A REVIEW OF THE IMPACT OF MEDICAL CARE AND TECHNOLOGY IN REDUCING TRAFFIC FATALITIES

Robert B. NOLAND

Centre for Transport Studies
Department of Civil & Environmental Engineering
Imperial College London
London, UK

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Over the last 30-40 years dramatic improvements have been seen in the development of new methods for saving the lives of those involved in traffic crashes. This ranges from improvements in emergency medical response systems to advanced trauma care procedures to specific surgical intervention techniques. This paper reviews the evidence for these improvements as documented in the safety and medical literature. The overall impact on traffic fatalities has been examined in several recent studies that have attempted to examine these effects empirically using data from the US, Great Britain, and international data from a selection of western countries. Overall results suggest impressive reductions in total fatalities when trends in medical care and technology improvements are controlled. This has interesting implications for maintaining future reductions in fatalities and the likelihood of attaining significant further improvements in many countries. In addition, analysts and policy makers should be aware of how fatality reductions from these factors may affect analyses of traffic safety policies.

Key Words: Traffic safety, Medical technology, Health care, Emergency medicine, Negative binomial models

1. INTRODUCTION

Over the last 50 years developed industrialized countries have largely become fully motorized with a large proportion of daily travel being made by individuals using cars. At the same time that total travel has increased, fatality rates, whether measured per kilometre of travel or on a per-capita basis, have generally decreased. The reasons for this reduction are a result of specific policy measures taken to both increase the safety of the vehicle and to change the behaviour of individual drivers. This includes major improvements in the design of vehicles, spurred by regulations, such that crashes are more survivable; legislation to require the use of safety-belts; and increased attention and enforcement of laws on drunk driving.

Less attention has been paid to reducing excessive speeds, with the exception of traffic calming measures in residential areas. Roadway design has also often been mentioned as providing safety benefits, and while some design measures are likely beneficial, those that lead to increased speeds are probably less effective[1,2].

The other major factor that has contributed to decreased mortality in road vehicle accidents is changes in medical care and technology. This includes a broad range of medical techniques, including development of emergency management and trauma care systems. The fatality reduction effects from these are likely quite substantial and a further understanding of these effects is beneficial for at least two reasons. First, it provides a framework for understanding how to direct limited resources available for reducing traffic fatalities. Second, large reductions in fatalities due to medical technology improvements may often distort the analyses of other safety policies and may lead analysts to incorrectly conclude that some policies are more effective than they actually are.

This paper will provide an overview of some of these issues. A brief review of the medical literature is provided that discusses the development of trauma care systems and various life-saving technologies that have contributed to reduced mortality from road crashes. An overview of recent empirical research that has examined these issues is then provided. Finally, the implications for policy makers as well as for those studying road safety issues are provided.

2. REVIEW OF THE MEDICAL AND HEALTH CARE LITERATURE

Mortality from road vehicle accidents has been considered a "disease of affluence". That is, as general prosperity in society increases it leads to changes in the types of factors associated with mortality[3]. In the case of motor-vehicle related fatalities, increasing affluence is associated with increased rates of motorization which leads to an increasing level of fatalities. In most industrialized countries there is a peaking of this effect, after which increasing affluence leads to a decrease in the level of fatalities. This same pattern has been found in analyses of mortality from cardiovascular disease which is also considered a "disease of affluence"[4,5].

The long-term trend in traffic crash mortalities was examined by van Beeck et al.[3] using cross-sectional and time series data from a selection of industrialized countries, confirming this pattern. They found that for most countries, traffic-related mortalities increase until some critical level of income after which mortalities decrease. One explanation for this effect is that both learning effects and the introduction of policies to counteract a growing mortality problem are enacted, as countries become more affluent. Learning effects can include the development of new methods of medical care and treatment of trauma, while enactment of other policies in response to the increase in mortality, are also likely to be implemented.

