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NEW DEVELOPMENTS IN UTMOST: APPLICATION TO ELECTRONIC STABILITY CONTROL

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APPLICATION TO ELECTRONIC STABILITY CONTROL

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16. Abstract

The Unified Tool for Mapping Opportunities for Safety Technology (UTMOST) is a model of crash data that incorporates the complex relationships among different vehicle and driver variables. It is designed to visualize the effect of multiple safety countermeasures on elements of the driver, vehicle, or crash population. We have recently updated UTMOST to model the effects of the time-course of fleet penetration of vehicle-based safety measures, as well as changes in the populations of drivers and vehicle types in the fleet. This report illustrates some of the capabilities of UTMOST with examples of predicted effects for one reasonably well understood countermeasure (electronic stability control, ESC) and three countermeasures just entering the vehicle fleet (forward collision warning, FCW; road departure warning, RDW; and lane change warning, LCW). Results include the relative effects of the countermeasures on the overall number of crashes and on drivers of different ages. The report also illustrates the time-course capability of UTMOST by showing year-to-year savings in serious injuries and fatalities for a driver-based countermeasure (increased belt use), which would have an immediate effect throughout the vehicle fleet, compared to ESC, which as a vehicle-based countermeasure would affect new vehicles as they enter the fleet.

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CONTENTS

INTRODUCTION

In a previous report, we described the development of the Unified Tool for Mapping Opportunities for Safety Technology (UTMOST), a model of crash data that can be used to visualize the complex effects of different countermeasures on total harm in road crashes (Flannagan & Flannagan, 2007). In the present report, we illustrate some of the capabilities of UTMOST by using it to model the effects of electronic stability control (ESC), by itself and in the context of some additional countermeasures.

Three recent UMTRI reports described the current states of vehicle safety in China (Zhang, Tsimhoni, Sivak, & Flannagan, 2008), India (Mohan, Tsimhoni, Sivak, & Flannagan, 2009), and Brazil (Vasconcellos, & Sivak, 2009). Each of these reports included a discussion of possible countermeasures, organized in terms of the three-dimensional representation of total harm that is illustrated in Figure 1. The three sides of the cube, which is based on the work of Thulin and Nilsson (1994), are exposure, risk, and consequences; total harm can be represented as the product of these three factors. Any change to one side of the cube increases or decreases the volume accordingly.

The cube is a useful way to visualize total harm, to categorize the effects of countermeasures, and to begin to estimate their effects. However, the full analysis of total harm can be more complex because exposure, risk, and consequence are neither constant nor independent across subgroups of the driver population. For example, young drivers generally have higher crash risk but experience lower consequences than older drivers. UTMOST represents such interactions in crash datasets in order to estimate how the effects of countermeasures on various crash types will combine in reducing total harm.

We described the structure of UTMOST in detail in the previous report (Flannagan & Flannagan, 2007). However, a few key elements are worth reviewing here. UTMOST is based on data from U.S. national databases, including the National

Automotive Sampling System's General Estimates System (GES) and Crashworthiness Data System (CDS), as well as the Fatal Analysis Reporting System (FARS). UTMOST is built on a cross-tabulation of crash type, vehicle type, and driver demographic variables from GES. This is expanded using a series of models, including an occupancy model, a model of crash direction as a function of crash type and driver, a model of the crash severity distribution for each crash scenario, a model of belt use, and a model of risk as a function of all of the above.

