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Safety-related risk and benefit-cost analysis of crash avoidance systems applied to transit buses: Comparing New York City vs. Bogota, Colombia

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ABSTRACT

Recent and continuing advances in active safety vehicle technology have created new possibilities for improving road safety. Crash-avoidance systems with the capability to warn and assist drivers are now available in most automotive market in developed countries. Despite this availability, investment in high-technology transit buses to prevent fatalities and injuries has been very slow. In this paper, we examine the safety benefits of using forward- and side-collision warning systems and active collision-avoidance systems in transit buses in New York City and Bogota, Colombia. Using historical data, we develop a transportation risk profile for each city by type of user (driver, passenger, pedestrian, and bicyclist) and crash severity. Because there is no historical data on the effectiveness of crash avoidance systems on buses in the U.S., we surveyed 12 leading experts on autonomous and connected vehicles to assess the potential reduction in injuries and fatalities in road crashes that involve buses. We report on the agreements and disagreements of expert's judgments and contrast their judgment with the break-even combination of risk reduction needed to overcome the cost of providing crash avoidance technology in the bus fleet. Additionally, we perform a benefit-cost analysis under uncertainty using Monte Carlo simulation to compute distributions of benefit-cost-ratio. The benefit-cost analysis reveals that implementing any of the technologies in NYC is economically justifiable. In Bogota, even though fatality and injury risks are higher, statistical valuation of lives and injuries are much lower. As a consequence, policy makers are likely to reject the investment in the technologies.

1. Introduction and literature review

Motor vehicle accidents affect millions of Americans every year and have an enormous effect on the GDP. In 2012, there were over 5.6 million crashes in the U.S., resulting in more than 33,000 deaths (a rate of 10.7 fatalities per 100,000 people) and 2.3 million injuries (a rate of 7500 injuries per 100,000 people) (National Highway Traffic Safety Administration, 2013). Additionally, motor vehicle crashes are the main cause of morbidity and mortality in teenagers and young adults (Center for Disease Control and Prevention, 2012). In 2010, the economic cost of motor vehicle crashes was the equivalent of 1.9% of the GDP. Monetary costs include productivity losses, property damage, medical and rehabilitation costs, congestion costs, legal and court costs, emergency services, insurance administration costs, and the costs to employers, among others (Blincoe et al., 2014a). While the economic impact of crashes in the U.S. is still very significant, fatality rates associated with crashes have been decreasing. In fact, between 1998 and 2012, the fatality rate in crashes in the U.S. decreased 30%, most likely due to technological improvements in vehicles and infrastructure (Noland, 2001; Vahidi and Eskandarian, 2003). Implementation of Intelligent Transportation Systems (ITS), including smart sensors, advanced traffic lights, and vehicle-to-infrastructure and vehicle-to-vehicle telecommunications technology, is expected to continue this trend.

Automatic vehicle driving technology is increasingly discussed as the next step in intelligent transportation systems. These technologies will automate driving tasks and would likely change crash fatality rates (Bertozzi et al., 2000). According to the National Highway Traffic Safety Administration (NTSA), different levels of vehicle automation have the potential to greatly reduce the

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societal costs related to lives lost, hospital stays, days of work missed, and property damage, among others (National Highway Traffic Safety Administration, 2014). Since 2010, some vehicles have been equipped with technological features for partial automation of driving tasks. Deployments of driver-assist systems (DAS), also called warning systems and crash avoidance systems (CAS), in light-duty vehicles and trucks are increasingly penetrating the market, while research on fully autonomous vehicles continue, with Uber, Tesla, and Google working to deploy such vehicles before 2030 (Waldrop, 2015).

To date, most innovations in automation technology in the U.S. have focused on light-duty vehicles, where DAS and CAS are showing clear success in preventing crashes. Forward-collision avoidance systems, which can brake autonomously, along with adaptive headlights, which shift direction as the driver steers, led to the biggest crash reductions in the studies by the Highway Loss Data Institute in 2012 (They're Working. Special Issue: Crash Avoidance, 2012). Insurance data similarly show that the 2012 Volvo City Safety Package, which includes forward collision avoidance with autonomous emergency breaking is reducing insurance claim frequency, severity, and overall losses (Insurance Institute for Highway Safety, 2013). Insurance Institute of Highway Safety studies have also shown that currently available DAS and CAS in Honda, Acura, and Mercedes Benz vehicles are also reducing the likelihood of collision in light-duty vehicles (Eichelberger and McCart, 2014; Highway Loss Data Institute, 2009; Insurance Institute for Highway Safety, 2014).

