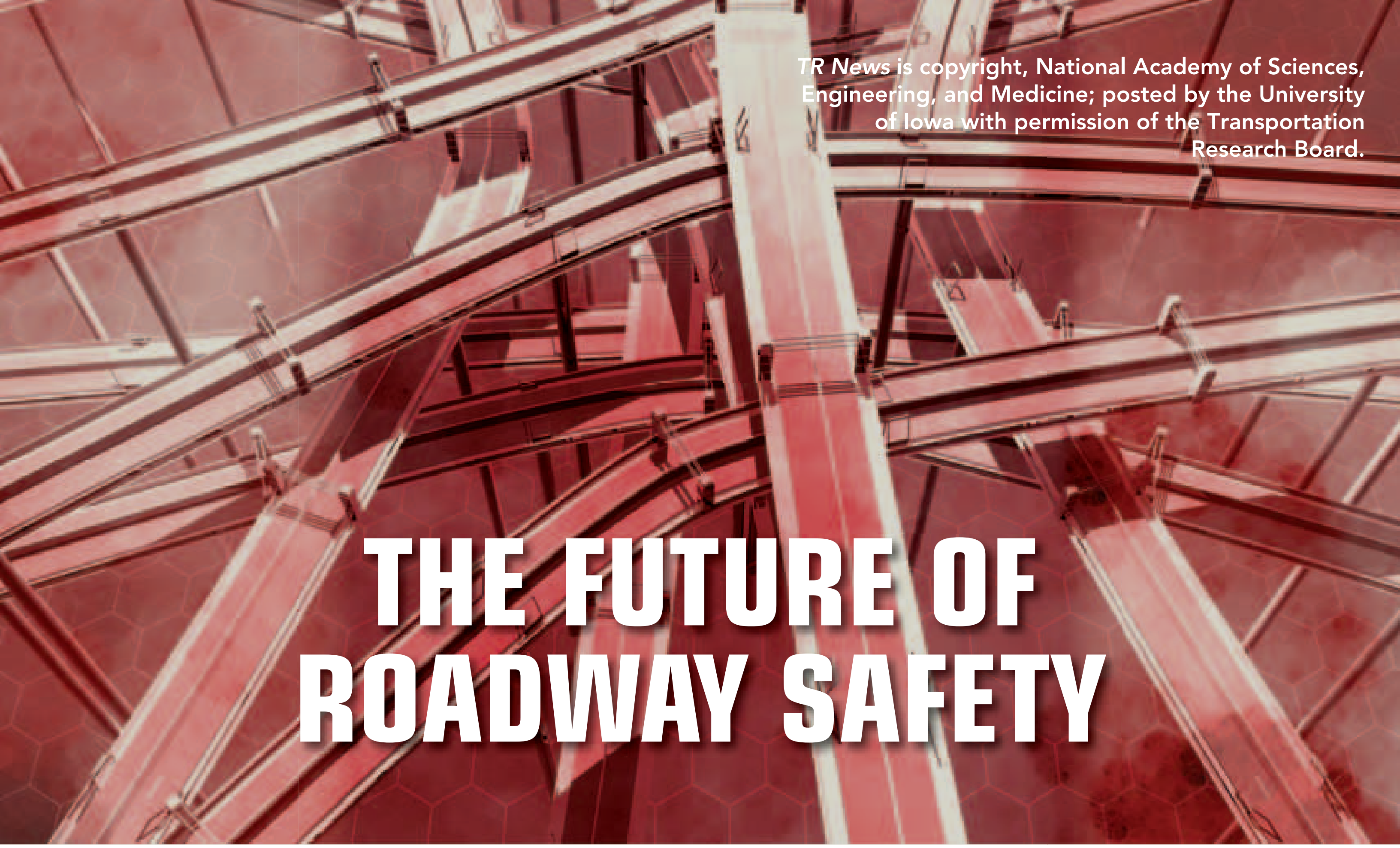

THE FUTURE OF ROADWAY SAFETY

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Above: In 2070, as artificial intelligence–controlled vehicles share roadway networks with human drivers, researchers must meet the challenge of making the roads safe for all concerned.

From the Year 2070: My car will die for me once again, as it did decades ago.

Looking back from our vantage point in 2070, certain big events shaped roadway safety in the United States. Here is a summary:

By 2040, fully automated driving systems (ADS) were deployed in increasing numbers but in very limited operational design domains (ODDs). In the increasingly rare crash scenario involving an ADS, it became apparent that we could no longer rely on prior safety assumptions that vehicles would crumple to maximize occupant protection. Instead, artificial intelligence (AI)–controlled evasive actions in preventing crashes tended to minimize physical damage to the vehicle. Why? Sensors evolved and expanded awareness to onboard AI controllers, which acted to preserve the vehicle as opposed to the passenger. It turned out that there was an unintended software bias. Most early AI software was developed for fleets and ride-hailing companies and inadvertently optimized for vehicle, rather than passenger, survivability. This unduly influenced the entire roadway ecosystem. Humans eventually adjusted the imbedded software systems and AI controllers to optimize passenger and roadway user safety.

