A Review on Methodological Approaches of Highway Safety Research and Future Directions

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Abstract: *The analysis of highway crash data has long been used as a basis for influencing highway and vehicle designs, as well as directing and implementing a wide variety of regulatory policies aimed at improving safety. And, over time there has been a steady improvement in statistical methodologies that have enabled safety researchers to extract more information from crash databases to guide a wide array of safety design and policy improvements. In spite of the progress made over the years, important methodological barriers remain in the statistical analysis of crash data and this, along with the availability of many new data sources, present safety researchers with formidable future challenges, but also exciting future opportunities. This paper provides guidance in defining these challenges and opportunities by first reviewing the evolution of methodological applications and available data in highway accident research. Based on this review, fruitful directions for future methodological developments are identified and the role that new data sources will play in defining these directions is discussed. It is shown that new methodologies that address complex issues relating to unobserved heterogeneity, endogeneity, risk compensation, spatial and temporal correlations, and more, have the potential to significantly expand our understanding of the many factors that affect the likelihood and severity of highway crashes. This in turn can lead to more effective safety counter measures that can substantially reduce highway related injuries and fatalities.*

Keywords: Highway Safety, Crash Frequency, Crash Severity, Accident Analysis.

Introduction:

Worldwide, more than 1.2 million people die annually in highway related crashes and as many as 50 million more are injured. In addition to the statistics on death and injuries, highway related crashes result in immeasurable pain and suffering and many billions of dollars in medical expenses and lost productivity. The enormity of the impact of highway safety on human societies has resulted in massive expenditures on safety related counter measures, laws governing highway use, and numerous regulations concerning the manufacturing of highway vehicles. While the success of many of these efforts in reducing the likelihood of highway crashes and mitigating their impact cannot be denied, the toll that highway crashes continue to extract on humanity is clearly unacceptable. Critical to the guidance of ongoing efforts to improve highway safety is research dealing with the statistical analysis of the countless megabytes of highway crash data that are collected worldwide every year. The statistical analysis of these crash data has historically been used as a basis for developing road safety policies that have saved lives and reduced the severity of injuries. And, while the quality of data has not always progressed as quickly as many safety researchers would have liked the continual advance in statistical methodologies has enabled researchers to extract more and more information from existing data sources. With this said, as in most scientific fields, a dichotomy has evolved between what is used in practice and what is used by front line safety researchers, with the methodological sophistication of some of the more advanced statistical research on roadway accidents having moved well beyond what can be practically implemented to guide safety policy. However, it is important that the large and growing methodological gap between what is being used in practice and what is being used in front-line research not be used as an excuse to slow the methodological advances being made, because the continued development and use of sophisticated statistical methodologies provides important new inferences and ways of looking at the underlying causes of highway crashes and their resulting injury severities. Continuing methodological advances, in time, will undoubtedly help guide and improve the practical application of statistical methods that will influence highway-safety policy. Thus, while the intent of this paper is to focus on the current frontier of methodological research (after reviewing current methodological issues), it is important that readers recognize the different objectives between applied and more fundamental research, and the role that sophisticated methodological applications have in ultimately improving safety practice and developing effective safety policies. The current paper begins by quickly reviewing traditional sources of highway accident data and the evolution of statistical methods used to analyze these data. It then moves on to present some critical methodological issues relating to the analysis of highway accident data. This is followed by a discussion of some emerging sources of crash data that have the potential to significantly change methodological needs in the safety research field. The paper concludes with a discussion of some of the more promising methodological directions in accident research, and a summary and insights for the future methodological innovation in accident research.

Review of Literature:

Most existing highway accident studies have extracted their data from police crash reports. These reports are used to establish the frequency of crashes at specific locations and the associated injury-severities of vehicle occupants and other involved in these crashes. While the occurrence of a crash and the severity levels reported by police data have been used in many previous studies to provide insights relating to the factors affect highway safety, the inaccuracies of police-reported data are well documented. For example, it has been well established in the literature that less severe crashes are less likely to be reported to police and thus less likely to appear in police databases. With regard to the severity of crashes, considerable inaccuracies have been found when comparing police severity reports with the severity assessment made by medical staff at the time of admission to the hospital. A wide variety of methodological approaches have been used to explore traditional crash data, and these methodologies have become increasingly sophisticated over time as researchers seek to address the many less obvious characteristics of the data in the hope of uncovering important new inferences relating to highway safety. Two relatively recently published papers provide a comprehensive review of current methodological approaches for studying crash frequencies, the number of crashes on a roadway segment or intersection over some specified time period, and crash severities, usually measured by the most severely injured person involved in the crash. The intent of this paper is not to replicate the detailed discussions of the methodological alternatives provided in those papers, but instead to focus on discussing the methodological evolution, the current methodological frontier and remaining methodological issues. And, because crash frequency data bases were often found to have many observations with no observed crashes, researchers considered zero-inflated Poisson and negative binomial regressions, which attempt to account for the preponderance of zeros by splitting roadways into two separate states, a zero state and a normal count state. Other methodological advances models have sought to address what might be considered as more subtle issues with crash frequency data. Issues such as the effect of unobserved factors on crash frequencies, spatial and temporal correlations among crash-count data, the possibility of roadway segments shifting among multiple crash states discrete crash situations that fundamentally shift roadway safety and others have all been addressed in the steady progression of methodological advances in the field. A similar path has been followed by studies that have addressed the severity of crashes. Starting with simple binary discrete outcome models such as binary logit and probit models, models evolved to consider multiple discrete outcomes. For the multiple discrete outcome models, multinomial models that do not account for the ordering of injury outcome have been widely applied from the simple multinomial logit model, to the nested logit model to the random parameters logit model. The data available to researchers is often limited, and many variables known to significantly affect the frequency and severity of crashes may not be available. There may also be a need to develop relatively simplistic models using only explanatory variables that can be gathered and projected for use in practice, where municipalities may have access to little data or technical expertise. Given these data limitations or the need to specify models with a few simplistic explanatory variables, parsimonious models are often estimated an example would be estimating a model of crash frequency using only the volume of traffic as an explanatory variable. Clearly many other factors affect the frequency of crashes such as environmental conditions, roadway geometrics, the vehicle mix of traffic, lane widths, and so on. The problem with just using traffic volume as the explanatory variable is that the model will be excluding significant explanatory variables and the model estimated parameter for traffic volume will be estimated with bias and application of the model will be fundamentally flawed because changes in the omitted variables cannot be captured and the predicted crash frequencies will be incorrect. In addition, a model with only traffic volume is limited in its value for designing countermeasures, precisely because the impacts of design features that can be controlled by traffic engineers are not considered. In summary, the real problem with parsimonious models is that practitioners, and even researchers, do not fully grasp, or often conveniently overlook, the limitations of these simplistic models in terms of biased parameter estimates and policy value. For practitioners, the application of such models can easily produce erroneous estimates and provide lesser information for countermeasure design relative to a more fully specified model that includes variables that are amenable to changes in design.

Researchers often extend simplistic parsimonious models with more sophisticated statistical methods often not realizing that the omitted variable bias present in their model compromises all of the conclusions that they are likely to draw. Thus, it is extremely important to recognize the limitations of parsimonious models, avoid them if at all possible, and consider more sophisticated statistical approaches to mitigate their adverse consequences.

Unobserved Heterogeneity:

Some of the many factors affecting the frequency and severity of crashes are not observable, or the necessary data may be nearly impossible to collect. If these unobserved factors are correlated with observed factors, biased parameters will be estimated and incorrect inferences could be drawn. For example, consider a statistical model of crash injury severity that has age as one of the explanatory variables. Age is correlated with many underlying factors that are likely to affect crash injury severity such as physical health, susceptibility of bones to breakage, body positioning at the time of crash, reaction times that may mitigate the severity of the crash, and so on. By including only age, age is acting as a proxy variable for many underlying factors that are likely to vary considerably across crash-injury observations because people of the same age are likely to have differences in these unobserved factors. By assuming that age has the same effect on injury severity across the population, the analyst is placing a potentially significant restriction on the model that may affect not only the inferences drawn from the age variable parameter estimate.