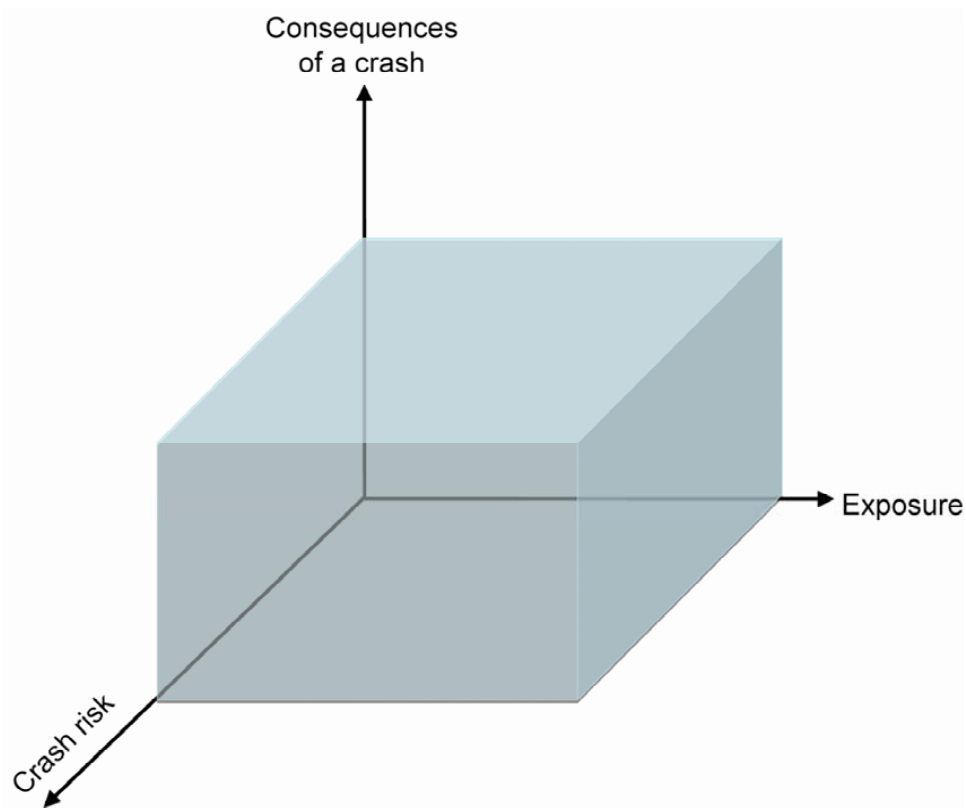

Figure 1. Total harm as the volume formed by a three-dimensional space of exposure, risk, and consequences. (Adapted from Thulin & Nilsson, 1994.)

Since the 2007 report, a version of UTMOST has been implemented on a website that has been made available to members of the Sustainable Worldwide Transportation consortium. The web version can be used to examine the predicted effects of various countermeasures on the overall crash picture in the U.S. The website includes two outcome measures: crash count and injury cost. Cost estimates use the formula from Blincoe and colleagues (Blincoe, Seay, Zaloshnja, Miller, Romano, Luchter, & Spicer, 2002) for cost as a function of maximum injury on the Abbreviated Injury Scale (AAAM, 1998). Most countermeasures are implemented so that different levels of effectiveness can be explored. Once a countermeasure is selected, the user can examine the change in crash count or crash cost that would occur if the countermeasure were implemented with various levels of effectiveness. Predicted safety effects can be graphed and broken down by a variety of variables, including driver age and vehicle type.

The web version of UTMOST does not yet include modeling of the time-course over which countermeasures enter the fleet. However, we have recently added that capability to a development version of UTMOST. The model can therefore predict year-by-year changes in crash outcomes based on various potential scenarios for fleet penetration.

In this report, we illustrate the current capabilities of UTMOST by applying it to electronic stability control (ESC), under different scenarios and in comparison to other countermeasures: forward collision warning (FCW), road departure warning (RDW), and lane change warning (LCW). The results are all from the current web implementation, with the exception of the time-course results, which are from the development version.

ANALYSES

Independent and Combined Effects

We used UTMOST to estimate the overall reductions in police-reported crashes that could be expected from four countermeasures (ESC, FCW, RDW, and LCW) implemented both independently and in combination with each other. Results for the individual countermeasures are presented in Table 1. All crash reductions are relative to the number of police-reported crashes that UTMOST predicts would occur in a typical year without the influence of additional countermeasures (5,964,193). This prediction does not precisely apply to any one specific year, but can be thought of loosely as a representation of the current state of safety in the U.S. More specifically, it is based on GES data from 2002 to 2007. As represented by UTMOST, "current" conditions are therefore actually an average of conditions in the recent past. For many purposes, this will not matter, but for others it may. The baseline data used by UTMOST can of course be changed when it does matter, but there will always be a tradeoff between temporal specificity (for which perhaps only a single year of data would be chosen) and overall statistical power (for which it is better to use many years of data).

