Considerations for Deploying Automated Driving Systems Around Schools

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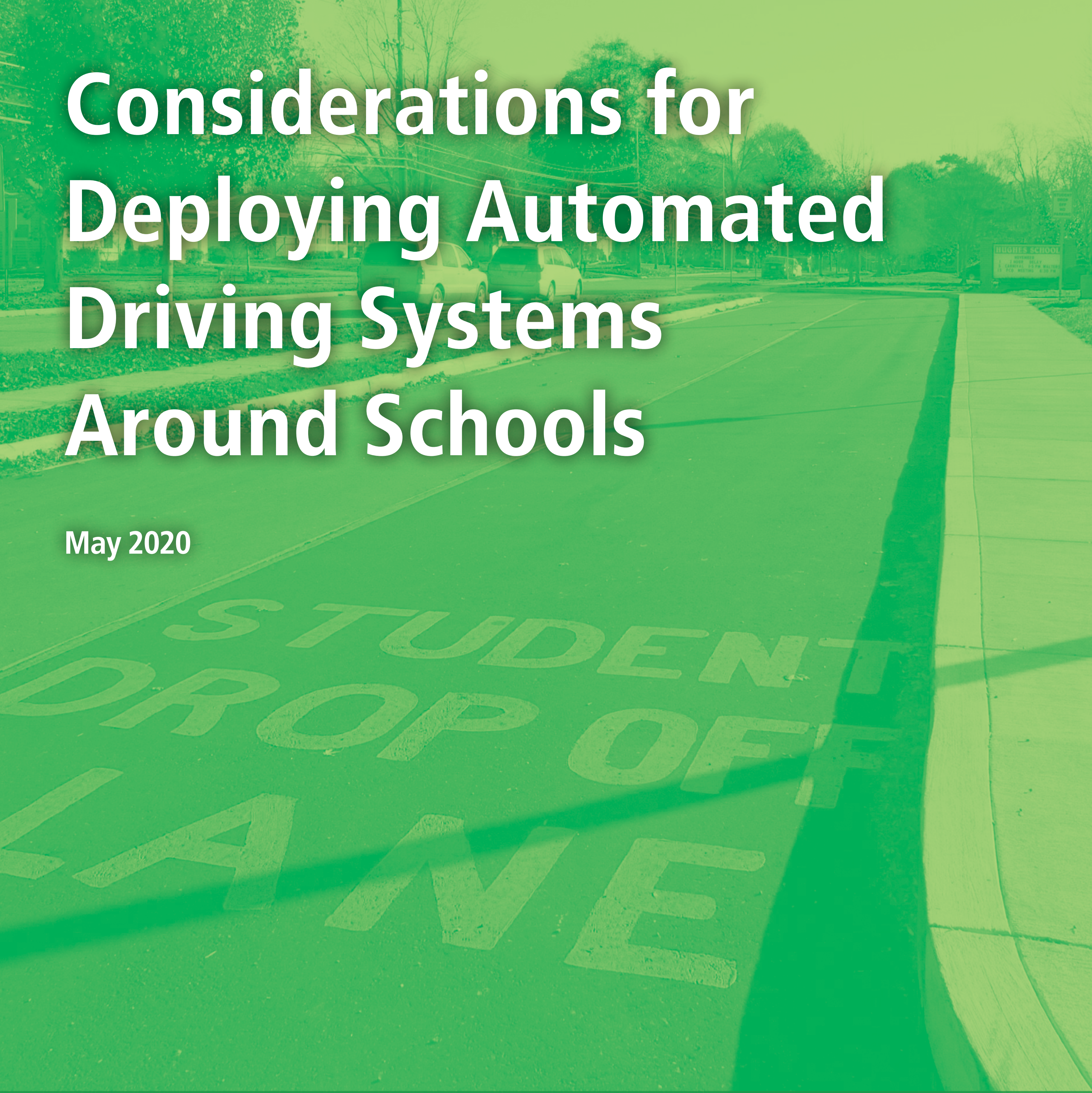

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Executive Summary

The purpose of this work is to summarize key issues and research needs related to deploying automated driving systems (ADS) near school zones, with an emphasis on pedestrian safety. The material was informed through interviews with school transportation experts at multiple venues with the goal of identifying themes at the intersection of ADS deployment and transportation issues in and around school zones.

The inconsistency of traffic conditions and procedures, an increased density of traffic during peak times, and frequent interactions with student pedestrians in school zones presents a difficult design challenge for ADS. It is imperative that ADS developers understand and address these characteristics before ADS are deployed in school zones so appropriate technology, design, and regulatory approaches can be implemented.

This document is intended for audiences developing ADS technologies designed to navigate through or in the vicinity of school zones. It may also be beneficial to a variety of stakeholders in communities affected by those deployments. It summarizes the challenges of ADS deployment from technical, policy, infrastructure, and educational perspectives, and stakeholders will gain a general understanding to inform conversations before ADS are deployed broadly near schools. The result of the research is a set of ten recommendations that highlight the variety of challenges that will need to be addressed by ADS developers and local stakeholders prior to broad deployment:

1. ADS developers should ensure pedestrian detection systems can accurately recognize children.
2. ADS developers should collaborate with traffic safety educators to incorporate ADS deployment topics in future materials intended for children and adults.
3. ADS developers should work with school administrators to understand pick-up and drop-off procedures and collaboratively develop compatible technology and traffic management plans.
4. ADS developers should work with school transportation stakeholders to identify low-cost solutions that support safe ADS navigation on school property.
5. ADS developers should work with entities who develop training programs for crossing guards to develop and validate procedures for crossing guards.
6. ADS must be able to detect when they enter and exit school zones and comply with posted speed restrictions.
7. ADS should only operate where local roadway infrastructure is sufficient for safe ADS navigation.
8. ADS should consistently comply with school zone traffic regulations.
9. ADS test plans should account for school zones.
10. Localities should explore the feasibility of temporary street closures for all vehicles during school arrival and dismissal.

Each section of this report provides the background and explanation behind each recommendation.

Contents

1 : Introduction

Developers of automated driving systems (ADS) are optimistic about their potential to reduce the number of injuries and fatalities occurring on United States (U.S.) highways each year. The intent is that they will operate effectively for prolonged periods of time without compromising performance due to distraction, fatigue, or alcohol impairment (U.S. Department of Transportation [USDOT], 2018). By removing these human shortcomings, it is expected that broad ADS implementation can dramatically reduce the over 36,000 lives lost annually due to highway crashes (National Center for Statistics and Analysis, 2019). However, the true extent of these reductions can only be fully realized if ADS are designed to be safer than human drivers in all driving scenarios, or, in some situations, to support human drivers who share control of an automated vehicle (AV). The reality is that while AVs may be reliable in routine situations, a variety of complex scenarios remain for which ADS are unprepared. School zones are one such example.

A key component in reducing highway injuries and fatalities includes addressing crashes involving pedestrians, who are tragically overrepresented in traffic deaths. In 2017, pedestrians made up 16 percent of all traffic fatalities (Governors Highway Safety Association [GHSA], 2019), although walking accounts for just under 11 percent of all trips (McGuckin & Fucci, 2018). Annual U.S. pedestrian fatalities increased more than 30 percent between 2009 and 2016, totaling approximately 6,000 in 2016, the highest level in nearly three decades (Chang, 2008; Yanagisawa, Swanson, & Najm, 2014). Consequently, leveraging ADS technology to address these increases remains a topic of extensive ongoing research (Fuest et al., 2017; Gerónimo et al., 2010; Merat et al., 2018; Rothenbücher et al., 2016). AVs thrive in carefully controlled or closed systems. Pedestrian behaviors, however, are not particularly constrained by traffic infrastructure and regulations, which makes them unpredictable much of the time (Lavalette et al., 2009). This is a challenge ADS will eventually need to address on a broad scale.

The challenge of predicting pedestrian behaviors is amplified and further complicated around grades K-12 schools, where large numbers of motorists interact with children entering and departing schools. Currently, close to half (54 percent) of students ride to school in a personal vehicle (Federal Highway Administration [FHWA], 2019). Students driving or being driven to school generate 10 percent of vehicle trips in the morning (7:00am to 9:00am) and eight percent of vehicle miles traveled (Kontou et al., 2019). As ADS integrate with existing traffic by replacing or augmenting drivers, many of these trips will likely include AVs, which will be incorporated into these same scenarios. Therefore, if the goal is to improve safety through broad ADS deployment, AV design will need to account for the complexity and uncertainty in and around school zones. Unfortunately, there is currently little published research or guidance for stakeholders on this important topic.