Additional evidence for this effect was found by Bester[6]. Using international road fatality data, fatality rates were found to be associated with a Human Development Index that included Gross Domestic Product, life expectancy, and educational levels. Beenstock and Gafni[7] found correlations between crash rates in Israel and with an index of international crash rates. They hypothesize that this may be due to a "globalization model" of road safety whereby technology transfer of vehicle and road infrastructure technology have led to decreases in fatalities in all industrialized countries. Oppe[8] also hypothesized that learning effects can explain the downward trend in traffic fatalities for developed countries. Clearly medical care improvements could likewise disseminate between countries. Slade and Anderson[9] found that dissemination of new medical technologies is correlated with per-capita income, lending support to this theory.

There is good anecdotal evidence that the development of trauma systems and delivery of medical care for crash victims follows this sort of pattern. The development of trauma systems was originally a by-product of experience gained in treating wounded soldiers dating back to at least World War I. Mullins[10] and Trunkey[11] both provide a historical overview of the development of trauma care systems. The introduction of helicopter evacuation of wounded soldiers during the Korean and Vietnam wars was found to significantly reduce mortality rates, and this led to the use of helicopters for emergency medical transportation. In the mid-1960's many of the physicians with experience gained in the military transplanted these systems to civilian situations. Nathens et al.[12] point out that rapid movement of injured patients to hospitals capable of effectively treating them is an essential component of trauma care.

The dissemination of new knowledge and the development of new surgical skills did not happen immediately. Nathens et al.[13] find in an analysis of US data, that it took about 10 years to achieve the full benefit of a trauma care system. Cutler and McClellan[14] describe how new medical technologies can be more effective, but that much of the benefit results from the extension of new technologies to treat more patients as knowledge about the effectiveness of treatments is disseminated. This is consistent with the evidence that trauma system benefits take time to accumulate.

Mullins[10] describes the identification of public injury as a health problem, primarily due to a National Research Council[15] report in 1966. In the US, this made the issue a political one. This coincided with concern over the design of vehicles and new regulations to improve crash-worthiness and survivability for occupants. The political response led to initial funding of trauma systems in selected states via the National Highway Safety Act of 1966[10].

While the development of comprehensive trauma systems has clearly played a role in reducing traffic related fatalities, overall advances in medical care and technology have also been significant in this time frame. Newhouse[16] lists many of the advances that have occurred over the last 40 years in the health sciences. These include items of physical capital, such as magnetic resonance imaging but also a variety of new procedures ranging from transplantation to artificial joints to endoscopy. As evidence for the effectiveness of these practices, Newhouse[16] examines hospital admission rates which have not increased in line with an aging population. Average hospital in-patient stays have decreased suggesting that treatment techniques are more effective and that many more can now be conducted on an outpatient basis. Another example is improvements in infant mortality rates over the last 40 years which are the result of many life-saving technological interventions and improvements in medical care[17].

While these measures are not necessarily directly associated with the trauma which occurs in traffic crashes, they serve as an indicator of general advances in medical practices and technical abilities. Advances more directly linked to traffic crashes include the treatment of traumatic brain injury which has also undergone significant advances over the last 30 years. This includes the introduction of clinical tools such as computed tomography (CT) scanners, which were introduced in the 1970's[18]. Computer based storage systems for clinical images, radiographs, photographs, and ECGs have been developed and implemented that help in teaching and research within accident and emergency departments[19]. In the UK, telemedicine has also been applied to two major areas of accident and emergency practice[20]. These are the transmission of CT scans for urgent neurosurgery and the ongoing support of minor injury units.

This review of recent literature builds a case that medical interventions, either through technology improvements or systemic improvements such as trauma care systems, have significantly contributed to reductions in motor-vehicle crash fatalities. Next, results from analyses of various databases that shed some further light on these issues, especially in terms of the likely quantity of lives saved is reviewed and summarized.

