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16. Abstract

This report describes a software tool that is being developed at UMTRI to represent the effects of nonindependent safety measures (the Unified Tool for Mapping Opportunities for Safety Technology, UTMOST). The tool has as its core a model representing crashes in terms of precrash conditions, occupant characteristics, crash type, and outcome. Overlaid on this is a model of the effect of implementing each of a number of safety measures, including public policy and technological measures. This portion of the model allows for visualization of the potential benefits of various approaches and combinations of approaches to safety. UTMOST is being developed and validated using existing U.S. crash databases for the purpose of understanding future safety trends in the U.S., as well as current differences between the U.S. and selected other countries, and future trends in those countries. Our goal is to be able to use this model to: 1) predict the benefit of specific changes in policy or technology in the context of other safety measures; 2) describe the largest remaining problems after a policy or technology has been implemented; and 3) assess the overall safety performance of individual vehicles, both in general and with respect to particular demographic groups.

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Introduction

Over many years, automotive safety in the U.S. (as measured by fatalities per vehicle-mile) has improved at the same time that vehicle-miles traveled have gone up. The improvement in fatality rate has come through a wide variety of efforts. Examples include public policy changes (e.g., seat-belt laws), improvements in crashworthiness (e.g., side airbags), and increasingly, crash-avoidance technology (e.g., electronic stability control). These examples indicate that multiple approaches to safety are being used to address a common problem in different ways. Each of the approaches also involves a characteristic set of costs. Because different safety measures can influence the same kinds of crashes, some choices may depend on the costs of implementing each safety measure.

Because the effects of safety measures are not independent, it is important to assess the benefit of any approach to safety, whether technological or behavioral, in the context of alternative approaches. Moreover, the demographics of the occupant population will influence the relative benefits of one kind of safety measure over another. For example, the U.S. population is aging (USDHHS, 2006), and some approaches to safety are more effective for elderly people than others. In some cases, it matters whether elderly occupants are drivers or passengers. Such demographic issues interact with other safety issues at all levels of analysis, and thus must also be incorporated into a comprehensive assessment of benefit.

This report describes a software tool that is being developed at UMTRI to represent the effects of nonindependent safety measures (the Unified Tool for Mapping Opportunities for Safety Technology, UTMOST). The tool has as its core a model representing crashes in terms of precrash conditions, occupant characteristics, crash type, and outcome. Overlaid on this is a model of the effect of implementing each of a number of safety measures, including public policy and technological measures. This portion of the model allows for visualization of the potential benefits of various approaches and combinations of approaches to safety.

The Five Major Risk Factors

Sivak, Luoma, Flannagan, Bingham, Eby, & Shope (2006) examined the current state of road traffic safety in the U.S. and presented a list of the five risk factors that, if they could be addressed, would yield the largest improvements. Those factors are: alcohol, failing to use seat belts, young drivers, nighttime driving, and speeding. They listed the proportion of crashes influenced by each, which can be used as an estimate of the potential benefit if the problem could be entirely solved. However, they also noted the lack of independence of these problems, as indicated by the fact that the total estimated benefit from addressing all five problems is a reduction in crashes of more than 100%.

Sivak et al. (2006) discussed the possible countermeasures for each of the five major risk factors, and in each case they concluded that, although new vehicle technologies could be effective and should be pursued, there was also an opportunity for substantial improvement using established means—including means that involved primarily changes in policy and driver behavior. If that view is correct, it suggests that in a model designed to assess the potential benefits of crash-avoidance technologies, it is important to provide for incorporating the current and the possible future states of policy on these five issues. For example, the overall benefit of electronic stability control might depend on how well speed limits are enforced.

Sources of Data

A comprehensive model of safety benefit should be built using as much hard data as possible. The National Highway Traffic Safety Administration (NHTSA) keeps a number of databases of crashes in the U.S. A survey of the characteristics and availability of international crash databases was provided by Luoma & Sivak (2006). Table 1 shows a list of some U.S. databases and their strengths and weaknesses.

Table 1
Characteristics of major crash databases in the U.S.