Since 2016, the USDOT has released four versions of guidelines to inform AV deployment. These guidelines have noted the importance of safe interactions between AVs and other road users and cite the technologies as an additional means of detecting and avoiding all road users, including pedestrians and bicyclists (USDOT, 2018). However, the word “school” is mentioned only once as a recommendation that State policies regulating AVs “may prohibit” AVS developers from testing in certain “safety-sensitive areas” (US-DOT, 2016; p.42), which includes school zones, among other examples. In other words, the 2016 guidance to States indicated that jurisdictions could, at their discretion, keep AVS out of school zones entirely to ensure the safety of other road users. While this strategy keeps students safe from AVS in the near term by eliminating the possibility of any AVS-to-student encounters, it also limits the ability to collect real-world data that could be used to train AVs in the future. AVs will require updated infrastructure, regulation, and technology that should be carefully evaluated by ADS developers and school stakeholders to determine their feasibility. However, to date there has been no coordinated effort to assess the unique challenges of deploying ADS in school zones or to systematically identify relevant research gaps, and there is little guidance for AV developers regarding school zones. While ADS developers are highly qualified to implement effective computer vision algorithms and path planning software, they likely do not share the real-world experience of planners and school administrators in the context of safety around school zones. For this reason, safe deployment of ADS around schools will require a coordinated effort by ADS developers to collaborate with local planners, school administrators, and other community members to understand and prepare for the unique transportation challenges inherent to school zones.

The purpose of this work is to summarize key issues and research needs related to deploying ADS in kindergarten through 12th grade (K-12) school zones, with an emphasis on pedestrian safety. Because nearly every student walks or rolls on school property to some extent, whether traveling from a bus, a car, or from home, this work applies to a broad array of students. The material was informed by interviews with school transportation experts at multiple venues with the goal of identifying themes at the intersection of ADS deployment and transportation issues in and around school zones.

This document is intended for audiences researching and developing ADS technologies designed to navigate through or in the vicinity of school zones. It may also be beneficial to a variety of stakeholders in communities affected by those deployments. It summarizes the challenges of ADS deployment from technical, policy, infrastructure, and educational perspectives and stakeholders will gain a general understanding to inform conversations before ADS are deployed broadly near schools.

The report begins with an overview of ADS technology and its relevance to safety in school zones and the transportation environment around schools. After providing background, the report describes seven challenge areas identified. Each challenge will include a summary of relevant research needs.

2 : Background

2.1 Automated Driving Systems

The scope of the technology addressed in this report includes automated driving systems (ADS), which are defined by SAE International (SAE) J3016 (2016) and USDOT's *Automated Driving Systems 3.0: Preparing for the Future of Transportation* (2018) to include Level 3, 4, and 5 driving automation systems (see **Table 1** for descriptions of the SAE automation levels). When in operation, these systems will be capable of performing "all of the real-time operational and tactical functions required to operate a motor vehicle in traffic" (SAE, 2016; p.6). This includes maneuvers such as steering, acceleration and deceleration, monitoring the environment, and recognizing and responding to objects on and near the roadway. It also includes signaling to other road users, including mixed traffic that could include human-driven vehicles and ADS as well as pedestrians, bicyclists, and other road users. These signals could mirror current human capabilities, such as indicating the intent of the vehicle with turn signals, brake lights, and back-up lights. They could also be used to advise road users outside of vehicles when it is safe to cross, such as with vehicle-mounted walk/don't walk signs, or to warn them of imminent danger with an auditory signal. While researchers and manufacturers generally agree that the format of these signals should be consistent across vehicles, the exact implementation is unknown and remains a topic of ongoing research.

Effective detection is the foundation of ADS technology. Before vehicles can interpret and respond to events and objects in their environment, they must be able to detect important road elements, including pedestrians. ADS currently face substantial challenges in accurately and reliably detecting and recognizing pedestrians, who are more difficult to identify, predict, and protect in the event of a crash compared with other road users. While improving pedestrian safety is certainly an objective for ADS developers, the real-world performance of available technologies is limited, and without dramatic improvements, emerging ADS technologies may be limited in their ability to enhance safety for vulnerable road users (Sandt & Owens, 2017).

Pedestrians have variable physical characteristics and appear in a variety of environments with different background features, obstacles, and weather conditions, making them difficult to see. This was demonstrated by a 2017 study using the California Institute of Technology (CalTech) Pedestrian Detection Benchmark data (a 10-hour video recorded from a vehicle's perspective), which suggests a tenfold improvement in this technology is needed to replicate human performance (Zhang et al., 2018; CalTech Pedestrian Detection Benchmark, 2017). Vehicle-based sensors can fail, especially when pedestrians are small (like children), too far or too close to the vehicle, or partially occluded by nearby objects (Dollar et al., 2012). This can account for detection failures of children occurring at more than double the rate for adults.

The limitations of ADS detection systems are evident in current advanced driver-assistance systems (ADAS). The Insurance Institute for Highway Safety (IIHS) estimates that pedestrian detection systems could potentially mitigate or prevent up to 65 percent of single-vehicle crashes with pedestrians in three of the most common crash configurations, and 58 percent of pedestrian deaths in these crashes (IIHS, 2019). This leaves a large number of pedestrians who will remain vulnerable when ADS is broadly available. Similar work by American Automobile Association (AAA) that expands on the number of vehicle-pedestrian conflict scenarios shows that even at just 20 mph, a vehicle equipped with automatic emergency braking with pedestrian detection will fail to avoid a collision almost 90 percent of the time when encountering a child (AAA, 2019). For this reason, neither IIIHS nor AAA recommend dependence on pedestrian detection systems to avoid collisions (AAA, 2019; IIHS, 2019). This means that there is a need to design other ways to separate AVs from other road users and protect people who are walking.

Many of the technical challenges facing ADS are similar to those that have faced automated system designers for decades. In general, automated systems excel at repeating actions with precision in controlled settings. Automated systems do not get tired or distracted and are generally as reliable as the hardware that hosts them. In this respect, they can outperform human ability which may decrease in performance over extended periods of time. Automated systems also dutifully follow their programming, which includes rules they are required to follow.

People still outperform automated systems in novel situations that require inductive reasoning. When a human driver encounters a situation they have not seen before, they can often quickly identify a new goal and develop and implement a solution. Automated systems, in contrast, do not do well in uncertain environments where their understanding of rules and deductive reasoning is not sufficient. New situations and environmental conditions can confuse automated systems, often with unpredictable results. This inability to deal with uncertainty is at the center of the design challenges surrounding ADS, and one approach to resolving it is to constrain the operational design domain.

An operational design domain (ODD) refers to the conditions under which an ADS functions. The ODD includes restrictions due to environmental, geographical, and temporal conditions, as well as other factors. Examples of current vehicles being tested in limited ODDs include slow-moving urban shuttles that transport people short distances along well-mapped routes, and automated trucks that operate only on controlled-access highways. An ODD does not just include a specific geographic area; it can also include environmental factors like weather and lighting. For example, an ADS may function reliably on a known route without operator input in the daytime, but its sensors may be compromised at nighttime or in adverse weather such as heavy rain or snow. In those circumstances, a human driver may be required to take control of the vehicle. A school zone represents a unique ODD, particularly during arrival and dismissal hours, which combines these factors as well as others that are characteristic of schools. Some specific challenges associated with school zones are described in the next section.

2.2 Schools

The Manual on Uniform Traffic Control Devices (MUTCD) defines a school zone as "a designated roadway segment approaching, adjacent to, and beyond school buildings or ground, or along which school related activities occur" (USDOT, 2012). In practice, school zones usually extend one to two blocks in each direction from a school. Speed limits are often reduced in school zones during morning and afternoon hours. Special traffic control measures, including crossing signs, speed signs, and school zone pavement markings, are used to inform motorists that they should drive with special care and extra attention. However, school zones represent the final portion of the students' trips and the natural convergence of students arriving from multiple locations. Students also arrive at schools using a variety of forms of transportation, including walking and bicycling. Therefore, many issues concerning student travel extend beyond the conceptual borders of the school zone.