3. REVIEW OF RECENT EMPIRICAL STUDIES

These issues have been analyzed in recent work using a variety of different databases by Noland[1,21] and Noland and Quddus[22]. The data analyzed was from the United States, Great Britain, and international data from a selection of industrialized countries. In all cases, aggregate crash analysis models were developed. These correlate total fatalities or injuries in a multivariate analysis of factors likely to be associated with changes in those variables. In addition, all the estimations used time-series cross-sectional data that enabled control for heterogeneity and changes in unmeasured factors over time. This latter is critical to control for, as many other elements of the transport system have changed over time including vehicle design and other safety initiatives that cannot be explicitly controlled.

To measure changes in medical care and technology, a variety of proxy variables were used. A review of existing data sources found no clear guidance on the best variables to represent these changes. Data availability limited what could practically be tested in the models. This also led to different proxy variables being tested for different datasets, which provided additional robustness to the overall conclusions.

Most of the models estimated also used a fixed effect negative binomial regression technique as specified by Hausman et al.[23]. This method is appropriate for cross-sectional time-series data. As the dependent variable is a count variable, one cannot assume that this data is normally distributed. Hausman's method also controls for heterogeneity in the data. Noland and Karlaftis[24] examined the need for using models for count data and concluded that these methods are most appropriate for this data.

Each of the three studies is reviewed and discussed below.

3.1 Analysis of US data

In the US data white infant mortality rates were used as the proxy variable to represent medical technology change. This was based on an assessment of the variation in infant mortality rates over the time series of the data with a reduction of 34% nationwide between 1985 and 1997. This improvement has been documented to be due primarily to medical technology improvements[25]. There was also substantial regional variation between states, for example, in 1996 West Virginia had a rate of 9.1 per 1000 births while New Hampshire had a rate of 4.3. This variation in outcomes could be associated with relative affluence between states, and represent the dissemination of new medical care procedures. White infant mortality rates were used to reduce the correlation between per capita income and total infant mortality rates[1].

This variable was found to be statistically significant with the expected directional effect. As infant mortality rates improved, traffic related fatalities were reduced. This variable was not statistically significant when models were estimated with total injuries as the dependent variable. Injuries would tend to be correlated more strongly with overall crashes and be more affected by policies aimed at reducing the incidence of crashes. Therefore, we would not expect medical technology changes to affect the incidence of total injuries, which was confirmed by the estimation results. Finally, when the white infant mortality variable was omitted from the model, much of the residual effect was captured by the time trend variable which was not statistically significant when this variable was included. This suggests that much of the residual change over time is being explained by underlying changes in medical care and technology.

3.2 Analysis of British data

The analyses of these effects in British data again used a cross-sectional time-series approach. Data on traffic fatalities and both serious and slight injuries were aggregated at the regional level based on the Standard Statistical Regions of the United Kingdom[22]. Three different proxy variables were tested in the models estimated. These included the average length of in-patient stay in the hospital, which has fallen over time and as Newhouse[16] states is a good indicator of improvements in technology. National Health Service (NHS) staff per capita and the number of people waiting for hospital treatment were also included as proxy variables. These two variables would serve to indicate the level of economic resources devoted to health care. Much of the increase in economic resources devoted to health care has been devoted to technology as indicated by Newhouse[16]. This may include the need for more labor, but not necessarily.

In a count model with total fatalities as the dependent variable, estimated with a negative binomial regression, these variables have the expected effect. Average length of hospital in-patient stays are positively associated with fatalities. This means that as there has been a reduction in average length of in-patient stay (due to technology improvements) there has also been a reduction in total fatalities. More NHS staff per capita was negatively associated with total fatalities (significant above the 85% confidence level). This means that as staff per capita numbers increase there is a reduction in total fatalities. Wa™iting times for hospital treatment are positively associated with total fatalities. Again, this is a resource issue and as more resources are devoted to medical care we would expect waiting times to decrease and we would expect a reduction in fatalities.

Effects on all of these variables are different in the injury models (i.e., with serious injuries and slight injuries as the dependent variable). This suggests an inherent difference in the association of these variables with fatalities as opposed to injuries. It could represent a shift from crashes resulting in fatalities to more serious injuries, as survivability increases.

