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Applying the AcciMap approach to a fatal e-scooter crash: A Safe System approach to analyzing micromobility

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16. Abstract

Micromobility devices (e.g., standing electric scooters or "e-scooters") are a rapidly emerging area of transportation worldwide. As these devices become more popular, there has been a coinciding rise in micromobility-related injuries and fatalities. Therefore, this study sought to apply a system mapping tool, the AcciMap, to a fatal e-scooter collision. The purpose of this exercise was to identify the factors that likely contributed to the incident and generate potential countermeasures to prevent similar future events. In addition, this report assessed the strengths and limitations of using the AcciMap approach as a more holistic tool for assessing safety, and future directions for applying the AcciMap approach in a practical setting.

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Table of Contents

Introduction

Micromobility Safety

With technological advances and the growth in shared mobility services, micromobility is an emerging area of transportation worldwide, with standing, light electric scooters ("e-scooters") at the vanguard. Shared e-scooter trips doubled from 2020 to 2021; however, the number of trips in 2021 remained 27% below the trips taken pre-pandemic in 2019 (NACTO 2022). The rapid emergence of these devices has left many unknowns about their safety profiles (for riders and other road users) and effective injury prevention strategies.

A recent U.S. Consumer Product Safety Commission (CPSC) report documented a rise in e-scooter injuries, estimating that 117,600 persons with e-scooter-related injuries were treated in U.S. emergency departments from 2017 through 2021 (Tark 2022). In terms of injury patterns, the most common locations of injury were in the upper extremities, lower extremities, and the head, with fractures being the most frequent diagnosis, accounting for roughly a third of all e-scooter injuries. Regarding injury circumstances, the majority of nonfatal e-scooter injuries involved single-vehicle incidents, such as falls, collisions with objects, excessive speed, and unfavorable road conditions (Toofany et al. 2021). While single-vehicle incidents were the leading cause of nonfatal injuries, collisions between e-scooters and motor vehicles were the leading cause of e-scooter operator fatalities, with 76% of U.S. e-scooter-related deaths involving a motor vehicle collision (Vann et al. 2022). Finally, rider perceptions align with these statistics, with 92% of survey respondents citing being struck by motor vehicles as their primary safety concern and deterrent to using micromobility systems (Sandt et al. 2020).

The increasing trend of e-scooter use, compounded with an increasing number of reported injuries and fatalities, underscores the need for preventative measures and novel approaches, such as strategic, systemic thinking around micromobility-related injury prevention. As with other complex transportation safety problems, there is a recognition that micromobility-related collisions, injuries, and fatalities are influenced by a complex system, with injury and safety stakeholders operating at multiple levels, from the individual (e.g., specific mode use decisions, impairment) to the governmental (e.g., policies leading to high-speed environments) to the societal (e.g., a culture prioritizing motor vehicles over other modes of transportation).

With an urgent need to reduce micromobility injuries, combined with a recognition of the broader dynamic transportation system and environment at play, we sought to examine the applicability of a systems mapping tool to help disentangle potential injury influencers and relatedly, pinpoint strategic intervention opportunities for e-scooter injury prevention in a U.S. context.

Systems Thinking

Systems thinking is an approach that is used across disciplines and when applied to road safety, as Naumann et al. (2020) elucidate, "accepts that complex problems, like speed-related crashes, cannot be understood by studying individual factors in isolation." (p. 6). Systems thinking requires practitioners to consider the "whole" when approaching road safety problems. Further, as Ottino (2003) asserts: "...many important problems cannot be decomposed; looking at subparts does not provide the answer and they must be looked at as a whole." (p. 298). Systems thinking is a tool that can help practitioners apply a Safe System approach by considering underlying risks in the transportation system and how the relationships between stakeholders impact desirable or undesirable outcomes (Naumann et al. 2020).

The U.S. Department of Transportation has adopted a Safe System approach through the *Safe System Strategic Plan* and the *National Roadway Safety Strategy*, which set immediate, nearterm, and long-term goals for achieving a Safe System (Federal Highway Administration n.d.; Office of the Secretary of Transportation 2022). In a Safe System approach, road safety incidents are considered in the landscape of organizational and sociopolitical systems in which they take place, rather than being attributed to human error (Larsson and Tingvall 2013). In addition, a Safe System approach to road safety diverges from traditional safety approaches through the four guiding principles of accommodating and adapting to human behavior; recognizing the role of speed and energy transfer; prioritizing safety; and strengthening all parts of the system (Naumann et al. 2020).

Thus, utilizing systems thinking tools and methods enables practitioners to apply a Safe System perspective and approach by strategically understanding and intervening on interconnected components of the larger transportation system.