Despite the existence of standards, traffic regulations in school zones can vary greatly. While the MUTCD sets design standards and guidelines for signage and street markings on public roads, state and local law regulates traffic. Although school transportation professionals are experienced in setting up school routes, it is difficult to predict how students move from their arrival mode (i.e., walking, bicycling, school bus, private transport, etc.) to a school. For example, some schools have their own road infrastructure with bus lanes on campus property separated from

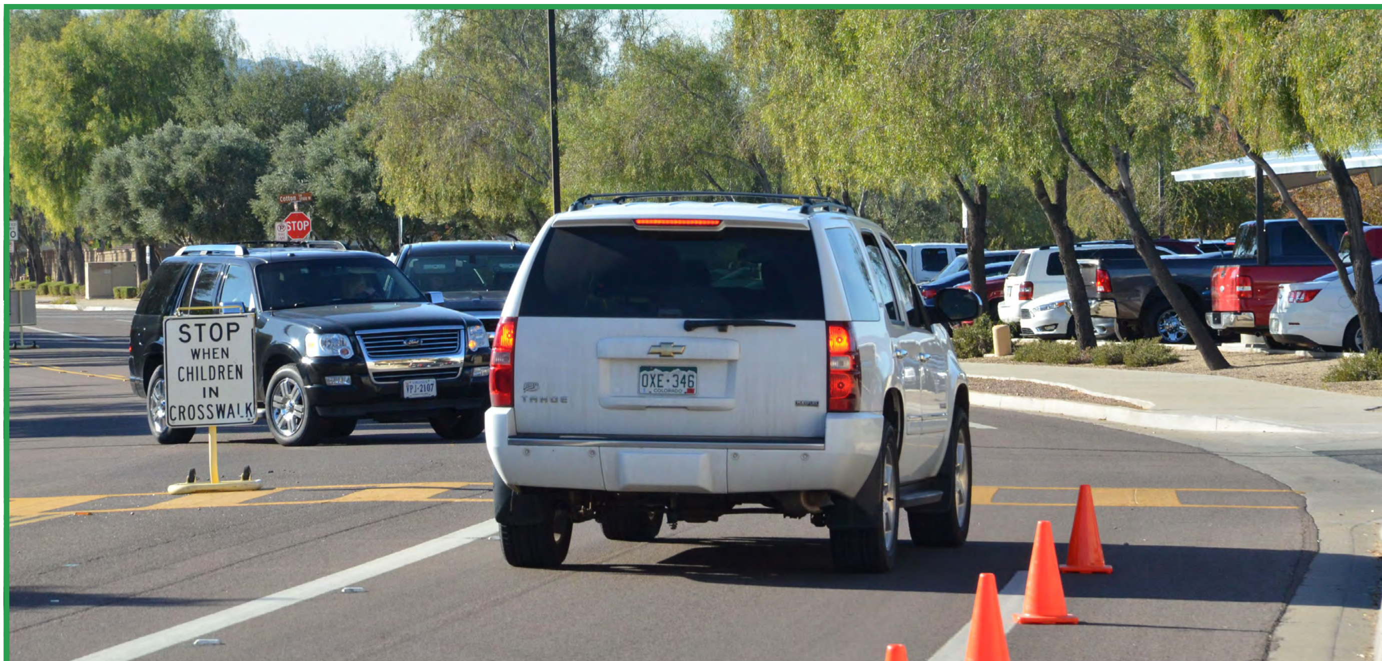

Figure 1. Vehicles dropping off students near a school (Image: National Center for Safe Routes to School)

parent drop-off zones. Other schools are built adjacent to city streets, requiring large numbers of cars to queue on public roads to drop off and pick up children. **Figure 1** illustrates this latter example, showing a car turning left in front of a queue of vehicles waiting to turn onto campus.

Figure 2 shows examples of traffic control elements that can be used to set up pick-up and a drop-off zones on school property. Temporary signs (top-left) and custom stencils (top-right) provide instructions to drivers; a series of traffic cones (bottom) creates an ad-hoc driving lane in front of the school entrance. Gaps between the cones provide openings for pedestrians to cross through the drop-off line; however, the drop-off line requires cars to navigate across painted lines that are inconsistent with conventional roadway markings. An ADS attempting to navigate this location could be misled by the presence of the painted lines, and it is unlikely that it would correctly interpret instructions like “please pull forward and stay in line” and “student drop off lane” without prior programming. These examples are only a small number of the elements found on school campuses, which can also include a-frame signs, white boards with handwritten instructions, traffic tubes and barrels, rope, metal gates, and moveable traffic signs. Appendix A describes two additional case studies of schools with pick-up and drop-off procedures that would likely be a challenge for ADS.

Pick-up and drop-off procedures that take place on school grounds (e.g., **Figure 2**) are often managed by school administrators who determine which traffic control elements will be used and which staff will be present on a daily basis. This contributes to the variability of traffic patterns among schools as each is able to set up its own temporary infrastructure independently according to its own resources. Depending on local funding levels, school administrators may have access to different control elements, ranging from permanent installation of standard devices to setting up improvised materials and procedures. Schools are free to make changes to these patterns at any time, notifying drivers via a phone call, text, email, or newsletter. While this is convenient for the school staff (who have limited options for communicating with large numbers of parents), it is ineffective for modifying a navigation algorithm for an ADS.

Figure 2. Different traffic control elements used at schools
(Images clockwise from top, New Jersey Family Magazine; Oakland Unified School District; Hillside, Il School District 93)

Travel patterns and related traffic density have changed over time and will be impacted by the incorporation of ADS. In 1969, half of grades K-8 students walked or rode bikes to school. By 2009, this number had decreased to just 13 percent (Hubsmith, Ping & Gutowsky, 2007; National Center for Safe Routes to School, 2011). About 30 percent of parents cite traffic risks as a barrier to walking or biking (McGuckin & Fucci, 2018). This suggests, somewhat ironically, that parents who are afraid to walk their children to school because of traffic risks solve the problem by contributing to the overall traffic risk. Looking to the future, it is further possible that availability of ADS could increase the number of vehicles on the road. According to USDOT, it is possible that public transit could shift to larger numbers of reduced occupancy vehicles. These same vehicles may even be empty on return trips. Importantly, ADS may also provide mobility options to disabled populations who previously did not have access to transportation. Combining all these possible outcomes could result in additional traffic (USDOT, 2018). An increase in the number of vehicles could be beneficial if a critical mass of ADS dutifully complying with speed limits and following local regulations became the norm. However, increasing congestion in a mixed fleet that includes ADS navigating alongside human drivers could create new problems in school zones, particularly during times when large numbers of caregivers are picking up or dropping off children.

Today, the volume of traffic adds to the frustration of driving a vehicle through a school zone. Drivers may exhibit poor behaviors, such as illegal passing and erratic movements, making an even more dangerous environment for child pedestrians and bicyclists. Under those conditions, AVs can become a source of further aggravation as demonstrated by their tendency to get rear-ended by human drivers. For example, in California in 2018, almost two-thirds of reported AV crashes were rear-end collisions (Stewart, 2018). This is likely because these prototypes drive cautiously with some hesitation, which is inconsistent with other drivers' expectations and can increase the likelihood of a collision. Vehicles that do not adhere to local conventions may inadvertently be a source of future problems, despite the best intentions of the designers.

Because student safety is paramount, the rules of engagement for vehicles in school zones can differ from other contexts. For example, if a vehicle stops in an active roadway to let out a passenger or make a delivery, it would not be unusual for other vehicles to go around the stopped vehicle if there is no oncoming traffic. This would not always be acceptable when dropping off a student in front of a school. On school property, drivers dropping off students often wait in long queues while students near the front of the line depart their vehicles. In some cases drivers move forward in batches only after each group of students unbuckles, collects their belongings, and leaves their vehicles with varying levels of urgency. Traffic is supervised and controlled to protect students crossing through pick-up and drop-off traffic. Drivers are generally discouraged from taking short cuts that create dangerous situations in school zones, such as overtaking stopped vehicles, making U-turns, or double parking, that might be acceptable elsewhere. ADS will need to be taught to differentiate between these situations that necessarily trade convenience for safety.

The variability of conditions among school zones combined with a high density of traffic during peak times and pedestrians and bicyclists whose safety is paramount represents a complex ODD for ADS. Beyond that, schools often operate in a variety of environmental conditions, such as in different weather (heavy wind, snow, or rain), or different lighting (dark, light, and, in some locations, glare that accompanies sunrise and sunset). All of these conditions represent safety challenges to ADS. It is imperative that ADS developers understand and address these issues before ADS are deployed in school zones so appropriate technology, design, and regulatory approaches can be implemented.

3 : Challenge Areas for Schools and Automated Driving Systems

This work builds on a research framework developed for the *Discussion Guide for Automated and Connected Vehicles, Pedestrians and Bicyclists* (Sandt & Owens, 2017). The Discussion Guide was developed by an interdisciplinary group of transportation experts to highlight AV topics that affect pedestrians and bicyclists. It consolidates these topics into 10 interrelated "challenge areas" that provide a basic framework for future research and policy needs. Five of the challenge areas are also relevant to student safety within school zones. These areas include (see the Discussion Guide for detailed descriptions of each challenge area):

- **Pedestrian and bicyclist detection** – The ability of ADS vision systems to effectively detect, interpret, and predict movements within and near the roadway are essential to road user safety. Even in ideal circumstances, these systems are challenged by the detection of vulnerable road users.
- **Communication between AVs and humans** – The formal and informal communications between pedestrians and bicyclists and ADS should be as effective as they are with human drivers, at a minimum. This needs to go beyond simply replicating the human driver's communication role, as new technologies inevitably create blind spots and unintended consequences. AVs will require significant training and exposure to a variety of scenarios to understand human intent.
- **Determining right-of-way** – Local laws and social customs governing right-of-way will need to be preserved. The circumstances under which ADS will yield right of way to pedestrians are not well established, and additional communication challenges, behavioral adaptations, or other unintended consequences still need to be explored.
- **Regulation of vehicle speed** – Vehicles must maintain safe speeds around vulnerable road users. It is an open question whether operators will be able to direct ADS to exceed the speed limit to allow for personal preference while maintaining safety.
- **Curbside pick-up and drop-offs** – The challenge of curbside management in the presence of other incoming and outgoing vehicles and pedestrians needs to be addressed. Vehicles entering and exiting passenger loading zones often must maneuver around vulnerable road users arriving by vehicle, bicycle and on foot, while sight lines may be limited for everyone involved.