An additional analysis was conducted in Noland and Quddus[22] that examined the association of these proxy variables with a ratio of fatalities to slight injuries. As the evidence suggested some shifting between classes of injuries over time, we would expect these variables to be strongly associated with this ratio. Over time the fraction of total injuries that are fatal has been declining. Since the dependent variable is no longer a count variable an ordinary least squares estimation using a fixed effects method which further allowed for a correction for autocorrelation in the data was applied. In this model, it was found that the medical technology and care proxy variables had the highest level of statistical significance (all above the 90% confidence level), while many of the other variables in the model were at a relatively lower level of statistical significance and much lower than in the count model estimates. The results were as expected, showing the proxy variables to have the expected direction which was the same as in the total fatality count model (i.e., average length of in-patient hospital stays was positive, NHS staff per-capita was negative, and number of persons waiting for hospital treatment was positive). This result, again adds reinforcing evidence for a strong effect from medical care and technology improvements.

3.3 Analysis of international data

Noland[21] performed an analysis using international data from a selection of industrialized countries from the Organization for Economic Cooperation and Development (OECD). A number of different models were estimated with and without various proxy variables for medical technology improvements. These proxies included, infant mortality rates, physicians per capita, and average acute care days spent in the hospital. These are similar to the variables used in the previous two studies and were obtained from *OECD Health Care* data.

The most robust result was found for average acute care days in the hospital. This should be more closely associated with medical technology changes than the average in-patient days in the hospital used in the British analysis. The relatively higher coefficient value found in this analysis (0.36 – 0.50) compared to the British study (0.28 – 0.32) suggest a stronger association, which would be expected. A similar result was found for the physicians per capita variable which was also highly significant and robust across different model specifications. The coefficient value ranged from –0.24 to –0.27 compared to –0.09 to –0.14 in the British analysis. This again should be more strongly associated with improvements in medical care (especially more specialized care) as opposed to total medical staff increases. Infant mortality rates were not found to be statistically significant and were also highly correlated with per capita income in this data. When per capita income was removed from the model and infant mortality was the only medical technology proxy variable included, then it had the expected sign and level of significance.

3.4 Overall fatality reductions

The overview of these studies provides good evidence that improvements in medical care and technology has been a factor in reducing traffic fatalities. A key question is how substantive an effect this has been.

Noland[1] and Noland and Quddus[22] report results on how the changes in the proxy variables over time have led to changes in total fatalities using elasticity calculations. Using the US data set, Noland[1] concluded that 2,047 fewer fatalities would have resulted in 1985 if the technology of 1997 were available then. This would result in 4.5% fewer fatalities in 1985. This actually exceeds the reduction of 1,847 fatalities between 1985 and 1997. The British analysis shows a reduction of between 640 and 726 fatalities, based on the coefficient for average in-patient stays in the hospital. This would account for up to one-third of the 2,100 fewer fatalities between 1979 and 1998 (note that this data excludes fatalities for London and Scotland).

Further analysis of the international data is shown in Table 1. The total fatalities for 1970 and 1996 are shown for the OECD countries listed. Based upon parameter estimates from Noland[21] that were estimated with logarithmic independent variables and thus can be used as elasticity values, and based upon the changes in the proxy variables we get a large range for the potential reduction due to medical technology improvements. Table 1 shows the reductions that would have occurred in 1970 if 1996 technology had existed in that year. These range from 9,708 to 35,847 fewer total fatalities from these countries. This reduction would be from a total of 142,636 traffic fatalities in 1970, therefore representing anywhere from 6.8% to 25.1% of the total.

While the potential range shown here is quite large, the implication is clear that medical care and technology improvements have had a major effect on overall reductions in fatalities in the last 40 years. A good consensus estimate based on the results of the studies above is that between 5% and 25% of the reductions in fatalities in this time frame are due to improvements in medical care and technology, which includes trauma and emergency response systems. The implications for future policy associated with reducing traffic fatalities in the next section are discussed.