Well into 2070, individual vehicle ownership still persists as fleet owners bump into the truth that 150 years of aspirational automotive marketing cannot be easily undone. At first, continued vehicle ownership was explained away as a generational phenomenon. Then, sociologists and marketers found large numbers of people preferred to drive their own vehicle because it is convenient and configured according to each owner's preferences and with each owner's personal belongings on board. In short, the vehicle as appliance worked best in mass transit or commodity delivery.

In 2070, a mixed fleet of automated and human driver–required vehicles coexist. All vehicles must conform to an appropriate level of vehicle-to-vehicle and vehicle-to-infrastructure communication and must strictly follow traffic laws to optimize

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By 2040, when AI software showed bias toward protecting the vehicle over the passenger during a crash, humans interceded and adjusted systems to give themselves more control over personal safety.

safety and flow. Figure 1 describes the levels of driving automation found in the current fleet mix.

Levels 4 and 5 vehicles, whether personal or commercial, are still primarily deployed to transport humans in limited areas such as airports, retirement homes, college and hospital campuses, and smaller cities or suburbs. In commercial transport, Levels 4 and 5 vehicles either ferry goods on limited-access Interstate highways; are truck trains on trips to and from large terminals adjacent to those highways; are local, slow moving, specially designed buses or delivery vehicles; or are operated by businesses moving or extracting bulk commodities. The few Level 5 cars owned individually are treated as exotic cars. In urban areas, vehicles classified as SAE Level 0 and Level 1 long ago were relegated to specific roadways on Sundays only, giving new meaning to the term "Sunday driver."

The Road to Zero Coalition produced a report in 2018 that suggested roadway safety should focus on three areas (*1*). This framework proved prophetic. We reached zero fatalities on the road in 2060 by 1) doubling down on what works, 2) encouraging automation, and 3) improving safety culture and safe systems. However, injuries from crashes—while less numerous and severe than when that report was written—are still a major problem for the United States. As the auto industry slowly recovered from the COVID-19 crisis in the early 2020s, advanced driver assistance systems quickly gained market share and further helped reduce the frequency and severity of the crashes.

Double Down on What Works

In 2070, effective, research-based behavioral and infrastructure countermeasures are still emphasized and employed, primarily for the millions of Levels 0, 1, and 2 vehicles still on the road. In addition, vehicles' average age and reliability continues to increase (hitting 16-plus years by 2070). Along the road to more highly automated driving, people learned how to interrupt ADS operation through a variety of means—from spoofing to hacking to interference techniques such as altering street signs to fool AI algorithms or driving recklessly to deliberately cause a crash. These interruptions resulted in short-term and limited chaotic situations, and, as a result, Americans lessened their resistance to automated enforcement and reduced privacy concerns. Automated enforcement then became widespread and included speed cameras, red light cameras, cameras

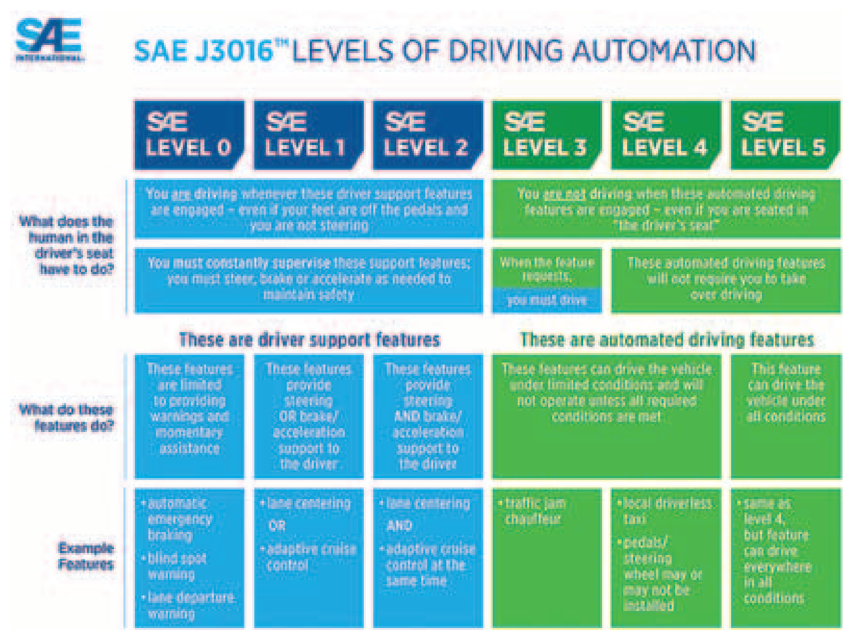

FIGURE 1 The SAE J3016 levels of driving automation look at the actions and features supported by the human driver and the automated driver. (Source: SAE International.)

Smartphones of the future will use apps that track driver behavior, mandatory metrics that are then shared with automakers, local authorities, and insurance companies. In this case, safe driving results in an insurance discount.

in work zones, and new detection means for reckless driving.