Table 1
Potential reduction in annual crashes assignable to various countermeasures (assumes 100% fleet penetration for each countermeasure individually).

Countermeasure	Effectiveness for relevant crashes	Crash reduction	Percent of total[1]
Electronic Stability Control (ESC)	0.45 cars 0.72 larger vehicles	459,852	7.71%
Forward Collision Warning (FCW)	0.49	885,438	14.85%
Road Departure Warning (RDW)	0.24	148,238	2.49%
Lane-Change Warning (LCW)	0.37	163,589	2.74%

[1] Percentage is of all police-reported crashes, at all levels of severity (5,964,193 annually).

The effectiveness values in Table 1 are taken from information available in the literature. ESC has been available in production vehicles for some time, and therefore has relatively good estimates of effectiveness available. The definitive work from NHTSA is by Dang (2007). She estimates the overall effectiveness of ESC to be 45% for cars and 72% for SUVs, vans, and light trucks. The relevant crashes include run-off-road, loss of control, and rollovers.

In UTMOST, ESC is implemented as a reduction in five types of crashes from the Volpe taxonomy (Najm, Smith, & Yanagisawa, 2007): control loss with and without maneuver, run-off-road with and without maneuver, and rollover. Reduction of 0.45 is used for cars and 0.72 for larger passenger vehicles. Interestingly, in theory, ESC should only work when there is a driver maneuver such as braking or steering. In GES, many more crashes are classified as "no maneuver" than "with maneuver," based on police reports. However, if only no-maneuver crashes are counted, the total number of crashes reduced is not nearly high enough to correspond to the published estimates for crashes prevented by ESC. Thus, we chose to implement ESC on all control-loss, run-off-road, and rollover crashes, without regard to police-reported prior maneuver. We hypothesize that police may record maneuvers only when clear evidence is present, thereby biasing the data towards no-maneuver designations.

For systems that are not widely available on production vehicles, effectiveness is not as well established as it is for ESC, and our implementation allows the user to choose the effectiveness level. However, UTMOST includes as recommendations the values in Table 1 for FCW, RDW, and LCW, based on the available literature. The recommended effectiveness value for FCW (0.49) is a rounded average of two slightly different values (0.477 and 0.51). The lower value is directly from the work of Najm, Mironer, and Yap (1996), whereas the higher value is a corresponding estimate as reported in a summary of benefits of Intelligent Transportation Systems (Proper, Maccubbin, & Goodwin, 2001). (The slight discrepancy appears to be because of different use of "total" versus "relevant" crashes as a denominator value. Other estimates used in UTMOST are the same in both the 2001 and earlier reports.) The effectiveness value for RDW (0.24) is from the work of Emery, Daniel, Hertz, Partyka, Wang, and Mironer (1996), and the value for LCW (0.37) is from Tijerina and Garrott (1996).

As with many other decisions that we have made in developing UTMOST, we do not regard these choices for estimated effectiveness as definitive. Clearly, many values are still open to further research and analysis. Our strategy for UTMOST, in this and similar cases, has been to make decisions somewhat arbitrarily when necessary, but always to document the sources of the values used, so that the strengths and weaknesses of the current version of UTMOST can be determined, and future research can be used to make improvements. The values we have used for FCW, RDW, and LCW are all from 1996, and various newer estimates are available. For example, the later work by Najm, Stearns, Howarth, Koopman, and Hitz (2006) has certainly advanced understanding of the possible benefits of FCW. However, the estimates from 1996 are based on clear principles and are well documented, so that their strengths and weaknesses can be reviewed and understood. They also form a methodologically consistent set. These qualities make them attractive as recommended values to include in UTMOST, at least for comparison purposes. The structure of UTMOST makes it simple to incorporate alternative estimates as desired.

FCW is implemented as a reduction in rear-end collisions and object crashes; RDW is implemented as a reduction in road-departure crashes, with and without maneuver; and LCW is implemented as a reduction in lane-change crashes. Although the effectiveness for these countermeasures is not yet fully determined, the number of crashes prevented, relative to the estimated effectiveness, can give some idea of the overall size of the problem addressed by each countermeasure. For example, FCW addresses a much larger problem than any of the others. Thus, even at a lower effectiveness, FCW could have a large effect on the overall crash picture.