Database	NASS-GES	NASS-CDS	FARS	CODES	CIREN
Cases/Year	50,000	5,000	~ 43,000	varies	400
Sampling Criteria	Sample survey of all police-reported crashes	Sample survey of all tow-away crashes	All fatal crashes	14 States; links police reports and hospital data	Complex, but all cases are severely injured
Data Source	Police Accident Report (PAR)	Crash investigation	PAR	PAR	Crash investigation & medical records
Costs	No	No	No	Yes	Yes
Injury Codes	No	Yes (AIS)	Some	Yes (OCD-9)	Yes (OCD-9, AIS)
Crash Detail	Limited	Yes	Limited	Limited	Yes
Precrash detail	Limited	Limited	Limited	Limited	Limited
Strengths	Sample size & comprehensive national weights	Detail & crash investigations; national weights	Census	Large sample size	Detail on worst outcomes and biomechanical scenarios
Weaknesses	Lack of detail & investigation	Smaller sample size	Lack of detail & crash investigation; can't estimate risk	Only some states & no national weights; lack of detail	Not stratified sample; smaller sample size; can't estimate risk

The crash databases listed in Table 1 can be used in combination to generate a model that gives a good representation of types of crashes and the outcomes for occupants. Much of the past work with these databases has been on improving crashworthiness, and they are rich in data relevant to crashworthiness. However, as the development of crash-avoidance technologies has progressed, there has been more concern that the databases are not as strong in information on precrash conditions and on exposure to relevant crash conditions. Naturalistic-driving databases are becoming more available, although so far the sampling of the national driving population has been limited. Therefore, for the immediate future a comprehensive model of benefit must incorporate relatively weak data and assumptions about precrash conditions and exposure—circumstances for which substantially better data may soon be available.

Crash Taxonomies

In order to make effective use of crash data in understanding the possible benefits of safety measures, it is important to use an appropriate classification system, or crash taxonomy. Taxonomies can be developed at many different levels; at the most complex, a taxonomy could consist of the complete cross tabulation of all cases in a database. However, for practical purposes it is usually necessary to summarize the data in some way. In order to understand the possible effects of new crash-avoidance technologies, it is important to include two types of information. First, crashes must be characterized in terms of their relevance to occupant outcome. For example, the location of damage on a vehicle is closely related to the probability of occupant injuries and the nature of those injuries. However, location of damage may be less informative for determining the relevance of various types of crash-avoidance technology than other variables, such as the type of maneuver involved. Thus, a second type of information should describe elements of the crash relevant to avoidance, and the UTMOST model is designed to have both an outcome-relevant taxonomy and a technology-relevant taxonomy.

The elements of outcome-relevant taxonomies have been studied extensively over many years. For example, typical models of injury risk in crashes include the CDC code as well as crash-severity measures such as delta-V and intrusion. The CDC code uses four letters to describe aspects of the damage location, as well as whether the damage was wide or narrow. Other potential outcome-relevant measures include principal direction of force (PDOF), which describes the direction the occupants moved within the vehicle after impact. Delta-V and intrusion distributions will vary in reasonably well-established ways with these outcome-relevant crash variables.

In contrast, technology-relevant crash taxonomies are probably less well developed, and must describe a more complex set of circumstances. Such taxonomies can be based on variables such as location of the crash relative to an intersection, avoidance maneuver attempted, and the influence of driver distraction. Recent work has begun to use these kinds of variables to categorize crashes and identify those that might be affected by different avoidance technologies. For example, Najm, Sen, Smith, and Campbell (2003), identified a number of precrash features that could be important for crash avoidance technology. They discussed a number of crash classifications, and in some cases gave cross-tabulations for them. In one analysis, they described crashes in terms of their relationship to an intersection, the traffic control present, and the maneuver attempted, among other variables. Their approach, which maintains several classification schemes, has the advantage of allowing the data to be viewed in different ways, depending on the solution being considered.

Development of the Tool

Goals

The UTMOST system is being developed with a number of goals in mind. First, it is meant to assess the benefit of new safety technologies in the context of other safety measures—primarily those that would affect the five major factors discussed by Sivak et al. (2006). For example, if belt use rates continue to go up and the population ages, then what will be the added benefit of forward-collision warning in five years, or ten years?