Table 1 Changes in fatalities based upon parameter estimates from international data analysis

Country	Total fatalities 1970	Total fatalities 1996	Reduction based on infant mortality parameter	Reduction based on physicians per capita parameter	Reduction based on average acute care days in hospital parameter
Australia	3,798	1,970	–262	–1,011	–379
Austria	2,574	1,027	–211	–633	–453
Belgium	3,070	1,356	–224	–956	–589
Canada	5,080	3,092	–353	–499	–380
Denmark	1,208	514	–78	–318	–232
Finland	1,055	404	–75	–547	–229
France	16,445	8,541	–1,005	–4,975	–3,876
Greece	1,099	2,157	–99	–388	NA
Ireland	540	453	–40	–100	–99
Italy	11,025	6,688	–904	–10,840	–472
Japan	21,795	11,674	–1,578	–3,409	NA
Luxembourg	132	71	–11	–32	–14
Netherlands	3,181	1,180	–192	–782	–576
New Zealand	655	514	–37	–146	NA
Norway	560	255	–39	–138	–119
Portugal	1,615	2,394	–144	–926	–289
Spain	5,456	5,483	–451	–2,992	–91
Sweden	1,307	537	–85	–445	–264
Switzerland	1,643	616	–115	–519	–121
UK	7,771	3,740	–531	–441	–1,466
US	52,627	42,065	–3,274	–5,749	–4,033
Total	142,636	94,731	–9,708	–35,847	–13,680
Percent of total			–6.81%	–25.13%	–9.59%

4. IMPLICATIONS FOR POLICIES TO REDUCE FATALITIES

These results have important implications for our understanding of how best to further reduce traffic-related fatalities. As the review and the empirical data suggests, medical care and technology improvements have been substantial over the last 30-40 years and this knowledge has been put to good use in reducing overall traffic-related fatalities.

One implication of this work is that it may change our understanding of the effectiveness of other policy interventions. A significant body of research has documented the effectiveness of wearing safety-belts, reducing drunk driving, reducing speed limits, and changing vehicle design and infrastructure design. Many of these initiatives have occurred concurrently with the changes in medical care and technology. The difficulty for analysts is to clearly disentangle the effects of the various mechanisms, something that is not always done.

Much of the statistical analyses of traffic crashes has not accounted for many of these confounding factors and has often not used the most current statistical techniques[2]. This situation is improving as count data estimation methods become more widespread. Many studies also do not attempt to disentangle the effects on fatalities as opposed to injuries or total crashes. As Noland and Quddus[22] showed, the impact of medical technologies on fatalities is not the same as the impact on injuries. Clearly one limitation of many studies is that data on fatalities may be sparse or non-existent while injury or crash data is more abundant.

The problem (for analysts, but not for motorists) of sparse data sets of fatalities leads to the use of time-series analysis in before and after studies. If the time-series stretches over more than a few years, then trend reductions in fatalities need to be controlled for. Medical care and technology improvements may account for much of this trend reduction, and excluding some control for the trend can distort conclusions as to whether the policy or intervention being studied is effective.

As medical care and technology has improved dramatically over the last 40 years, a relevant question is whether this trend will continue. Eng[26] outlines numerous possibilities for further technology improvements in medicine. Cutler and McClellan[14] document the cost-effectiveness of past improvements, suggesting that further improvements are clearly worth the investment. If trends do not continue, it may be difficult to achieve further major reductions in crash fatalities, without other policy interventions. These are then probably best focussed on reducing crash rates and the severity of crashes when they occur.

If further technical change in medical care and technology can improve survivability rates and this is desirable from a public policy perspective, then this has implications for the funding of road crash reduction programs. As Mullins[10] documented, in the US the implementation of trauma care systems received a boost from Federal funding. Continued funding and incentives to develop and improve technology and disseminate new knowledge may be more effective at reducing fatalities than other crash reduction programs. Current knowledge can not answer this question, but clearly this should be of priority for further research in this area.

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