6364			
	Lag 2	−1.0000	0.6620			
	Lag 3	−0.2650	0.6421			
	Lag 4	0.3383	0.5038			
Beer consumption	Lag 0	0.0966	0.8253			
	Lag 1	−0.0029	0.8134			
	Lag 2	1.4340	0.8122			
Percent young drivers		−0.9469	0.5509			
Serious injuries						
65 mph highways						
ARIMA (0, 0, 0) (0, 1, 1)$_{12}$ $R^2 = 0.49$						
Anticipatory effect		0.4322	0.1809			
Implementation effect		0.2764	0.0887	31.8	13.9	52.5
Adult belt law		−0.0175	0.0799			
Vehicle miles traveled		0.2014	0.3846			
Unemployment rate	Lag 0	−0.3372	0.2376			
	Lag 1	−0.0474	0.3075			
	Lag 2	0.1673	0.3289			
	Lag 3	0.1748	0.3391			
	Lag 4	0.1384	0.2453			
Beer consumption	Lag 0	0.8060	0.3765			
	Lag 1	0.2168	0.3742			
	Lag 2	−0.5671	0.3730			
Percent young drivers		−0.3883	0.2895			
Moderate injuries						
65 mph highways						
ARIMA (0, 0, 0) (0, 1, 1)$_{12}$ $R^2 = 0.51$						
Anticipatory effect		0.2839	0.1525			
Implementation effect		0.2647	0.0848	30.3	13.3	49.8
Adult belt law		0.0393	0.0712			
Vehicle miles traveled		0.2752	0.3247			
Unemployment rate	Lag 0	0.1035	0.2045			
	Lag 1	−0.0307	0.2655			
	Lag 2	0.0272	0.2811			
	Lag 3	0.0174	0.2819			
	Lag 4	−0.2512	0.2163			
Beer consumption	Lag 0	0.2253	0.3205			
	Lag 1	0.2166	0.3186			
	Lag 2	0.1899	0.3099			
Percent young drivers		−0.5948	0.2622			
Minor injuries						
65 mph highways						
ARIMA (0, 0, 0) (0, 1, 1)$_{12}$ $R^2 = 0.67$						
Anticipatory effect		0.3374	0.2404			
Implementation effect		0.1802	0.1516	19.7	−6.7	53.7
Adult belt law		0.0468	0.1185			
Vehicle miles traveled		−0.8417	0.4090			
Unemployment rate	Lag 0	0.0257	0.2251			
	Lag 1	−0.0200	0.2626			
	Lag 2	−0.2387	0.2795			
	Lag 3	0.3863	0.2741			
	Lag 4	−0.3669	0.2403			
Beer consumption	Lag 0	0.0547	0.3559			
	Lag 1	0.7039	0.3515			
	Lag 2	0.0163	0.3453			
Percent young drivers		0.5313	0.4365			

Table 4. (Continued)

		Estimate	Standard error	Percent change	90% confidence interval	
					Low	High
Property damage only crashes						
65 mph highways						
ARIMA (0, 0, 0) (0, 1, 1)$_{12}$						
$R^2 = 0.84$						
Anticipatory effect		0.2342	0.1722			
Implementation effect		0.2413	0.1036	27.3	7.3	50.9
Adult belt law		0.1631	0.0798			
Vehicle miles traveled		−0.8257	0.2957			
Unemployment rate	Lag 0	−0.0900	0.1680			
	Lag 1	−0.0834	0.2053			
	Lag 2	0.2430	0.2181			
	Lag 3	−0.0356	0.2118			
	Lag 4	−0.2136	0.1761			
Beer consumption	Lag 0	0.1406	0.2615			
	Lag 1	0.1805	0.2609			
	Lag 2	−0.2293	0.2588			
Percent young drivers		−0.4472	0.3037			

where the limit was raised are relatively safe, compared to other roads in the state. Because limited access highways have relatively low injury and death rates, the proportional increase in casualties on these roads represents a smaller increase in the actual number of people killed or injured than would occur if the limit were raised on other types of roads. Nevertheless, our results show that 27 additional people were killed, 222 experienced serious injuries, and 271 experienced moderate injuries in the first 13 months with the raised limit (Table 5). Estimated total costs in terms of the rational investment to prevent these additional injuries and fatalities is $57 million. Similar costs to prevent property-damage-only crashes total $4.8 million.

Many observers argue that there are also substantial benefits of the raised limit, primarily cost savings due to reduced travel time. Miller argues that the costs of the raised limit in terms of years of life lost from premature death and injury are roughly equal to the years saved from reduced travel time (Miller 1989). However, Miller also points out that the costs and benefits are not equally distributed—savings accrue to all drivers and passengers of motor vehicles, but costs are born disproportionately by those who are killed or injured in crashes. Furthermore, the risk of death or injury is not equally distributed throughout the population of motorists (young males are at higher risk, for example). It is argued by public health ethicists that equal aggregate costs and benefits of a public policy should not necessarily be considered offsetting if the *distribution* of the costs and benefits is unequal (Rawls 1971; Beauchamp 1976).

There are other issues that are part of the debate concerning the appropriate maximum speed limit. One might argue that there are other policies that can prevent as much or more damage than the 55 mph limit, perhaps at lower cost or at least with a different distribution of costs. The majority of the public supports the 65 mph limit (52%) (Wagenaar et al. 1988), a fact used to argue for maintenance of the 65 mph limit, or to argue for better dissemination of information regarding increased casualties caused by higher speeds. Although we found ambiguous evidence of spillover effects in this short-term study, it is possible that higher speeds on selected (safer) road segments over the long term may gradually spread to other (less safe) road segments, increasing the deleterious effects of the raised speed limit. Furthermore, increasing the speed limit on some road segments may increase the acceptability of higher speeds by both the driving public and the law enforcement community, contributing to the "spillover" effect. Finally, raising the speed limit on some roads but not other similar roads could divert some traffic from the low-speed roads to the higher-speed roads.

Ultimately, support or opposition to the 65 mph limit must be based on one's structure of values. Is the increased convenience of faster travel worth the increased deaths and injuries? Each individual may make his or her own decisions regarding these

Table 5. Estimated injuries attributable to increase in speed limit to 65 mph

	Actual	Expected*	Difference	Costs†
Fatalities	1,558	1,531	27	$44,142,000
Serious injuries	22,250	22,028	222	9,437,000
Moderate injuries	43,504	43,233	271	3,544,000
Total casualties	67,312	66,792	520	$57,123,000
Property damage only crashes	623,016	620,808	2,208	4,813,000
Total	690,328	687,600	2,728	$61,936,000

*Expected represents the estimated number of deaths or injuries that would have occurred in the 13-month post-law period analyzed had the speed limit not changed.

†Based on 1988 adjusted willingness-to-pay values of $1,634,904 per fatality, $42,508 per serious injury, $13,079 per moderate injury, $2,180 per property-damage-only crash (Federal Highway Administration 1988). Original calculated in 1986 dollars, adjusted annually by consumer price index to 1988 dollars.

trade-offs. But a safe and efficient transportation system is inherently a collective good. Therefore, collective acknowledgement and public debate on the benefits and costs of alternative speed limit policies is necessary (Beauchamp 1988). Moreover, decisions regarding appropriate speed limits must be based on the welfare of the community as a whole. Results of the current study showing increased morbidity and mortality following the raised speed limit are a central dimension of the debate.

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