Second, it is meant to assess the overall benefit of a collection of safety features on a specific vehicle. This would also incorporate driver demographics for the vehicle, which could be specific or average. Clearly, driver demographics will have a great influence on the total harm involving that vehicle. Such driver effects will not necessarily be related to the safety components of that vehicle, so that, at a simple level of analysis, specific demographics may distort the apparent safety value of a given vehicle, relative to other vehicles (e.g., minivans driven by soccer moms relative to passenger cars driven by young males). A comparison among vehicles would need to be made for a standardized population. However, customized safety features could be a cost-effective way to reduce total harm, to the extent that the nature of a vehicle's driver population is relatively stable. For example, a vehicle driven mostly by older drivers might incorporate 4-point belts or other restraint systems that are tuned for maximum distribution of forces so as not to load older bones, especially ribs. In contrast, a vehicle driven largely by younger drivers might incorporate electronic stability control to reduce the single-vehicle run-off-road crashes that are more common among inexperienced drivers.

Third, UTMOST is intended to model the collective effects of new safety technologies and any changes in the five major safety factors, and then characterize the nature of the remaining crash problem in order to identify the most promising further countermeasures. The flexibility of the technology-relevant taxonomy will be critical for this purpose because the goal is to identify areas in which technology could do the most good. Since the technology is not necessarily well defined, the description of the remaining crashes must be as rich as possible.

Components of the Tool

First, in order to represent the total harm from current crashes, and possible changes in total harm that could be achieved by reducing a particular mix of those crashes, the model needs to incorporate one or more cost metrics. The metric will ultimately drive the relative merits of different safety measures, so it may be important to include multiple metrics and be able to consider possible benefit in several ways. Table 2 lists some possible cost metrics that could be included.

Table 2
Potential Cost Metrics

Metric	Description	Source
Incidence	Each crash is counted equally, regardless of outcome	
MAIS	Maximum injury, based on AIS is assigned a cost	Blincoe et al. (2002)
Fatality Only	Only fatalities are counted and are assigned a cost of $3.7 million	Saelensminde (2003)
MAIS plus fatality	MAIS metric is used, but fatalities are assigned a cost of $3.7 million	Blincoe et al. (2002); Saelensminde (2003)
All Injuries	All injuries are assigned a cost based on details of the AIS code	Zaloshnja, Miller, Romano, & Spicer (2004)

The second component is a model of outcome probability as a joint function of the categories in the outcome-relevant taxonomy and of demographics. This model is based on the crash data and relationships among variables in those data. Figure 1 shows a simplified version of such a model, applied to one crash type. In this example, frontal crashes occur with some probability (p(frontal)), and within frontal crashes, there is a distribution of crash severity. Next, there is an injury risk associated with each crash severity. When the probabilities are multiplied by injury cost and summed across the range of severity, they result in a total expected cost associated with the crash type. It is important to note that each of these components is affected by other variables such as age, gender, and precrash conditions. The underlying model must account for those influences, but Figure 1 is meant to illustrate the simplest model of outcome-based costs.

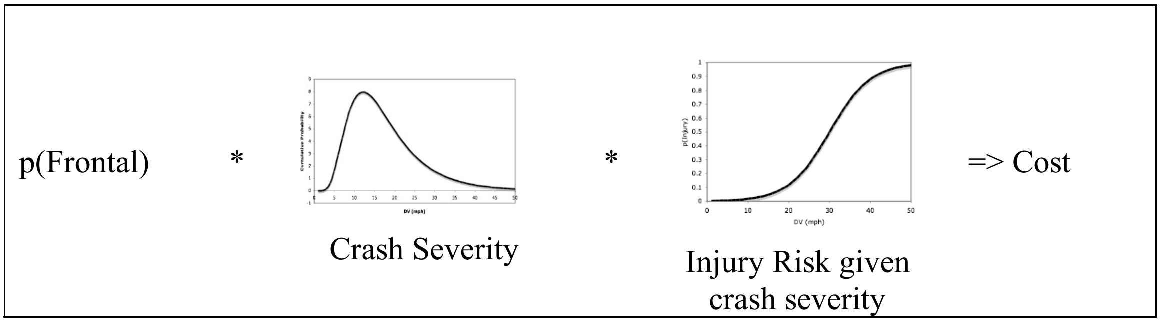

Figure 1. Schematic illustration of linkages between crash type and cost, incorporating the crash-severity distribution associated with the crash type and the risk of injury associated with each crash severity. The total cost is summed over all crash severities.