To prepare this report, semi-structured interviews were conducted with school transportation experts to broadly define current challenges related to transportation within school zones. Eighteen experts participated in this phase of the research. Participants included staff from the University of North Carolina (UNC) Highway Safety Research Center (HSRC) and the Institute for Transportation Research and Education (ITRE), as well as the Transportation Research Board's (TRB) School Transportation Subcommittee. Participants were also asked to recommend relevant literature for follow-on reviews. This was combined with an independent literature review conducted by the project team to identify previous research on AVs and schools. The results of the interviews and literature review were analyzed to identify emerging themes related to student safety within school zones. The emerging themes were cross referenced against the five challenge areas identified from the Discussion Guide to determine which were relevant to ADS. The results are the following list of challenge areas for schools and automated vehicles, which build on the previous 10 Challenge Areas identified in the Discussion Guide (Sandt & Owens, 2017):

Seven Challenge Areas for Schools and Automated Vehicles

1. **Levels of automation**
2. **Operational design domain**
3. **Young students**
4. **School transportation stakeholders**
5. **Speed maintenance**
6. **Traffic control devices**
7. **Test methods**

The challenge areas are summarized below.

3.1 Levels of automation

ADS-equipped vehicles are categorized within one of three different automation levels, including Levels 5, 4 and 3 (**Table 1**). The key difference between these levels is defined by the role of the human operator. At Level 5 (Full Driving Automation) the vehicle can perform the entire driving task, without exception. Level 5 vehicles will not require a steering wheel or pedals, as the ADS will be responsible for all aspects of driving, and the human will be a passenger primarily responsible for selecting destinations. Level 4 (High Driving Automation) vehicles are capable of sustained operation within a particular ODD. Within that ODD the ADS will be capable of all aspects of the driving task, including responding to emergencies. Level 3 (Conditional Driving Automation) vehicles are also capable of sustained operation within a particular ODD, except the human operator must be prepared to drive the vehicle if they are requested by the automation to intervene. In SAE terminology, the human operator is a fallback-ready user in a Level 3 vehicle. Each of these three levels has different implications for operating near school zones.

3.1.1 Level 5 implications for school zones

Because Level 5 ADS will be expected to operate in all driving situations, the assumption is that they will also be able to operate safely in school zones and on school property. This includes adapting to changing conditions and traffic patterns, including nonstandard and ad-hoc equipment, driving in all weather and lighting conditions, and responding appropriately to gestures by crossing guards with varying levels of traffic control experience. All of these tasks would need to be performed while detecting and recognizing students moving to and from the school. While these conditions may seem straightforward to human drivers who drive their children to and from school, they would be an enormous challenge for ADS, which (among other technical challenges) would need to be taught through demonstration about the various driving conditions before they can navigate the school zone. Given the dynamic nature of traffic patterns on school property and the variability of school traffic patterns, it is impractical (or perhaps even improbable) for a team of ADS developers

Table 1. Summary of Levels of Driving Automation (SAE 2016)

Level 0	No Driving Automation	**Human driver performs all or part of the driving task**
Level 1	Driver Assistance	
Level 2	Partial Driving Automation	
Level 3	Conditional Driving Automation	**ADS performs the driving task while engaged**
Level 4	High Driving Automation	
Level 5	Full Driving Automation	

to support every possibility through conventional system design techniques. An alternative approach would be to assign the burden on schools to adopt a homogeneous procedure for ADS to operate in school zones. This would require coordinating efforts across the more than 132,000 K-12 schools in the US to come up with guidance for signage, pavement markings, and loading and unloading procedures that would be in effect during arrival and dismissal (as well as lower-demand periods) and would apply to all schools, independent of location, position, socioeconomic status, along with the variety of characteristics that differentiate schools. However, these issues may not be relevant for decades as Level 5 vehicles are unlikely to be available in the near future, or they may be determined to be completely infeasible (Berman, 2019). The technical challenges of developing these vehicles are substantial, and it is far more likely that vehicles with intermediate levels of automation will be available much sooner.

3.1.2 Level 4 implications for school zones

Level 4 ADS can operate reliably within a limited ODD. In other words, the vehicle will be able to reliably navigate within an area it is designed to operate, provided the environmental conditions are also within its operating parameters. If an ADS is designed to navigate a particular school zone, then, in theory, it will be able to operate without human intervention. However, if something changes or there is a weather event outside the vehicle's ODD, then the human operator will need to take over. It is also possible that school zones prove too difficult a task for ADS, and the human driver will be required to take control of the vehicle when entering a school zone.

While this latter scenario simplifies the task of designing an ADS, it has some troubling implications regarding driver skill. Under Level 4 control, the ADS performs the majority of the routine driving, including responding to emergencies and system failures, and the human is asked to take over only during the most challenging part of the drive, requiring sustained attention and shorter response times. There is a question of how prepared the human driver will be to operate a vehicle in a future where the Level 4 ADS may be performing most of the driving. As a passenger, the human operator will no longer consistently practice driving skills under routine conditions, which means they will experience some level of skill loss. This suggests that in the future, the responsibility of driving in school zones could be handed off to human drivers who have experienced some degree of driving skill loss over time or may have limited driving experience due to ADS reliance. In this sense, the automation with more driving experience may be abruptly handing off control to a less experienced driver in an environment where greater proficiency is required.

3.1.3 Level 3 implications for school zones

The issues of deploying vehicles with Level 3 ADS are similar to those associated with Level 4, except the handoff of control to the driver could happen with less advanced warning. Like Level 4, the Level 3 vehicle will notify the human driver when to take control if it knows it is about to leave its ODD. However, in Level 3 automation, the human driver is also responsible for taking over spontaneously upon request, which could theoretically happen at any time due to a software or hardware failure, when encountering an unrecognized road hazard, or when the ADS exceeds the limits of its ODD. The same challenges related to driver skill loss apply in these scenarios, but with an additional challenge for the driver to rapidly regain situational awareness and respond safely. While simple human response times can be quick in response to a stimulus (e.g., press the brake when an alarm is heard), emergency maneuvers can require novel combinations of steering and braking that must be identified, evaluated, and executed within a short time span. In many cases, it can take over 30 seconds for a driver to fully assess a hazardous situation after receiving a request to regain control (Eriksson & Stanton, 2017). Even at 25 mph, a car can travel more than three football fields in 30 seconds. Clearly, this would be unacceptable in a school zone.

3.2 Operational design domain

It is important to fully understand an ODD prior to deploying ADS. Most AV tests and demonstrations take place in locations that were meticulously mapped and analyzed by an engineering team before allowing an ADS to operate a vehicle. Careful examination of the location during a test phase can provide a detailed assessment of the conditions under which the ADS will need to operate, with regards to environment, infrastructure, and other road users. This will also be important as ADS are allowed to operate around school zones, and although there is an enormous variability in the characteristics of these locations, some observations can be made that can help in deciding where an ADS should operate. As the following sections show, a vehicle travelling from the school route, into a school zone, and onto school property experiences an increasing complexity of the ODD as distance to the school decreases.

3.2.1 School route

School routes are public roads that will experience increased traffic density around arrival and dismissal times. School routes do not necessarily post temporary speed restrictions such as those seen in school zones, but they will have more traffic from students arriving in private vehicles. School buses will be present, making frequent stops to pick up children. School routes will also have additional children and parents biking or walking to school and to bus stops. While ADS should always look out for vulnerable road users, school routes will have greater numbers of people walking around arrival and dismissal times, even in areas that do not experience much pedestrian activity at other times.

ADS will also need to recognize and follow local laws and conventions for operating around school buses. For example, while vehicles are not supposed to overtake a school bus when the red lights are activated and the stop arm is extended, the law varies with respect to the distance the vehicle must stop from the bus and road characteristics that determine when vehicles in the oncoming lane must stop (e.g., number of lanes, presence of a median). In locations where it is possible for students to walk to and from school, crossing guards may also be present to control traffic and help students cross the street. ADS will need to be able to understand the variety of gestures used by crossing guards while also attuning to a higher volume of vulnerable road users.

3.2.2 School zone

Like school routes, the school zone consists of public roads where conventional traffic rules apply. The main difference is the presence of traffic control measures that instruct drivers to reduce their speed during arrival and dismissal. When a school is built adjacent or close to a public road, pick-up and drop-off times will often result in heavy traffic congestion. ADS functioning in school zones will need to be able to interpret when speed restrictions apply as well as interpret non-verbal commands from school crossing guards.

3.2.3 School property

Some schools have their own on-campus road infrastructure to allow pick-up, drop-off, parking, and bus access separated from public roads. Traffic control devices and paint on school property are not regulated as strictly as they are on public roads, and traffic patterns can be changed during arrival and dismissal to maintain a steady traffic flow and supervise the safety of students walking and biking. In many cases, school administrators determine how traffic will be regulated on school property. ADS will be challenged by the variety of unconventional and sometimes dynamic traffic rules that differ among schools and may not be known to the ADS developers.