Although the four countermeasures in Table 1 appear to cover, in combination, a total of 28% of all crashes, there is overlap in the crashes addressed by these systems that reduces the actual total coverage. In particular, ESC and RDW both address the problem of road-departure crashes. ESC is an automatic system that applies brakes to avoid loss of control when turning or on slippery roads, situations that frequently result in the vehicle leaving the road. Although ESC is very effective in preventing this loss of control, it only works if the driver is braking and/or steering.

In contrast, RDW is a warning system that alerts the driver when the vehicle is leaving the road. Some road-departure systems are combined with a curve-speed warning system (e.g., Wilson, Stearns, Koopman, & Yang, 2007), which is designed to address pre-conditions of loss of control. In an effort to separate the effects of different systems, RDW is implemented in UTMOST without a curve-speed warning component, and therefore affects only road-departure crashes and not loss-of-control crashes. Although RDW works in situations in which the driver is inattentive and not braking or steering, it cannot directly prevent the loss of control that often leads to road-departure crashes. Thus, the crashes saved by these countermeasures are partially overlapping.

The overlap in the effects of ESC and RDW illustrates an important feature of UTMOST: the ability to assess the combined effect of countermeasures or to assess the additional effect of a particular countermeasure after a related one is implemented. Currently, ESC is widely available in production vehicles and is, in fact, mandated in a phased form starting with model year 2009 (NHTSA, 2007). Thus, it makes sense to look at the potential effect of RDW *after* the effect of ESC is considered. As shown in Table 1, UTMOST suggests that 7.71% and 2.49% of current crashes would be prevented by ESC and RDW individually. For RDW in the context of prior full implementation of ESC, the corresponding UTMOST prediction is an additional reduction of 1.60%. Thus, the crash reductions that would be expected from a prior implementation of ESC would reduce the expected benefit of RDW by a factor of 1.60% divided by 2.49%, or 0.64.

Benefits for Subgroups of Drivers

Because different types of drivers tend to be involved in different kinds of crashes, the safety benefits of certain countermeasures can be expected to differ by driver subgroup. UTMOST has been designed to make quantitative predictions for such differences, including estimates of the effects of various countermeasures on subgroups of crashes, drivers, or occupants. Driver age is a particularly important variable, with strong associations with various driving behaviors and the kinds of crashes that drivers are involved in. As a result, countermeasures have different overall safety benefits for different subgroups based on driver age. For example, ESC affects crashes that often result from errors that are more common among young drivers, including speeding, oversteering, and other judgment errors.

We used UTMOST to derive expected safety benefits for the four countermeasures (ESC, FCW, RDW, and LCW) for seven driver age groups. The results are shown in Figure 2, as crash reductions in terms of percentages within each age group for all police-reported crashes. The patterns for FCW and ESC include strong benefits for younger drivers that decrease with age. In contrast, RDW and LCW, which both have more limited benefit overall, show little age-related variation in their effects.

The relative lack of age trends for RDW compared to ESC may seem surprising. The key to the difference appears to be that, as described above, ESC is implemented as a change to loss-of-control crashes as well as run-off-road crashes, whereas the effect of RDW is implemented only on run-off-road crashes. In GES, the age trends for loss-of-control crashes are much stronger than for road-departure crashes. Loss-of-control crashes are a relatively large percentage of all crash involvements for younger drivers, and the proportion goes down with age. In contrast, among older drivers, road-departure crashes make up a higher percentage of all crashes than they do for middle-age drivers. These trends are consistent with the results in Figure 2, illustrating how UTMOST automatically takes into account many of the complex trends in the GES data.