Eventually, this component of the tool could be expanded to incorporate dummy response in different vehicles. One of the ways in which NHTSA can influence safety is to change the requirements for dummy response in crash tests. These responses have been studied extensively, and in many cases, the relationship between dummy responses and human risk is understood and can be incorporated in this tool.

The third component is a model of the links between the technology-relevant taxonomy and the outcome-relevant taxonomy. These taxonomies are almost entirely categorical, and so such a model generally takes the form of a log-linear model of the cross tabulation of crashes in the two taxonomies. This model will ultimately, as with all parts of the tool, incorporate demographic components, especially age and gender.

The fourth component of the tool is a characterization of the crash types affected by existing or future safety technologies. This is an area in which there is substantial uncertainty, but a useful and growing amount of data from a variety of sources. There are currently research programs aimed at answering this question through simulation and on-road testing. The tool is designed to incorporate the results of that work as it becomes available. In addition, the tool can be used for making initial, provisional estimates of the possible benefits of highly innovative crash-avoidance technologies by incorporating a range of reasonable estimates of the kinds of crashes that would be affected, and how much they would be affected.

Illustrative Prototype

A prototype of UTMOST has been developed to illustrate how it is intended to operate. For the prototype, occupant-level data from NASS-CDS years 1998-2005 were assembled in an Excel spreadsheet. Variables representing crash type (based on damage location or rollover condition), alcohol involvement, restraint, gender age, speeding, delta-V, avoidance maneuver, and relationship to intersection were included, along with the case weight.

Figure 1 shows the front panel of the UTMOST prototype in its base state. The base state is a straightforward summary of the NASS-CDS data for the years included, with no implementation of any models of the possible effects of new safety measures. The panel contains three components. In the upper left, three bars represent alternative cost metrics, any one of which may be appropriate depending on the user's intentions. The first, labeled *incidence*, simply represents the number of occupants in crashes per year. The second represents the total cost of their injuries, based on maximum AIS (Blincoe et al., 2002). The third represents the total cost of only the most severe injuries. For this metric, the same AIS-based costs were applied, but only MAIS of three or more was considered. In the starting state, all costs are normalized at 100% to represent the current state (actually, the recent past, from 1998 to 2005).

The second component of Figure 1 is a set of six sliders that allow the implementation of six models of changes to the state of traffic safety. The first slider represents the aging of the driver population. The next five sliders represent implementations of policies aimed at curbing the five major risk factors identified by Sivak et al. (2006). The models underlying these sliders reflect the outcome of policies without regard to the way in which they might be implemented. For example, the alcohol slider progressively reduces the weight assigned to alcohol-related crashes as it is moved to the right. The model does not change if the reduction is envisioned as resulting from changes in penalties for drunk driving or from the installation of alcohol interlocks in vehicles.

The third component of Figure 1 is a pie chart representing the proportion of the total severe-injury cost that is attributed to various crash types. In the base state, the cost of severe injuries from frontal crashes is approximately twice the cost from near-side impacts. The two together account for almost two-thirds of the total cost.

Figure 2 shows the panel after full implementation of the belt-use slider, representing a hypothetical future state with 100% use of seat belts. In the spreadsheet, this slider re-weights crashes so that those with unbelted occupants are weighted proportionately lower and those with belted occupants are weighted proportionately higher. In this model, increased belt use has no effect on the number of occupants involved in crashes, but it reduces the harm done to them. The cost metrics in Figure 2 reflect this: the incidence bar remains at 100%, but the two cost bars are markedly reduced. Interestingly, the effect of belt use on the most severe injuries is quite substantial.

The pie chart in Figure 2 illustrates how the remaining cost of severe injuries is distributed among crash types. In comparison to the recent past, a greater percentage of the remaining cost after achieving 100% belt use would be associated with side impacts. It appears that belt use preferentially helps in frontal impacts and rollovers, reducing their contributions to cost. However, belt use is less beneficial in side impacts, leaving those crashes with a greater share of the remaining cost. This result suggests that if a fully effective belt-use policy were implemented, it might then be desirable to give additional weight to countermeasures such as side airbags and intersection-collision avoidance, both of which affect the outcome of side impacts.