3.3. Young pedestrians

While there are no established external displays and signals for ADS, they will communicate differently from human-driven vehicles. Current methods, such as establishing eye contact with a driver, will need to be replaced with new techniques, which remain an emerging research area (Clamann, Aubert & Cummings, 2017; Merat et al., 2018). This will be more challenging with mixed fleets of human- and automation-driven vehicles where presence of a human driver is inconsistent and thereby no longer reliable as a source of information. In this sense, the arrival of ADS will necessitate a need for new education programs including age-specific skills practice to teach students how to interact safely with ADS and predict their maneuverings.

In the U.S., 245 pedestrians ages 14 and under were killed, and approximately 15,000 children in this same age group were injured while walking or bicycling in 2016 (GHSA, 2019). These statistics are consistent with research comparing traffic safety skills among different age groups. A review of the primary causes of pedestrian crashes, broken down by age, shows how children's attention to the road changes with age (Hunter et al., 1995; Tapiro, Meir, Parmet & Oron-Gilad, 2013). On average, 10- and 11-year-old children are more adept than younger children at identifying dangers on the road and identifying safe places to cross (American Academy of Pediatrics [AAP], 2009). When a child is under 10 years old, running into the street, running between parked vehicles, and playing in the road are the most common scenarios that lead to a crash. Children at this age are not as skilled at monitoring peripheral areas of their visual field. As children approach 10 years old, they typically begin to learn the difference between safe and unsafe crossing locations and recognize the dangers of oncoming traffic (Percer, 2009; Tapiro, et al., 2013). Even older children between ages 10 and 14 continue to run into the street, and are more likely to ignore traffic signals, exit stopped vehicles unsafely and ride on faster-moving transportation modes, like bikes and skateboards.

School children between K-8 grade cannot fully internalize complex traffic behaviors and the skills they have learned have not been fully developed into habits (Cross & Hall, 2005; Schieber & Vegega, 2002). However, on an individual level, younger children have been occasionally observed performing these tasks better than their older peers. Consequently, age is not necessarily the only predictor of a child's sense of safety, and adult supervision will remain essential when children are near traffic (AAP, 2007).

Schools are a critical venue for teaching children about roadway safety. They will be an essential setting for teaching children how to stay safe around AVs. Still, younger children are not equipped to safely navigate busy roads on their own even after learning safety lessons in school. Education is just one part in a multifaceted approach to safety that includes infrastructure, traffic operations, enforcement when needed, and education that also targets parents, neighbors, and other drivers in the community. In addition to supervising children, these members of the community are also in a position to teach children about ADS through discussion and by example.

Recommendation:

ADS developers should ensure pedestrian detection systems can accurately recognize children.

3.4 Coordinating with school transportation stakeholders

Numerous groups will be affected by the deployment of ADS in school zones, many of whom hold important perspectives relevant to safety such as school principals, school district transportation directors, and local law enforcement. It is therefore crucial that these perspectives are understood and addressed by ADS developers during the early development stages so that deployment is as safe and effective as possible. Developers should actively engage with these stakeholder groups to develop well-informed collaborative approaches to maintaining safety around ADS.

3.4.1 ADS developers

As the producers of navigation software and hardware, ADS developers have a responsibility to reach out to community stakeholders to fully understand the deployment environment to ensure the safety of the students and other local community members. In addition to reaching out at the local level, they can leverage professional groups (e.g., Partners for Automated Vehicle Education (PAVE)) with the ability to reach larger groups of stakeholders and experts.

3.4.2 School administration and staff

School administration and staff, which includes principals, vice-principals, office staff and faculty, will need to update existing internal training and procedures related to transportation. This includes pick-up and drop-off procedures for caregivers, information for students who walk and bike to school, and instructions and assignments for staff who monitor traffic during arrival and dismissal, just to name a few. Teachers and other staff often monitor bus and vehicle pick-up and drop-off locations to manage safe arrivals and departures. This includes ensuring children enter and exit vehicles safely and, for children who walk and bike, that traffic stops periodically to let them through.

School administrators are also responsible for communicating changes in traffic patterns. If human drivers are replaced with ADS, there will have to be a method to communicate these changes to the vehicles, or indirectly through their owners. Educators can play an important role in building student skills in how to behave safely around vehicles managed by ADS. New education programs aimed at children will need to be developed by professionals with experience in curriculum and instruction. These materials will need to be developed with input from other stakeholders (e.g., law enforcement, ADS developers) to ensure they are comprehensive.

ADS developers should work with school administrators, or professional groups representing schools, to determine the feasibility of ADS navigation on school property. ADS developers need to learn from schools the options that are available for controlling traffic across a range of local laws as well as socioeconomic levels, as schools vary greatly in the available funds for purchasing and setting up new equipment and infrastructure. Additionally, developers should educate school administrators about the functional ranges of ADS navigation technologies.

3.4.3 Local planners

ADS perform best in environments where traffic control devices are well-maintained and follow established standards. Bright, clear paint and consistent signage, for example, increase the likelihood that ADS will perform in a predictable manner. It is also possible that future transportation technologies may require new road treatments that improve ADS safety. It will be important for ADS developers to help local transportation agencies understand how ADS navigation is influenced by traffic control devices. It will also be important for ADS developers to learn what infrastructure changes are possible over ADS deployment timelines so the developers understand any local constraints they may have to work with. Planners should be familiar with local traffic conditions around schools during arrival and dismissal times.

3.4.4 Local community

The local community includes the variety of road users who travel along school routes. This includes students who walk and bike, parents who drive their children to and from school, and other road users who travel along school routes. These groups should be educated on the implications of travelling in mixed traffic that includes ADS and how they may behave differently from human-driven vehicles. Parents in the community play a central role in their children's safety skill development and therefore should also communicate any important details about ADS to their children who may encounter them while walking or biking. It is important for other drivers to understand these automated behaviors to reduce the chances for crashes involving ADS. Educational outreach also provides an opportunity for the public to express their concerns and ensure ADS support their community needs (USDOT, 2018).

3.4.5 Crossing guards

School crossing guards will need additional training. This is a challenge because, while the MUTCD lists minimum qualifications for crossing guards, there is little consistency in who fills the role (USDOT, 2012) and what agency employs them. At some schools, crossing guard functions are fulfilled by a law enforcement officer; in others, the crossing guard is a volunteer from the community, or a staff member assigned to the position for a limited time. In the absence of crossing guards, parents help children cross the street or children cross on their own.

When crossing guard training is provided, the entity that provides the training varies. It may be provided by the city as part of, or separate from, its law enforcement department. School districts may have their own police unit and members can serve as crossing guards. Some school districts outsource the crossing guard staffing to private companies such as security businesses. In some cases, training is controlled by the state instead of locally. All these variations will make universal education programs impossible as the target audience will vary from one location to another. This is concerning, as the complexity of the crossing guard's job is likely to increase with the arrival of ADS as they master multiple communication modes between human drivers and vehicle automation. Unless they are law enforcement officers, crossing guards do not explicitly control traffic flow; rather, they are expected to "pick opportune times to create a sufficient gap" (USDOT, 2012; p. 745). While the actions of a crossing guard may seem straightforward to a human driver, crossing routines will need to be built into the ADS vision and path planning software, accounting for variability among communities. Crossing guards will need confirmation that they (and the children) are safe walking out into traffic, and the AVs will need to understand when it is safe to continue driving. These interactions are not consistently possible across different types of prototype AVs, and more work is needed to design and test effective means of two-way communication.

Recommendations:

- ADS developers should collaborate with traffic safety educators to incorporate ADS deployment topics in future materials intended for children and adults.
- ADS developers should work with school administrators to understand pick-up and drop-off procedures and collaboratively develop compatible technology and traffic management plans.
- ADS developers should work with school transportation stakeholders to identify low-cost solutions that support safe ADS navigation on school property.
- ADS developers should work with entities who develop training programs for crossing guards to develop and validate procedures for crossing guards.