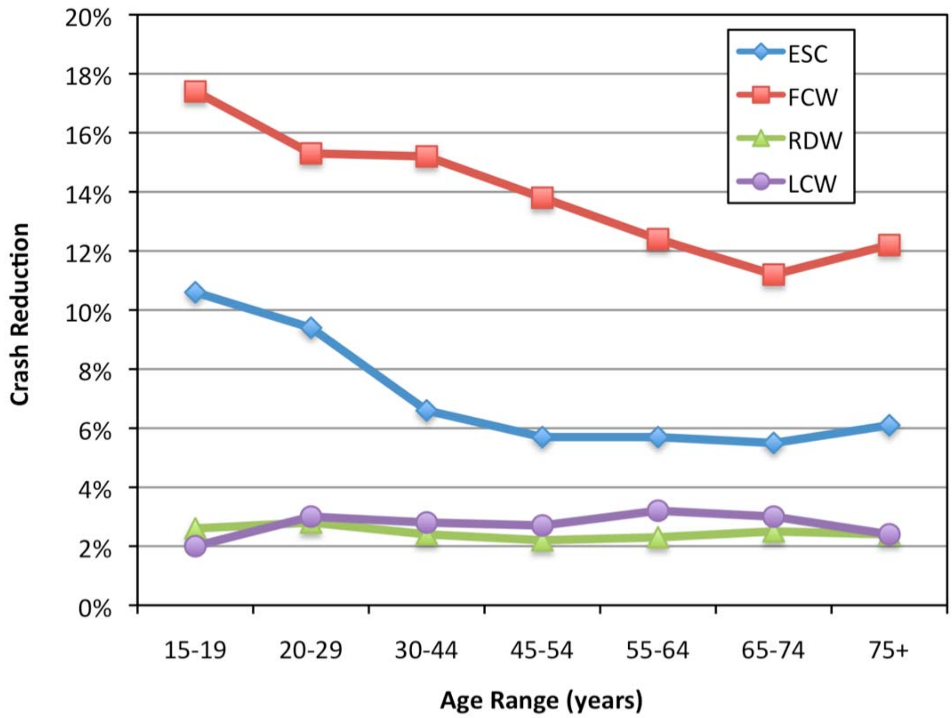

Figure 2. Predicted crash reduction, as percentages of all police-reported crashes for each age group, for four countermeasures implemented independently.

Time Courses for Vehicle-Based and Driver-Based Countermeasures

We have recently incorporated a new feature in UTMOST to account for the time course of entry of vehicle-based countermeasures into the fleet. The expected time course for a given countermeasure may be affected by various assumptions about the future, and UTMOST is designed to be flexible in accommodating such assumptions.

An important, and relatively well understood, aspect of the entry of new vehicle technologies of all kinds is the relationship of new vehicles to driver age. The crash record shows that, especially for more expensive vehicles, middle-aged drivers tend to be the drivers of the newest vehicles more than either younger or older drivers (e.g., Sullivan & Flannagan, 2009). This means that the safest drivers often drive the safest vehicles first, and that, as a consequence, a vehicle-based safety measure may have less effect in its initial years of availability than in later years.

Other time-course elements are less predictable. For example, "cash for clunkers" programs can speed up turnover in the vehicle population (e.g., Sivak & Schoettle, 2009b). Poor economic conditions can have the opposite effect, slowing turnover and changing the composition of the new vehicles that are added to the fleet (e.g., Sivak & Schoettle, 2009a). Similarly, the relative market share of larger and smaller vehicles, for which ESC has different effectiveness, appears to be changing. Larger vehicles are currently less popular than they were several years ago (Edmunds, 2008). However, this trend could change. UTMOST, as a visualization tool, can show the potential effects of a variety of possible market scenarios.

Figure 3 shows the expected effects of some selected possible market scenarios. For a baseline comparison, we include the effect of a 1% increase in belt-use rates per year. As a driver-based countermeasure, any increase in belt use applies immediately throughout the fleet. In contrast, vehicle-based countermeasures such as ESC apply first to new vehicles as those vehicles enter the fleet. Figure 3 shows four ESC market scenarios for comparison. Three scenarios assume different levels of reduction in the large-vehicle market, and one shows the effect of increased vehicle turnover—such as might result from cash-for-clunkers policies, and which would accelerate the introduction of new technologies.

Current belt-use rates are about 82% nationwide (NHTSA, 2008). Since 2001, this rate has increased by an average of about 1.5% per year, though changes have been smaller in the last three years. Even so, continuing, small increases seem possible. For example, a number of states still do not have primary belt-use laws, and introductions of such laws in other states have resulted in increases in belt use. Therefore, the hypothetical scenario with annual increases of 1% over the next several years appears plausible.