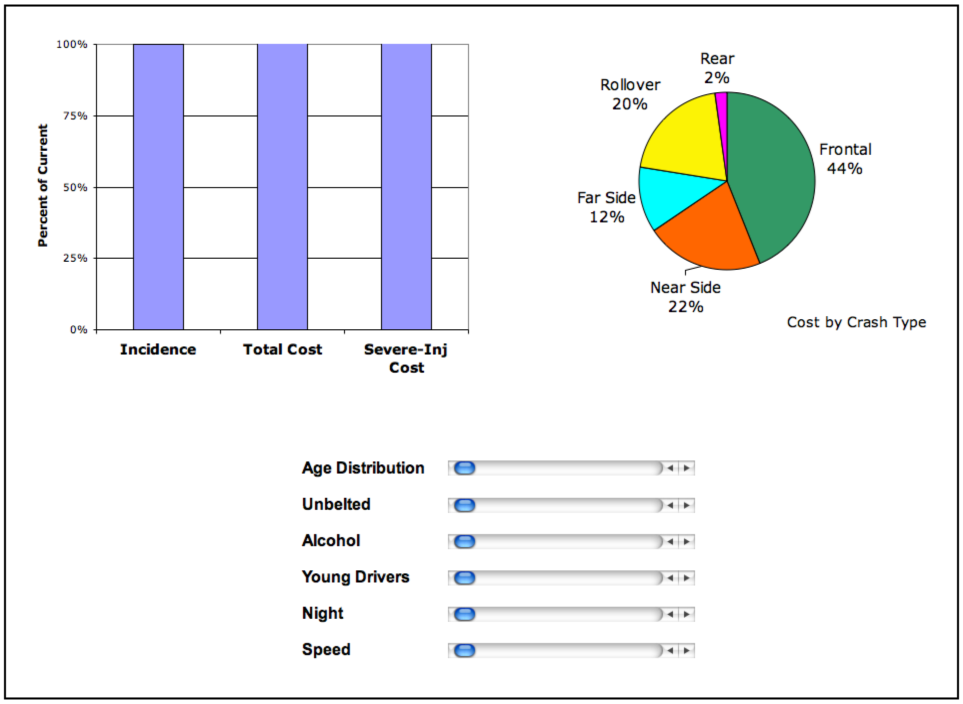

Figure 1. Front panel of prototype UTMOST showing base (current) state of crash costs. See text for details.

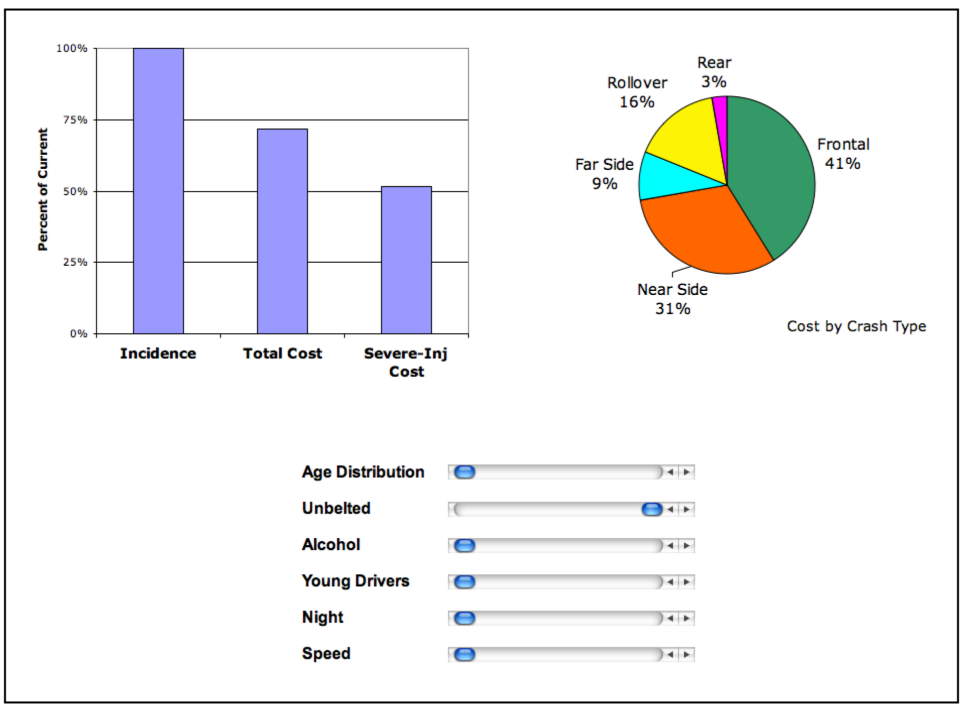

Figure 2. Front panel of prototype UTMOST showing a hypothetical modified state of crash costs. See text for details.