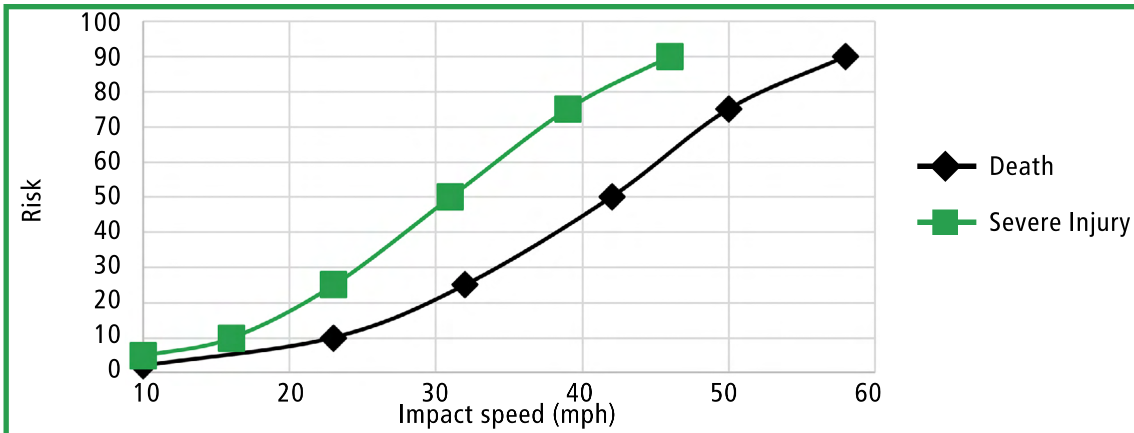

Figure 3. Car and light truck impact speed and risk of severe injury or death (Adapted from Tefft, 2013)

3.5 Speed management

Slowing traffic is one of the biggest challenges in keeping child pedestrians and bicyclists safe. Examples of traffic calming methods to reduce speed include narrowing lanes by adding chokers and chicanes, installing speed humps and raised pedestrian crosswalks, converting intersections to roundabouts, and adding neighborhood traffic circles. While these infrastructure modifications are often effective, the most broadly applied strategies for controlling speeds use relatively less effective signs and street markings.

School speed limit signs inform drivers when they are approaching a school zone and will need to slow down for school children. The MUTCD provides guidance for installing the recognizable yellow-green school area speed limit signs and "SCHOOL" stencils painted on the road's surface in school zones at a specified distance from marked school crosswalks or from the edge of school property. Reduced speed limits in school zones vary based on state law and local speed-limit setting practices.

There is a strong argument for supporting reduced speeds in the interest of safety. Specifically, slower moving vehicles will stop within a shorter distance than faster moving vehicles and, in the event of a collision with a pedestrian, there is a lower likelihood of an injury or fatality. A vehicle traveling on a level surface at 20 mph needs about 112 feet to stop in time to avoid hitting a stationary child. This increases to about 200 feet for a car traveling at 30 mph and to 300 feet for a car traveling at 40 mph (American Association of State Highway and Transportation Officials [AASHTO], 2001). Higher vehicle speeds also increase the likelihood and severity of injury (Rosen & Sander, 2009). As **Figure 3** shows, if a pedestrian is struck by a car traveling at 40 mph, there is a 45 percent likelihood that the pedestrian will be killed. This likelihood drops to around 22 percent at 30 mph and 5 percent at 20 mph. Despite these figures, a large number of drivers speed in school zones, with potentially grim safety implications (National SAFE KIDS Campaign, 2000).

AVs can regulate speeds more reliably than human drivers. If AVs are programmed to adhere to state and local laws, then their speed can be limited in school zones to ensure the safety of pedestrians (Essex, Shinkle, & Teigen, 2017). Whether it is computer vision systems that can detect and interpret standardized road signs or GPS map data that identifies the school zone boundaries, technology is already available that can inform vehicle automation when it approaches a school zoneduring arrival or departure times. This information could also be used to place a limit on a vehicle's speed, which, in turn, could serve to regulate speeds of the surrounding mix of automated and non-automated traffic.

Recommendation:

ADS must be able to detect when they enter and exit school zones and comply with posted speed restrictions.

3.6 Traffic control devices on streets and school campuses

3.6.1 On streets

Driving at a higher speed is not the only unsafe behavior observed in school zones. Human drivers also routinely violate rules intended to protect pedestrians crossing the street (Safe Routes to School, 2015). For example, in one observational study of driver behaviors at intersections, 45 percent of drivers failed to completely stop at an intersection with a stop sign, and seven percent of those drivers did not slow down. Even when pedestrians were waiting to cross, 36 percent of drivers did not come to a complete stop, and 24 percent of drivers did not come to a complete stop at the intersection while pedestrians were in the process of crossing (National SAFE KIDS Campaign, 2003). Even when drivers do stop, a large percentage of drivers stop on the crosswalk, blocking the pedestrians' ability to directly cross (National SAFE KIDS Campaign, 2004). Parents dropping off and picking up children can create hazardous situations around schools. Parents park illegally, drive through or stop in bus zones, pass stopped school buses, drop off children in the street and allow them to walk between parked cars, and may generally ignore established procedures. Administrators attempt to solve these issues by designating clearly marked pick-up and drop-off zones and educating parents on safe procedures. Law enforcement officers may also patrol areas around schools to issue warnings and citations.

Unlike their human counterparts, driver education and compliance are permanently embedded in ADS programming. ADS are expected to dutifully obey local rules and the directions of traffic control devices, including staying between lane markings, stopping at stop signs, and respecting crosswalks when pedestrians are present. This assumes, however, that the signs and markings are visible to the vehicle's sensors and that they are recognizable. This means that traffic control devices need to be maintained to be consistent with the needs of the vehicle technology, and that they follow a known standard, such as the MUTCD.

Figure 4. Sign with limited meaning for ADS

3.6.2 On school campuses

A need for consistency among traffic control devices has important implications for schools. In many cases, traffic on school property is regulated by school administrators. Unlike public roads, there is no universally agreed-upon or enforced standard for managing traffic on school property. There can be tremendous variability among schools, and training an AV to navigate one school may provide little or no information about navigating another. One school may have its own access road where vehicles line up to pick up or drop off children, while others may be built alongside public roads, which then become pick-up and drop-off zones twice a day featuring long queues of cars lining the street in both directions. School administrators use permanent and makeshift signs (e.g., Figure 4), traffic cones, school resource officers, plain-clothed school faculty and staff, and numerous other techniques to route traffic. Regulations are often provided directly to parents before the start of each school year, as general knowledge of traffic rules may not necessarily be enough. If the current model remains, ADS will need to become much better at dealing with uncertainty to safely and effectively navigate through school zones during pick-up and drop-off times. For example, on a busy city street, a car may be expected to leave its lane to drive around a car that has stopped to let out a passenger. This same behavior would be less acceptable at a school where the custom dictates that cars wait in batches for groups of students to leave their parents' vehicles and drive away only when all the students are out of the road. ADS will need to be able to reliably differentiate between these two contexts. Alternately, schools could broadly agree on traffic control standards on school grounds and update their infrastructure, but this would represent an unlikely upgrade to diverse and independent groups that often have limited budgets and schedules.

Recommendations:

- ADS should only operate where local roadway infrastructure is sufficient for safe ADS navigation.
- ADS should consistently comply with school zone traffic regulations.

Work Zones: A Model for ADS and School Transportation

While there has been limited research to understand the effects of deploying automated vehicles around school zones, there have been some efforts to leverage ADS technology to improve safety in work zones. Work zones share some similarities with schools, and the research may provide insights helpful to school stakeholders.

Challenges include:

- Traffic control elements such as cones, barrels, flashing lights, flaggers and hand signs that are often in conflict with permanent markings.
- Changing conditions that require reduced speeds that are often inconsistent with local speeds at other times.
- Vulnerable road users and work vehicles gathering immediately adjacent to the road and may or may not need to cross.
- Variable lighting conditions can make it more difficult to detect vulnerable road users.

Potential technological solutions:

- Vehicle-to-Infrastructure connectivity that would communicate work zone information to vehicles directly.
- High-visibility standardized markings that are easily detectable by vision sensors.
- High definition maps that are updated frequently that inform GPS-enabled vehicles when a work zone is on the current route.

3.7 Test methods

The fatal crash between an Uber test vehicle and a pedestrian in Tempe, Arizona in 2018 highlights the risks of testing on public roads. However, the variability among schools presents a real challenge for ADS development. Testing in school zones could put children and school staff at risk; while not testing in these challenging situations limits the breadth of ADS capabilities and potentially delays their deployment. ADS developers will need to work with local officials to find a way to strike a balance between maintaining public safety by testing on closed tracks and in simulation and the robust testing that comes with the variability and uncertainty inherent to real-world testing. In the meantime, ADS developers should be safely collecting data in school zones using observational methods to inform future work.

In AV 3.0, USDOT (2018) describes several characteristics of early state testing that are applicable to school testing. These characteristics provide a helpful framework for stakeholders to understand the components of ADS testing:

- The ADS being tested should be tested extensively in other environments (i.e., simulation, closed course) before initiating any tests on public roads.
- Driving scenarios and ADS functions used in school zones should be defined and tested in controlled settings prior to public road testing.
- Tests in controlled environments should continue in parallel of public road testing.
- Scenarios should include a broad variety of ODDs (school route, zone, and property), roadway characteristics, and traffic control devices used at schools (e.g., cones, signs, inconsistent paint, and crossing guards). Dynamic changes to the traffic control devices should also be included as part of the testing.
- All ADS should include a trained safety driver and a software engineer (or similar) in the vehicle during testing.

As is the case with the other challenge areas, collaboration among stakeholders is essential during ADS testing (USDOT, 2018). ADS developers, planners, local and state government agencies, and school administrators and staff all need to coordinate to ensure safe operations around schools.