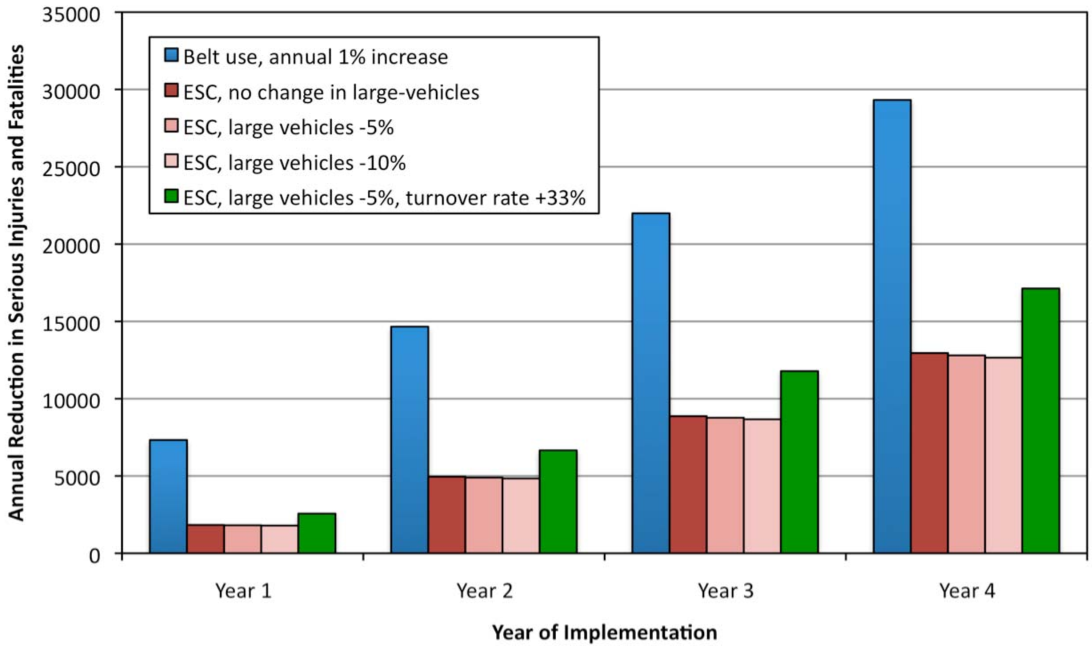

Figure 3. Annual reduction in the number of serious injuries and fatalities for increase in belt use vs. phase-in of ESC under different market assumptions (see text for details).

In the U.S., ESC will be required on all light vehicles starting with model year 2012. Prior to that, NHTSA has mandated a phase-in of ESC with 55% ESC required for MY 2009, 75% for MY 2010, and 95% for MY 2011 (NHTSA, 2007). This phase-in has been implemented in the modeling shown in Figure 3. In addition to the effect of the phase-in, market forces can have an important effect on casualties saved by ESC. Edmunds (2008) reports that large-vehicle sales decreased almost 5% from 2007 to 2008. Since ESC is more effective for large vehicles, such as SUVs, than for passenger cars, the reduction in casualties attributable to ESC should be somewhat lower than it would have been for a fleet with a larger proportion of large vehicles. One way to characterize such an effect would be to say that some casualties were eliminated by the change in vehicle type, so that ESC did not have the opportunity to eliminate them. As Figure 3 indicates, however, the expected reductions in effects of ESC caused by the hypothetical changes in large-vehicle market share (the differences among the red bars) are quite small.

In contrast, the increase that could result from accelerated vehicle turnover is more substantial. By the second year of the ESC mandate, a 33% increase in vehicle turnover (the green, rightmost, bar for Year 2) would result in a reduction in casualties nearly equal to the effect of the 1% increase in belt use in the first year (the blue, leftmost, bar for Year 1). At the vehicle turnover rate that has been typical of the last few years (about 5 %), it would take about three years to see benefits equal to a 1% increase in belt-use rates (the middle red bar for Year 3). Thus, cash-for-clunkers programs, although perhaps intended primarily to improve environmental aspects of driving, could also have significant positive effects on automotive safety.