Accelerate Advanced Technology

Here, the game changers were physical and digital infrastructure bills passed and signed in the 2020s. A bold initiative, on the scale of the planning and construction of the Eisenhower Interstate Highway System in the 1950s, was implemented and known as Eisenhower 2.0. Along with upgrading physical assets to provide for common recognition necessities of automation, the bills also included significant digital infrastructure to permit vehicle-to-infrastructure and vehicle-to-vehicle communications.

By 2070, vehicle purchase agreements, driver's license renewals, and motor vehicle registrations all include end user licensing agreements that grant permission to record and monitor driving behavior and permit the licensing and resale of the data. Driver state monitoring becomes ubiquitous, and data sharing with local authorities, automakers, and insurance companies is a requirement for use of the roads. If the vehicle has no telematics capabilities, then drivers are rated and identified through apps on their smartphones. Much like an individual's credit status, a driving safety score follows each individual driver or ADS. Individual contextual rules for the operation of the car place hard limits on destination, route, and other variables, depending on whether the driver—human or AI—has permission to operate in various ODDs.

Vehicle manufacturers that developed automated technologies spent little time with SAE Level 3 and went to Level 4 relatively quickly. However, Level 4 ODDs are still limited and greatly nuanced. Promised in-vehicle passenger productivity never reached projected levels, in part because approximately one-third of passengers are affected by virtual reality, motion sickness, or both. They and others prefer having ADS as their driving assistant and backup, rather than being chauffeured by an AI-powered vehicle. ADS ubiquity is still just over the horizon, as universal environmental coping and ODD issues prove harder to overcome than first imagined.

New educational and driving challenges arise with increasing over-the-air updates in partially self-driving vehicles. Gamification of driver state monitoring is adopted as a way to increase relevant understanding of vehicle software updates

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One of California's most popular motor-free zones, Third Street Promenade in Santa Monica, started as the open-air Santa Monica Mall in 1965. Twenty-four years later, it entered its second generation as the pedestrian-only Third Street Promenade, heralding a golden age of drawing people to landscaped outdoor spaces lined with bustling cafés, shops, and movie theaters. However, the venue continues to evolve. In 2020, the COVID-19 pandemic delayed plans for a move to a future of programmable space for farmers' markets, food festivals, and book fairs.

and new capabilities, as well as to help human drivers focus attention on the road.

Prioritize Safety

Infrastructure designed to reduce driver error that leads to fatal crashes continues to improve. Cities utilize shared data to maximize safety and mobility, adapt infrastructure, and implement intelligent design of corridors and transit. Decades ago, even as advanced modes of personal transport deployed, equity in safety and access to transportation became issues. Local jurisdictions stepped in to ensure that vulnerable and economically disadvantaged communities had access to the safest mode of transit. In addition, public transit partnered with increasing numbers of first-/last-mile solutions. Infrastructure inducements for automation, such as access to carpool lanes, proved largely untenable, as other classes of roadway users (e.g., electric vehicles and multiple-passenger vehicles) had already clogged the lanes. Tolling for those lanes further exacerbates the equity issue. Pedestrians and bicycles are effectively separated from the roadways to minimize vehicle interactions.

In urban areas, infrastructure owners mandated vehicle-to-everything communication, as vehicles and drivers acting as independent agents did not maximize benefits for the entire system. The solution was to implement transmitters and receivers that worked with multiple bands to accommodate legacy (e.g., DSRC and 5G, 6G, and 7G) and newer technologies.

Cities enacted more green space and motor-free—including electric—zones to encourage health and well-being of inhabitants, but it was not because the vehicle population vanished. It turned out that the vehicle as appliance flourished for first-/last-mile transit and commodity delivery and clogged city streets. Cities simply limited ride-hailing and deliveries as they once limited taxis through a permit or medallion system. Rural areas were the last to feel the effects of automation, as it was not cost-effective for fleet owners to deploy in limited-population areas.

Driving privileges continue to be earned each year by demonstrating safe and successful driving records, both by humans and Level 4 and Level 5 vehicles. Data shared with governmental agencies, manufacturers, law enforcement, insurance companies, and agreed-upon rating systems decide these privileges. Routes driven by those with spotty records, serious infractions, or repeat offenses are limited via automated enforcement of ODDs. Real-time feedback to traffic monitoring and fleet deployment centers occurs. Coaching to human drivers and ADS systems is provided via automated systems at the end of each day, week, or month with direct feedback to DMVs and insurance companies. Those who do not show improvement are limited in their access to the system.

Conclusion

The uniquely American notion of unfettered access to unlimited territory via unrestricted personal mobility will change slowly over time. In exchange for permission to use public infrastructure, human or machine drivers will comply with laws that ensure safety, equitable use, and maximized efficiency. The very technologies that enable machine driving will find multiple uses as elements of control for access, speed, and environmental preservation. Humans and machines will drive the same roads for a long time. The learnings achieved through data sharing, study, experimentation, practice, transparency, and continuous improvement make our roads safe for all users.

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