Recommendation:

ADS test plans must account for school zones.

3.8 Other issues

This report is the result of a series of interviews with experts and a comprehensive literature review. Although the objective is to describe issues related to ADS and students who walk to school, there are numerous tangential topics that were identified. Though they are not necessarily within the scope of this effort, they are still relevant to ADS and school safety and are provided here as potential future research efforts.

3.8.1 Connected vehicles

There is ongoing research to enhance the capabilities of traditional and automated vehicles by enabling communication with other traffic and road infrastructure. For schools this means communicating locations of school zones and any speed restrictions. For ADS this means receiving an electronic communication that replaces or is redundant with signs and roadway markings that advises them of local safe speeds.

3.8.2 Driver education

As the role of the driver changes from someone who actively controls a vehicle to someone who supervises an ADS, new driver education programs will need to be updated to teach drivers (or operators) to safely control an ADS. For intermediate automation levels, like Levels 3 and 4, education programs can be used to make sure new drivers develop and maintain skills even when an ADS can be relied on to do most of the driving. There will need to be education systems in place so drivers are prepared to intervene when automation fails or the vehicle is asked to perform outside its ODD.

3.8.3 Pick-up/drop-off

Parents, daycare providers, and bus drivers are responsible for making sure children traveling to and from school enter the vehicle (whether private vehicle or school bus), sit down, and use proper occupant restraints. If children ride in automated vehicles, someone will still need to ensure that they are safely secured in a vehicle heading to the correct destination. There is certainly a legal liability issue with someone other than the caregiver or daycare provider being responsible for the safety of the child passenger. There will also need to be methods for matching children to the correct vehicle and communicating that clearly to the person assisting the child. These extra steps will shift responsibility to the limited curbside staff and possibly result in delays during dismissal, which will be particularly frustrating for human drivers waiting in-between ADS-enabled vehicles.

3.8.4 School bus safety

Another ongoing safety challenge in many communities is protecting students around school bus stops. For example, a recent survey by the National Association of State Directors of Pupil Transportation Services (NASDPTS) reported over 95,000 instances of drivers illegally passing stopped school buses during a single day in 2019 (2019). Extrapolating these observations suggests illegal passing may be occurring 17 million times in the U.S. during the school year. While countermeasures such as stricter penalties and external school bus cameras have been implemented, this represents a profound danger for students riding on school buses. New technologies that leverage advances in connected and automated vehicles could help reduce these numbers. In-vehicle warnings that notify drivers about stopped school buses, alert systems to notify bus drivers about approaching traffic, or even active vehicle controls that stop vehicles from passing stopped school buses are all feasible with emerging technologies and represent possible areas for future research.

4 : Alternative Approaches

ADS developers have made tremendous technological advances over the years, moving their research from niche projects in a handful of university labs to public streets in numerous cities across the country. Despite this progress there are many environments where ADS continue to struggle. This is particularly true in areas where the environmental factors and behaviors of other road users are difficult to predict. In those situations, methods to improve safety in the long run may require integrated solutions that extend beyond replacing human drivers with reliable computers, incorporating local land use and policy.

In school zones, the key obstacle for deploying ADS is that the variability and uncertainty of traffic conditions and infrastructure will undoubtedly challenge ADS, and it may be determined that the ODD defined by school zones is too complex for safe operations. Relegating driving responsibilities to human drivers may also not be safe as their skills may have degraded from spending less time driving. One approach to addressing these future challenges is implement temporary traffic restrictions during school arrival and dismissal hours.

The school streets concept originated in Italy about 25 years ago to prioritize safe walking conditions during arrival and dismissal for children, caregivers, and school staff (Schmitt, 2018; 8 80 Cities, 2019). Temporary traffic control devices are set up to reroute traffic and students arriving by car walk to and from remote lots. Some exceptions are made for students with mobility impairments who need to be dropped off closer to schools. The program is credited with cutting collisions with school children in half and reportedly has resulted in more children walking to school and an increase in compliance with traffic regulations around schools.

The school street model aligns well with a proposed ADS testing plan in Reston, Virginia. Optimus Ride (**https://www.optimusride.com/**) offered to run its prototype automated shuttles between a public transportation stop and planned mixed use development (Lee, 2019). The shuttle would operate between the Metro stop and an overflow parking lot within walking distance of the development. Deploying the shuttles from a remote lot would keep them away from the residential, retail, and office spaces with higher densities of pedestrians, reducing the interactions between the automated shuttles and vulnerable road users (as well as other traffic). This would also reduce the complexity and uncertainty of the ODD. A similar model, in which ADS-enabled vehicles pick up and drop off students near schools instead of on or immediately beside them may also be an option for deploying ADS near schools. A program for ADS modeled after school streets could address the challenge of ADS dealing with school zone complexity. Instead of navigating on school property, the ADS could navigate to offsite locations with clear consistent markings that separate kids physically from vehicles. A remote drop-off location also supports routinizing physical activity into student daily activities. Exceptions would be needed for children with special needs.

Naturally, every school is different, and it would still be a challenge to broadly implement school streets on a broad scale. The functionality required for ADSs to perform in the most challenging ODDs is possibly decades away (Shladover, 2016), and it may prove easier to set up programs like these than to rely on automation. Limiting the scope of scenarios where ADS will be deployed will increase their feasibility.

Recommendation:

Localities should explore the feasibility of temporary street closures for all vehicles during school arrival and dismissal.

Summary of Recommendations to Prepare for Deploying Automated Driving Systems near School Zones

1. ADS developers should ensure pedestrian detection systems can accurately recognize children.
2. ADS developers should collaborate with traffic safety educators to incorporate ADS deployment topics in future materials intended for children and adults.
3. ADS developers should work with school administrators to understand pick-up and drop-off procedures and collaboratively develop compatible technology and traffic management plans.
4. ADS developers should work with school transportation stakeholders to identify low-cost solutions that support safe ADS navigation on school property.
5. ADS developers should work with entities who develop training programs for crossing guards to develop and validate procedures for crossing guards.
6. ADS must be able to detect when they enter and exit school zones and comply with posted speed restrictions.
7. ADS should only operate where local roadway infrastructure is sufficient for safe ADS navigation.
8. ADS should consistently comply with school zone traffic regulations.
9. ADS test plans should account for school zones.
10. Localities should explore the feasibility of temporary street closures for all vehicles during school arrival and dismissal.

Figure 5. Recommendations for ADS operating near schools

5 : Conclusion

The recommendations made in this document (**Figure 5**) require open and early communication among stakeholders and implementing comprehensive technology test plans to prepare for the broad deployment of ADS. While the timing of ADS deployment remains a speculative topic, fulfilling most of these recommendations in the near term could still enhance the safety of all schoolchildren, regardless of travel mode, if adapted to the current road environment. For example, in their policy statement on school transportation safety, the AAP recommends clearly marked pick-up and drop-off zones separate from school buses, speed-limits at or below 25 mph, trained crossing guards, and implementation of safe routes to school programs (2007). The organization also endorses multidisciplinary approaches to improve safety that incorporate engineering and education of both students and drivers by including school administrators, parent-teacher organizations, city planners, and law enforcement in conversations about school transportation. These recommendations are consistent with a general theme regarding the current benefits of infrastructure improvements implemented to prepare for ADS: that greater consistency and quality of road markings, signage, and pavement would be beneficial for human drivers and for ADS (USDOT, 2018). With this in mind, communities could begin efforts now to improve consistency around school zones and on school campuses to address current challenges resulting from variability among schools. Addressing these issues now would have the immediate benefit of addressing some near-term challenges while laying a foundation to prepare for future ADS deployments.