Consideration of Alternative Outcomes Measures

The comparison between the effect of belt-use rate increases and ESC implementation is complex. Figure 3 shows expected effects on serious injuries and fatalities. Using this outcome measure, an annual 1% belt-use increase reduces the total number of casualties by more than twice that of ESC. However, in a parallel analysis based on crash count, belt use would be completely ineffective and ESC would show substantial savings. This is because belt use, as a passive safety measure, is represented in UTMOST as affecting only outcomes rather than crash occurrence. Cost metrics, which assign a dollar figure to different kinds of injury outcomes are one way to combine this type of information. Since assessing cost is a complex decision that affects public policy, UTMOST is designed to incorporate several alternatives. The choice and interpretation of outcome measures is left to the user.

Extension to Other Countries

One of the goals in the development of UTMOST has been to adapt it for application to other countries. Because of its flexible, modular construction, it is possible to replace some or all of the components that are based on U.S. data with data from other countries. In countries in which the traffic infrastructure is broadly similar to that in the

U.S., it is likely that the relationships between driver characteristics, vehicles, crash types, and outcome are also fairly similar. Even when countries have different distributions of driver ages, different occupancy habits, and different distributions of vehicle types, those elements are easily altered in UTMOST, as long as comparable crash data sets are available.

Application to countries such as India, Brazil, and China may be more difficult because of a lack of detailed crash data (Mohan et al., 2009; Vasconcellos et al., 2009; Zhang et al., 2008). However, applications to those countries using partial data, supplemented by plausible estimates of unavailable data, might still be valuable. Data on the driver age distribution and the vehicle-type distributions could be useful in generating some initial estimates of benefits of some countermeasures.

SUMMARY

The Unified Tool for Mapping Opportunities for Safety Technology (UTMOST) is a model of crash data that incorporates the complex relationships among different vehicle and driver variables. It is designed to visualize the effect of multiple safety countermeasures on elements of the driver, vehicle, or crash population. We have recently updated UTMOST to model the effects of the time-course of fleet penetration of vehicle-based safety measures, as well as changes in the populations of drivers and vehicle types in the fleet.

This report illustrates some of the capabilities of UTMOST with examples of predicted effects for one relatively well-established countermeasure (electronic stability control, ESC) and three countermeasures that are just entering the vehicle fleet (forward collision warning, FCW; road departure warning, RDW; and lane change warning, LCW). Results include the relative effects of the countermeasures on the overall number of crashes and on drivers of different ages. The safety benefits of two of the countermeasures (ESC and FCW) are projected to be substantially greater for younger drivers, whereas the benefits of the other two (RDW and LCW) are projected to apply more evenly to drivers of all ages.

The report also illustrates the time-course capability of UTMOST by showing year-to-year savings in serious injuries and fatalities for a driver-based countermeasure (increased belt use), which would have an immediate effect throughout the vehicle fleet, compared to ESC, which as a vehicle-based countermeasure would affect new vehicles as they enter the fleet. The example results illustrate the acceleration in the growth of benefits from vehicle-based countermeasures that would be expected to result from influences that increase the fleet turnover rate, such as cash for clunkers programs.

REFERENCES

AAAM. (1998). *Abbreviated Injury Scale*. Des Plaines, Illinois: Association for the Advancement of Automotive Medicine.

Blincoe, L., Seay, A., Zaloshnja, E., Miller, T., Romano, E., Luchter, S., & Spicer, R. (2002). *The economic impact of motor vehicle crashes 2000* (DOT HS 809 446). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Dang, J. N. (2007). *Statistical analysis of the effectiveness of electronic stability control (ESC) systems—Final Report* (DOT HS 810 794). Washington, D.C.: National Highway Traffic Safety Administration, National Center for Statistics and Analysis.

Edmunds.com (2008). http://www.autoobserver.com/2008/05/seismic-shift-to-smaller-segments-rocks-us-market-edmunds-analysis-shows.html. Retrieved May 2009.

Emery, L., Daniel, S., Hertz, E., Partyka, S., Wang, J.-S., & Mironer, M. (1996). Preliminary safety benefits for road departure crash avoidance systems. In NHTSA Benefits Working Group (Ed.), *Preliminary assessment of crash avoidance systems benefits* (pp. 5-1 to 5-12). Washington, D.C.: National Highway Traffic Safety Administration.

