Abstract
This work discusses potential interactions and impacts between autonomous vehicles and micromobility. While fully automated passenger-only AVs are not yet commercially available to the public, micromobility and shuttle services are becoming increasingly common, especially in densely populated urban areas. New types of micromobility devices, such as scooters, are also being introduced into the same areas. This paper discusses the research and safety considerations relevant to both domains, potential interactions between these two types of mobility in real-world scenarios, and the potential implications of those interactions. By exploring the current state of both technologies and early evidence currently available, we catalogue the potential implications of their interactions, particularly with respect to communication, expectations, infrastructure, safety, and policy, and the impact of data limitations.

Introduction
Micromobility
Micromobility refers to a category of modes of transportation that includes very light, low-occupancy vehicles such as electric scooters (e-scooters), electric skateboards, shared bicycles, and electric pedal assisted bicycles (e-bikes). U.S. Department of Transportation Bureau of Transportation Statistics:

- E-scooters
  - Issues such as space sharing and safety concerns have negatively impacted public perceptions of e-scooters. Some common issues include:
  - Parking
  - Sidewalk safety
  - Incomplete regulations

Autonomous Vehicles (AVs)
AVs rely on machine learning (ML) models to predict and understand their environment. Recent advancements in ML allow AVs to perform well in predictable situations or on less routes. However, limitations and lack of transparency in AV ML raise routes.

- Domain shift (drift between the original context of the data and the application of the model)
- Lack of information/information among both consumers and car salespeople

Communication
Even in a scenario with a highly automated vehicle able to detect vulnerable road users (VRUs), the VRUs may have no way of knowing if they have been detected or even aware that they are interacting with an AV. Human drivers and AVs often communicate their intentions non-verbally, such as nodding or eye contact. Without a way to replicate these cues, AVs must be designed to communicate their intentions in other ways.

- Micromobility users must also be able to communicate their intentions to other road users, which will include AVs. While hand signals common to cyclists exist, they may be challenging for novice e-scooter riders to use. One solution for this issue involves including using signaling mechanisms on micromobility devices so riders could better communicate their intentions, however these have not been widely employed.

Concerns
Prediction
- Human behavior can be difficult to predict; even for humans; models have also struggled to accurately describe human behavior and often generalize poorly.
- E-scooter users often switch between traveling with traffic, against traffic, on the sidewalk, in the crosswalk, or in the road. The behavior of AVs is expected to be particularly unexpected to AVs, which may incorrectly apply context clues like “is standing” and “is traveling on sidewalk” to mistakenly a micromobility user as a pedestrian.
- Timing may also pose a challenge. While many models use datasets that focus on a time-to-event horizon such as 1 second or 2.5 seconds, an e-scooter will be moving at a very different speed. A pedestrian walking at 3 miles per hour is only moving at 4.4 feet per second, covering about 11 feet in that 2.5 second window; an e-scooter going 10 miles per hour is covering 10 feet in that window and would cover 30 feet in that same window. The difficulty of this geometry is illustrated in Fig. 1. This makes the prediction task more difficult because of the difference between the training data case and such a scenario, but it also means the prediction must be done much faster to avert a crash.

Expectations
- Interactions in the transportation system are largely dictated by expectations, formed by prior experience and predicted routine activities.
- AVs may interpret VRUs as pedestrian such as micromobility vehicles, particularly those not equipped with sensors.

- The higher the level of trust, the greater the potential for exploitation from bad actors. A pedestrian who knows that an AV can and will always stop for them has little incentive not to jaywalk, and VRUs have already reported engaging in exactly such risky behavior.

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Recommendations
Current evidence suggests that AVs cannot detect VRUs as well as they can other vehicles and cannot detect micromobility devices as well as they can detect pedestrian and cyclist. However, no AVs have the needs of both nascent technologies as they develop and interact, and the infrastructure needs for each become clear. Some recommendations include:

- Infrastructure
  - Historically, road networks have prioritized motorized vehicles over VRUs. Moving VRUs requires a similar level of infrastructure, environmental, and legal considerations

- Potential solutions include creating street types specifically devoted to VRUs and slow-moving automated vehicles; implementing AVs capable of covering 15 miles per hour for VRUs and 30 miles per hour for pedestrian traffic, and enhancing “smart city” technologies to improve communication between AVs and infrastructure.

Safety
- As there is no universal repository of crash data in either the domain, researchers are left to acquire data primarily through medical and police reports. This means that their work tends to be limited, incomplete, and relies on non-standardized methods.
- Potential solutions include developing data sharing partnerships that include researchers, regulators, and developers and harmonize data logging that is tied to specific hazards. Methods for gaiting and standardizing existing data should be developed for widespread reporting and research.

Risky Human Behavior
- Prioritization of non-occupant safety could create tension between AV occupants and non-occupants. While some existing AVs may inadvertently suggest VRUs should moderate their behavior to behave more predictably, this has been met with criticism – as one premise of AVs has been that they would increase safety, suggesting this can only happen if human behavior also changes effectively, impacting the benefits of AVs.
- AV technology could give rise to poor behavior on both the part of micromobility users (e.g., riding unpredictably) and future rule) and AV users (e.g., bypassing safety systems) that could harm and invalidate past experiences are subject to change.

Potential solutions should include developing methods of increased rule compliance and stickiness (the perception of legal or social norms) and educating users and the public about the potential implications of novel behavior.

Communication and Expectations
- The communication between AVs and VRUs must be able to communicate with others. Communication methods that exist for interactions between VRUs and human drivers (e.g., eye contact and body language) may not be readily adaptable for communication between AVs and VRUs.

- Potential solutions include exploring which methods of communication are most effective between AVs and VRUs. These solutions should be easy to understand by the full spectrum of VRUs (e.g., children, people with disabilities, and people who are not familiar with new technology), a car would not put the burden on VRUs. It will be important to continue to evaluate evolving expectations and update AV models based on emerging behaviors.

Implications for Interactions Between Micromobility and Autonomous Vehicles
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Communications

- Traffic
- Signals
- Safety
- Microscopic

Microscopic

- Safety
- Infrastructure
- Communication
- Expectations

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