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Appendix: Case studies

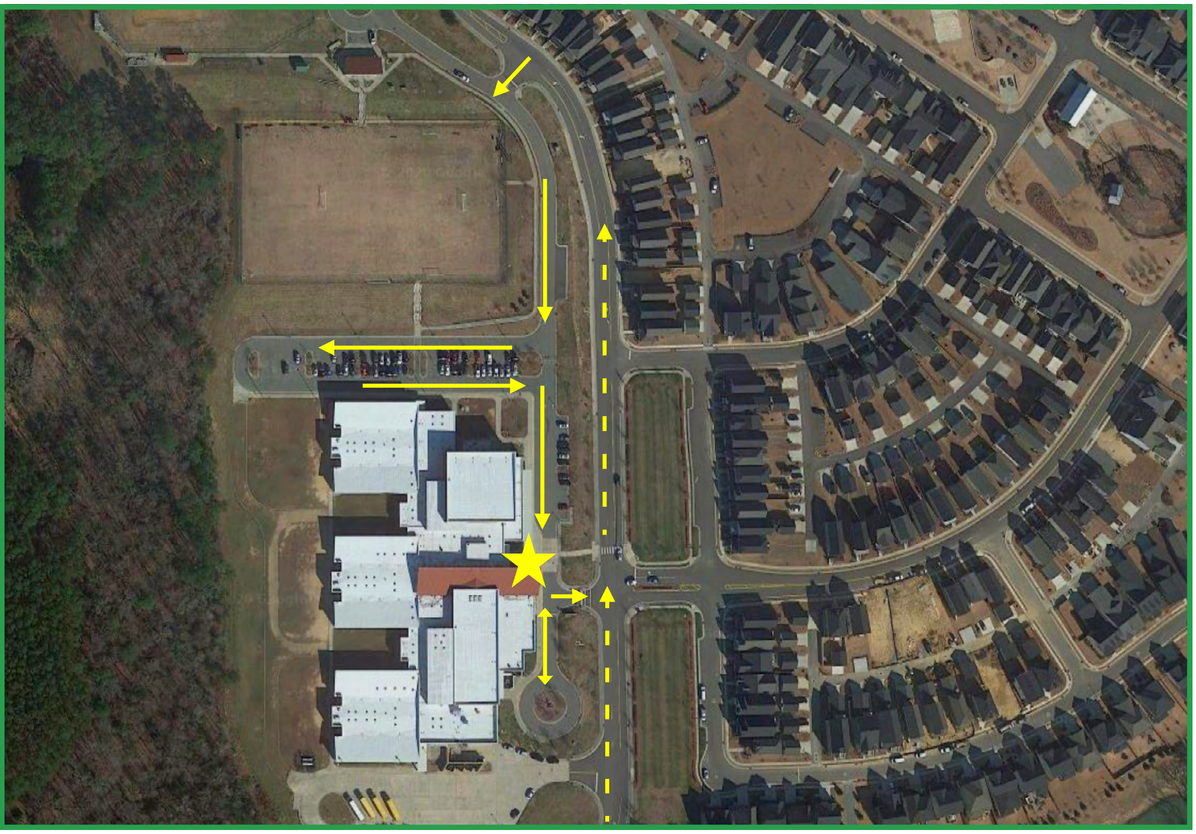
The following two case studies provide examples of real-world situations in school zones that would pose significant challenges to autonomous vehicles. Both schools were visited by the project team, who observed student arrival and dismissal on multiple days.

Case Study A – Middle School

School A is a middle school constructed adjacent to a 1,600-acre planned community. It serves students in grades six to eight who live within and outside the planned community. According to the principal, approximately 100 of the 700 students walk or bike to school, with the remainder arriving by bus or private vehicle. Nearly all roads in the community have sidewalks, and the speed limit is posted at 25 mph throughout. School bus pick up and drop off at School A is separated from personal vehicle pick up and drop off. The school has its own access roads for pick up and drop off and faculty and staff parking. This driving pattern that combines an approach on a public road with navigating on school property is a seemingly straightforward operation for a human driver that presents a challenge for highly automated vehicles.

During arrival and dismissal, vehicles pass by the school along an adjacent road (see dotted lines on **Figure 6**) and turn onto the school property near the athletic fields (**Figure 6**, top). Vehicles then drive toward the school (following the solid lines), loop through the staff parking lot, and pick up or drop off the students in front of the school. A metal gate (**Figure 7**) positioned in the middle forces visitors to turn right and drive through the parking lot, rather than drive straight to the school entrance. The students then walk to the school entrance (marked with the star in **Figure 6**). Vehicles continue past the school after pick up and drop off, drive through a loop and exit school property just before the school's entrance. While drivers navigate the access road, students arriving on foot or bicycle cross the street along a crosswalk directly toward the school's entrance.

Figure 6. Vehicle paths at School A



A uniformed school resource officer (SRO) controls approaching traffic and tells students when to cross the road. He parks his patrol car nearby and places cones by the crosswalk to improve visibility (**Figure 8**). After crossing the street managed by the SRO, walking students then cross another road on school property (**Figure 9**), where students arriving by motor vehicle are being dropped off. This road is managed by two or three plain-clothed school administrators who alternate between allowing students and vehicles to advance. Markings on the access road include the yellow curb, a white dashed line separating moving and stopped traffic, and the raised crosswalk students use to cross toward and away from the school's main entrance (**Figure 9**).

The differences in navigating the public road and the access road represent a challenge to AVs. The crosswalk and lanes on the public road are clearly marked with paint, and the SRO directs traffic according to his training. In contrast, the school crossing and lanes, which are just a few yards away, are marked differently, and the staff wear plain clothes and use impromptu hand signals. These are two very different situations for computer vision and navigation technology. Navigating on the roadway requires following established rules that are applicable in a variety of locations; however, navigating the road on school property and interpreting the staff's signals requires flexibility and adaptation, which presents a challenge to highly automated vehicles.

There will also need to be a method to allow the highly automated vehicles and children waiting in the crosswalk to alternate between driving and crossing to maintain traffic flow. This will mean highly automated vehicles will need to somehow distinguish between stopping at a midblock crossing when a child approaches the crosswalk and continuing to drive while a child waits at a crosswalk because the SRO has waved on a group of waiting vehicles. In other words, there could be situations when an AV is allowed to continue, even when pedestrians are waiting at a crosswalk.

Figure 7. Gate to reroute inbound traffic through staff parking lot

Figure 8. Pedestrian crosswalk marked with cones

Figure 9. Access road used for pick up and drop off

Case Study B – Elementary School

School B is a rural elementary school serving grades K to five with approximately 850 students. The school was constructed along a rural road with a 45-mph speed limit. The road is two lanes wide and has no sidewalk or bike lane. There is a left turn lane that allows people to turn onto school property. A small number of students bike or walk to school via gravel trails from a neighborhood that adjoins the school in the rear (not pictured). In 2019, this school changed the driving pattern used by parents during pick up and drop off in a manner that would have presented a challenge to highly automated vehicles.

The dotted lines (**Figure 10**) show the path used by vehicles picking up and dropping off students prior to 2019. The two stars indicate where students enter and leave the building. During arrival and dismissal times, cars would line up to wait to enter the school's access road, blocking traffic in both directions. Some drivers would make dangerous maneuvers to continue, such as passing in the turn lane and quickly moving back into the driving lane in between moving traffic.

To address this issue a new extended driving pattern on school property was completed in December 2018 (see solid lines on **Figure 10**). Beginning in January 2019 (following the county's Winter break), drivers would enter the access road nearly perpendicular to the county road and drive in a backward "S" pattern. The new sections of road were marked with arrows pointing in the same direction; arrows painted previously in the parking lot pointed in opposite directions. The new pattern also increased the number of lanes used by drivers on school property from one to two.

Parents were notified of the change in traffic pattern via email. A hand-made sign was placed by the road during the first week to inform drivers where to turn and enter the new pattern. An additional sign was placed near the first drop off location to indicate when to merge the two lanes into one. Later in the semester this was marked with traffic cones. The unconventional traffic

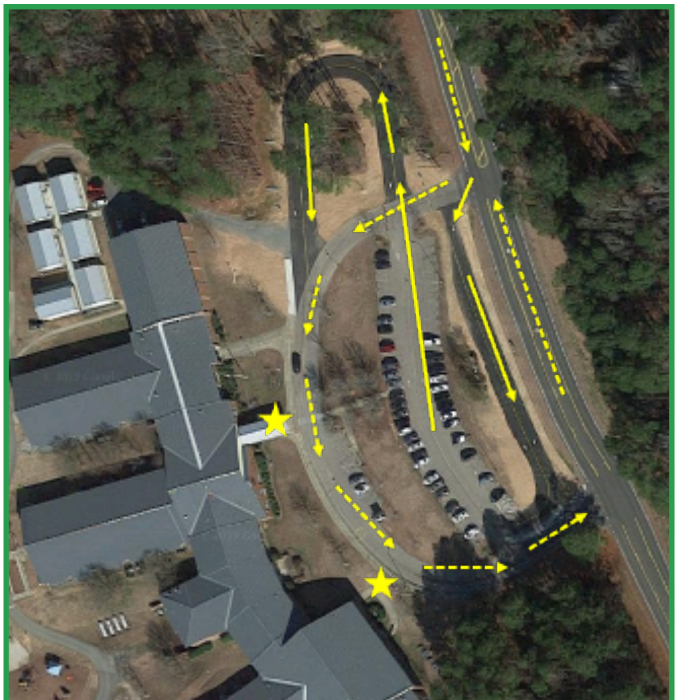


Figure 10. Vehicle paths at School B

pattern and signage would pose a challenge for automated vehicles; however, the important element in this example is how the change was communicated to the drivers. Use of email, flyers, or robocalls are common methods to communicate school news to parents, with varying success. A change in driving pattern could, for example, appear alongside meeting notifications, athletic schedules, and other announcements. Compliance is based entirely on whether caregivers attend to the messages. There is currently no method for communicating these changes to automated vehicles, and if routes need to be mapped (e.g., with LiDAR) in advance before they can be navigated autonomously, then sudden changes like these will result in delays, or worse. In this example, an autonomous vehicle following its existing map would have driven a few yards into the parking lot, where it would have encountered a locked metal gate.

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