Flannagan, C. A., & Flannagan, M. J. (2007). *UTMOST: A tool for comprehensive assessment of safety benefits* (Report No. UMTRI-2007-22). Ann Arbor: The University of Michigan Transportation Research Institute.

Kiefer, R. J., Salinger, J, Ference, J. J. (2005). *Status of NHTSA's rear-end crash prevention research program.* Paper presented at the 19th International Technical Conference on the Enhanced Safety of Vehicles, Washington, D.C.

Mohan, D., Tsimhoni, O., Sivak, M., & Flannagan, M. J. (2009). *Road safety in India: Challenges and opportunities* (Report No. UMTRI-2009-1). Ann Arbor: The University of Michigan Transportation Research Institute.

Najm, W. G., Mironer, M. S., & Yap, P. K. (1996). Preliminary safety benefits of a rear-end crash warning system. In NHTSA Benefits Working Group (Ed.), *Preliminary assessment of crash avoidance systems benefits* (pp. 3-1 to 3-18). Washington, D.C.: National Highway Traffic Safety Administration.

Najm, W. G., Smith, J. D., & Yanagisawa, M. (2007). *Pre-crash scenario typology for crash avoidance research* (DOT HS 810 767). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Najm, W. G., Stearns, M. D., Howarth, H., Koopman, J., & Hitz, J. (2006). *Evaluation of an automotive rear-end collision avoidance system* (DOT HS 810 569). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

National Highway Traffic Safety Administration [NHTSA]. (2007). Federal Motor Vehicle Safety Standards; Electronic Stability Control Systems; Controls and Displays. *Federal Register, 72*(66), 17236-17322.

National Highway Traffic Safety Administration [NHTSA] . (2008). *Traffic Safety Facts: Seat belt use in 2007 - Use rates in the states and territories* (Report No. DOT HS 810 949). Washington, D.C.: National Highway Traffic Safety Administration, National Center for Statistics and Analysis.

Proper, A. T., Maccubbin, R. P., & Goodwin, L. C. (2001). *Intelligent transportation systems benefits: 2001 Update* (Report No. FHWA-OP-01-024). Washington, D.C.: U.S. Department of Transportation, Intelligent Transportation Systems Joint Program Office.

Sivak, M., & Schoettle, B. (2009a). *Economic indicators as predictors of the number and fuel economy of purchased new vehicles* (Report No. UMTRI-2009-27). Ann Arbor: The University of Michigan Transportation Research Institute.

Sivak, M., & Schoettle, B. (2009b). *The effect of the "Cash for Clunkers" program on the overall fuel economy of purchased new vehicles* (Report No. UMTRI-2009-34). Ann Arbor: The University of Michigan Transportation Research Institute.

Sullivan, J. M., & Flannagan, M. J. (2009). *Relationships among driver age, vehicle cost, and fatal nighttime crashes* (Report No. UMTRI-2009-4). Ann Arbor: The University of Michigan Transportation Research Institute.

Tijerina, L., & Garrott, W. R. (1996). Preliminary effectiveness estimates for lane change crash avoidance systems. In NHTSA Benefits Working Group (Ed.), *Preliminary assessment of crash avoidance systems benefits* (pp. 4-1 to 4-25). Washington, D.C.: National Highway Traffic Safety Administration.

Thulin, H., & Nilsson, G. (1994). *Road traffic, exposure, injury risks and injury consequences for different travel modes and age groups* (Report Number Nr 390A). Linköping, Sweden: Swedish Road and Transport Research Institute (VTI).

Vasconcellos, E. A., & Sivak, M. (2009). *Road safety in Brazil: Challenges and opportunities* (Report No. UMTRI-2009-29). Ann Arbor: The University of Michigan Transportation Research Institute.

Wilson, B. H., Stearns, M. D., Koopman, J., & Yang, C. Y. D. (2007). *Evaluation of a road-departure crash warning system* (DOT HS 810 854). Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Zhang, W., Tsimhoni, O., Sivak, M., & Flannagan, M. J. (2008). *Road safety in China: Challenges and opportunities* (Report No. UMTRI-2008-1). Ann Arbor: The University of Michigan Transportation Research Institute.