Selectivity Bias/Endogeneity:

One of the most often overlooked elements in model estimation can be generally termed as selectivity bias/endogeneity. This can take many forms, some of which are obvious and some of which are more subtle. As an example, consider a model that seeks to determine the effectiveness of ice warning signs in reducing the frequency of crashes during icy conditions. The most common approach to studying this problem would be to collect crash-frequency data for roadway segments with ice warning signs and roadway segments without. Then, using a naïve approach, estimate a model that has the presence of an ice-warning sign as an indicator variable which takes a value of one if an ice warning sign is present and zero otherwise. If one were to estimate such a model, it is quite likely that the parameter estimate for the ice-warning sign indicator variable would have a substantial downward bias seriously understating the effectiveness of ice warning signs. This is because ice-warning signs are likely to be placed on roadway segments with a history of a large number of ice crashes. Thus, the presence of an ice-warning sign will be correlated with unobserved factors that affect the frequency of ice-related crashes. These unobserved factors could include things such local micro-climate conditions that make some roadway segments more likely to accumulate moisture and freeze relative to others, making them more susceptible to high ice-crash frequencies. There have been countless studies that have likely arrived at erroneous inferences by ignoring such effects and not undertaking the proper statistical techniques for correcting such a selectivity effect. Often times, the selectivity bias/endogeneity can be more subtle. An example would be a study to determine the effectiveness of a new vehicle safety feature in reducing the injury severity in crashes. The naïve approach would be to look at vehicles with the safety feature and those without, and assess the safety feature's effectiveness in reducing injury severity by, for example, using an indicator variable. The problem with this approach is that the drivers owning the vehicles with the safety feature are not likely to be a random sample of the driver population. In fact, studies have shown that the safest drivers are most likely to own cars with advanced safety features. Thus, the parameter estimate for the indicator variable for the presence of the safety feature will capture all the unobserved heterogeneity relating to its driver that will tend to result in less severe crashes (unobserved factors such as those relating to risk aversion and so on). This in turn will tend to impart a serious upward bias in the parameter estimate that would substantially overstate the effectiveness of the safety feature in reducing injury severity. Again, there are statistical corrections for this, but they are often overlooked in model estimation. Yet another example would be an attempt to capture the true effect of a posted speed limit on the frequency and severity of crashes. However, again there is a self-selectivity present in that speed limits may be set as a function of road classification or may be influenced by past crash histories. For example, a 70 mi/h maximum speed will likely only be observed on full-access-controlled rural interstates, so all of the unobserved characteristics (unobserved heterogeneity) of such roads may end up being captured by the model's parameter estimate of the speed limit variable, which may then tend to over or under estimate the true effect of the speed limit. Similarly, highways with many crashes (for whatever reason) may be given lower speed limits to improve safety, but a poorly specified model (with potentially important missing variables that truly explain why the highway is dangerous) may conclude that lower speed limits are less safe because the roads with low speed limits will be correlated with a higher than expected number of crashes. Resolving the self-selectivity/endogeneity issue can be achieved through various statistical corrections, but this is not done nearly enough in accident-related research and there is an urgent need for future studies to give full consideration to this issue.

Conclusion:

It is clear from the above discussion that accident research has benefited greatly from the application of more appropriate, and often more sophisticated, statistical methodologies. The application of these new statistical methodologies has enabled researchers to extract important new inferences from available data. However, many important methodological issues remain relating to model specification, unobserved heterogeneity, selectivity-bias/endogeneity, risk compensation, missing data, addressing spatial and temporal correlations, and so on. Important new data sources, such as data from naturalistic driving, are becoming available, but many of the fundamental issues facing the statistical modeling of current data will also pervade these new data sources, and many new methodological concerns will most certainly arise from these sources. To be sure, there have been recent methodological applications such as random parameters models, finite-mixture/latent-class models, multi-state switching models, and others that hold considerable promise for improving the statistical analysis of current and future data sources. Considering the above, the development and application of analytic methods in accident research is entering an era of unprecedented opportunities. This era that is being brought about by a combination of recent advances in methodological techniques and the availability of exciting new data sources. To show the interaction between methodology and data in the field and how it is evolving, it could be easily argued that the accident-research field has been dealing with relatively static data (quantity and quality) for decades (primarily police-reported crash data). This has kept a virtually constant "data frontier" while the "methodological frontier" has marched, in many respects, well beyond data capabilities. This is illustrated in Figure 3, where it can be seen that the methodological opportunities have been limited by data availability from traditional sources. However, as illustrated in Figure 4, the advent of many emerging data sources is beginning to greatly expand the data frontier, creating an urgent need for new methodological advances. As research relating to the statistical analysis of highway crash data (and new data that can provide information on near-crash events) progresses, it is important that researchers continue to address the fundamental methodological questions and continually strive to expand the methodological frontier. Not expanding the methodological frontier, and continuing to use methodological approaches with known deficiencies, has the potential to lead to erroneous and ineffective safety policies that may result in unnecessary injuries and loss of life.

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