Truck manufacturers and suppliers are likewise interested in crash-avoidance technology. Early research supports the launch and test of several DAS and CAS, including lane-departure warning, forward- and side-collision warning, vehicle-stability control, and driver-fatigue alerts. Field tests have shown the effectiveness of these systems in the reduction of traffic crashes (Jermakian, 2012). Penetration of those technologies has been slow, but as more data become available and safety benefits become more evident, deployment barriers will disappear (Rand Transportation, 2014).

While annual casualty and liability expenses for U.S. bus transit agencies increased at an average rate of 2.8% between 2002 and 2011 (Federal Transit Agency, 2012), the evolution of DAS and CAS in transit buses, which could reduce these costs, has been slower than in light duty vehicles or trucks. Since the year 2000, Carnegie Mellon University, the Port Authority Transit of Allegheny County (PTA), the Pennsylvania Department of Transportation, and the Federal Transit Administration (FTA) have worked together to develop crash avoidance technology for transit buses. As a result of these efforts, first-generation sensors and warning systems were tested in the field in PTA buses (McNeil et al., 2002). The software company Clever Devices commercialized these systems in 2004 (Steinfeld et al., 2004). Similarly, the Minnesota Valley Transit Authority (MVTA), in collaboration with the University of Minnesota and the FTA, experimented with DAS for transit buses. A GPS-based technology was installed on a prototype bus called "Technobus" for testing purposes. The system provided primarily two capabilities: lane keeping and forward- and side-collision awareness. The researchers did not report crash reductions, but evidence shows that drivers increased their time in the shoulder lane by 4.3% and were able to drive 3.5 miles per hour faster (Alexander et al., 2005). In 2004, the FTA also conducted a study using National Transit Database accident data to explore how advanced technologies in buses could reduce bus-related crashes (Dunn et al., 2007; FTA and FHWA, 2004). This report estimates that it would take two years to recover the cost of installing front-, side-, and rear-collision warning systems through reduced property damage claims. Finally, using casualty and liability claims data from the New Jersey Transit Agency, Lutin and Kornhauser report that installing advance collision avoidance and mitigation technology in transit buses is cost efficient (Lutin and Kornhouser, 2014). While these studies have demonstrated the feasibility of installing automated technologies in buses, they did not consider economic and societal crash costs of time lost, personal injury, or fatalities. This paper aims to fill this gap by exploring the potential safety benefits of up-to-date DAS and CAS (e.g., forward- and side-collision warning and active-collision prevention system (levels 1 and 2 of vehicle automation) in buses for two case studies: New York City (NYC) and Bogota, Colombia. By analyzing the two case studies, we identified factors that may influence policy makers' decision to promote crash-avoidance technologies in transit buses. Particular characteristics of NYC and Bogota make these two cities useful for a diverse analysis. They have some important similarities in their urban and transportation systems: they are both high-density cities, they both rely heavily on public transportation, and pedestrians and taxi trips are important in both cities. Some key differences between the two cities are their differing safety risk profiles and their different economic development.

2. Method

We estimate the expected safety benefits of forward- and side-collision warning and prevention systems when installed in transit buses in NYC and Bogota. We first defined a current baseline risk model and then estimated the potential mortality reduction using elicited expert judgments of safety system effectiveness. We then performed a benefit-cost analysis using monetized benefits.

2.1. Baseline: crashes involving buses

To develop a base case against which risk reduction of using DAS and CAS technologies in transit buses could be evaluated, we collected and summarized transportation data (e.g., urban travel conditions, transportation fatality and injury risk, and statistics for crashes involving buses) for our two case-study cities. The supplementary information contains a summary of these data. Since crash avoidance technologies could perform differently when facing specific crash situations, we place particular emphasis on the victim's transportation mode when analyzing the crashes that involved buses. We designated four groups, consistent with the mode type defined in police reports: motorist, passenger, cyclist, and pedestrian. Table 1 shows the annual average fatality and injury counts for crashes involving buses. In both cities, pedestrians have the highest fatality counts, while bus passengers have the highest non-fatal injury counts. Table 2 shows fatality and injury risk for transit bus passengers based on data from 2009 to 2013 for Bogota and 2012–2013 for NYC. Fatality risk is four times higher in Bogota compared to NYC, while injury risk is slightly higher in NYC.

2.2. Expert elicitation survey

Details on specific bus-crash characteristics (i.e. percent forward- or side-collision) were not available to inform a statistical analysis of the potential reduction in transportation risk associated with autonomous technologies. Thus, for the purpose of quantifying this risk reduction, we employed expert elicitation. Elicitation of experts' judgment is a widely used formal method that has been applied under similar conditions of uncertainty when technology is not fully defined or deployed (Curtright et al., 2008; Edwards et al., 2007; Morgan and Henrion, 1992; Zickfeld et al., 2010). For this paper, we recruited experts at the 2014 Automated Vehicle Symposium (AVS14) organized by the Transportation Research Board and