Figures 1 and 2 are intended to illustrate the kinds of elements that will be included in UTMOST to allow visualization of the combined effects of safety measures. However, the prototype illustrated in Figures 1 and 2 differs from the full implementation of UTMOST in a number of ways. Most importantly, the prototype implementation relies on changing the weights of actual observations from NASS-CDS. The full version, in contrast, will include a mathematical representation of the relationships among crash descriptors, occupant descriptors, and outcome descriptors. This approach will make it possible to implement more detailed models of how safety measures should affect outcome. For example, in the prototype, safety measures affecting night crashes can only be modeled by changing the weight on some or all nighttime crashes in the database. However, nighttime crashes involve a greater proportion of alcohol and fatigue, neither of which is likely to be affected by a countermeasure such as improved lighting, for example. In a mathematical representation of the database, the effect of light can be isolated from the effect of fatigue, allowing for a better estimate of the potential benefit of improved lighting.

Validation

There are several opportunities to validate the tool. Within existing U.S. data, versions of the tool can be built on past data and then used to predict one or more recent years. For example, NASS-CDS from years 1998-2003 could be used to build the component models, and the years 2004-05 can be validation years. Beyond the U.S., to the extent that it is possible to obtain data comparable to the U.S. databases (Luoma & Sivak, 2006), it would be very useful to validate predictions of the models across the differences in demographics and roadway infrastructure that are known to exist between countries.

Worldwide Applicability

Because of the detail and universal availability of crash data from the U.S., UTMOST is initially being built using U.S. databases. However, the ultimate goal is to adapt the model for application to other countries. The applicability of U.S. safety trends to other countries will depend a great deal on how similar the countries' traffic systems are to those of the U.S. In general, UTMOST makes it easy to change assumptions about exposure and demographics to represent the safety situation in other countries. Many aspects of the component models of UTMOST should remain valid across countries, once appropriate adjustments are made. For example, once a vehicle is involved in a crash of a specific type, outcome should be affected in predictable ways by crashworthiness features of vehicles and occupant demographics.

The differences across countries should be systematically related to quantifiable differences in circumstances such as the types of roads, the number of vehicles, and the exposure to different types of crashes. For example, as discussed by McManus (in press), China is in a phase of its transportation development in which safety is worsening as more people buy and drive cars on an insufficient infrastructure. For the current state of transportation in China, some parts of the U.S. model will not be directly applicable. However, it is likely that enough parts are transferable to make the attempt worthwhile, including effects of age and gender, as well as possibly historical data from the U.S. and other countries in which there is a longer record of road traffic safety. In other heavily motorized areas, such as Japan and Europe, extension of the model could be more direct, involving primarily changes in exposure and demographics, because traffic conditions in those areas are more similar to those in the U.S. As data become available from other countries, the model can be further tested by attempts to represent the various outcomes for their transportation systems.

Summary

As approaches to safety become more varied and more sophisticated, the difficulty in assessing the benefit of each measure becomes more challenging. Moreover, it becomes more important to treat safety in a comprehensive way to avoid missing important interactions among new safety technologies. Many safety approaches will affect the same crashes, so it is unlikely that individual safety measures will fully achieve their apparent potential benefit. It is therefore important to implement safety measures in a way that maximizes the actual benefit of the whole, preferably for the lowest cost.

The UTMOST system is intended to represent the joint effects of all types of safety countermeasures—including those based on public policy, demographics, crashworthiness, and crash avoidance technology. This tool is being developed and validated using existing U.S. crash databases for the purpose of understanding future safety trends in the U.S., as well as current differences between the U.S. and selected other countries, and future trends in those countries. Our goal is to be able to use this model to: 1) predict the benefit of specific changes in policy or technology in the context of other safety measures; 2) describe the largest remaining problems after a policy or technology has been implemented; and 3) assess the overall safety performance of individual vehicles, both in general and with respect to particular demographic groups.

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