Tools for Systems Thinking

Several systems thinking tools exist to assist practitioners in applying a holistic, systems-based approach to “accident” analysis. Examples of these tools include the Sequential Timed Event Plotting (STEP), the Systems Theoretic Accident Model and Processes (STAMP), the Functional Resonance Analysis Method (FRAM), and the AcciMap approach.

Stanton et al. (2019) applied the methods listed above, among other tools, to a case study involving a pedestrian and a test autonomous vehicle operated by Uber, a scenario that shares similarities with collisions involving micromobility devices. The authors found that all the previously referenced systems thinking tools displayed both considerable strengths and weaknesses (Table 1). For example, while most of these tools were effective at identifying systemic factors (e.g., governmental and organizational factors), they lacked emphasis on the diverse organizational actors associated with each factor and often favored proximal rather than distal (i.e., lower level vs. higher level) explanatory contributors to an incident. However, one of the more useful tools identified, the AcciMap approach, included the relational aspect of factors *and* organized interacting causal factors into specific organizational levels that spanned proximal and distal factors. In addition, the AcciMap approach was unique in that it provided space to consider a wide range of practical considerations for the development of countermeasures, providing a useful framework for identifying factors and intervention opportunities across multiple organizational levels without necessitating an inordinate amount of time, financial resources, or subject matter expertise (Salmon et al. 2012; Stanton et al. 2019; Underwood and Waterson 2014). Therefore, we selected this systems tool for pilot use—to examine its applicability and usability for analyzing a micromobility crash and making systems-based recommendations for intervention, consistent with a Safe System approach.

Table 1. Four example systems thinking tools for crash analysis

Tool	Description	Strengths	Weaknesses
STEP	The STEP method is multilinear and focuses on decisions and actions across time in contrast to looking at them across systemic levels.	• Low complexity and easy to use (requires minimal training) • Does not require a large time investment • High applicability to the analysis of road traffic incidents • Useful for generating interventions/ countermeasures (but only as it relates to proximal safety factors)	• Considered a multilinear rather than a truly systemic model of safety • Limited scope and is not designed to provide insight into more complex factors/ relationships
STAMP	The STAMP method is an "accident" causality model that uses a control structure.	• Addresses all levels in the system, including societal levels • Has a formal built-in classification system • Useful for generating interventions/ countermeasures	• High complexity • High reliance on subject matter experts • Can be time-consuming to generate • Assumes a hierarchical relationship between factors • More suitable for identifying technical factors over others (e.g., human factors)
FRAM	The FRAM method uses a resilience method by recognizing a range of human performance that systems need to accommodate.	• Addresses interactions between factors • Holistic approach • Useful for generating interventions/ countermeasures	• High complexity • Low applicability to road traffic incidents • Does not cover all system levels (especially higher levels)
AcciMap	The AcciMap method uses a hierarchical, multilevel diagram to illustrate potential proximal and distal causes to an "accident."	• Addresses all levels in the system, including societal levels • Lower complexity than other systems thinking tools (e.g., STAMP) • Allows identification of multiple causes • Illustrates relationships between causes within and across organizational levels • Useful for generating interventions/ countermeasures	• Subjective/difficult to replicate • May be more suitable to analyzing single versus multiple events • Relates unidirectional direction between factors • Hierarchical methodology

Abbreviations: Sequential Timed Event Plotting (STEP), Systems Theoretic Accident Model and Processes (STAMP), Functional Resonance Analysis Method (FRAM)
Adapted from Stanton et al. 2019; Branford et al. 2009.

What Is an AcciMap?

While a multitude of systems mapping and sociotechnical systems analysis approaches exist, AcciMap was chosen because of its ease of use and adaptability for transportation and public health practitioners. In short, the AcciMap approach is a method to “graphically represent the system-wide failures, decisions, and actions involved in accidents” (Salmon et al. 2011). Rasmussen originally outlined six organizational levels to include in an AcciMap, starting with the most proximal being equipment and surroundings, and the most distal being government policy and budgeting (Salmon et al. 2011). The AcciMap method has since been adapted with changes both in the methodology and application, but the main components of analyzing an incident through a series of levels and interactions in a sociotechnical system remain central to the method (Branford et al. 2009; Branford 2011; Salmon et al. 2020).

The AcciMap approach has several strengths. For one, AcciMaps facilitate consideration of the big picture, identifying higher-level organizational, governmental, and regulatory factors while avoiding undue focus and blame placed upon “front-line operators” (Branford 2011; Branford et al. 2009). Moreover, the pattern of inquiry inherent in developing AcciMaps involves structured methods of inquiry to elicit people’s thinking about dynamic complexity, time horizons, connections among system elements, connections’ strength and direction, and system accumulations, all constructs which emerge from group AcciMap procedures.

AcciMaps have multiple applications. Waterson et al. (2017) reported that AcciMaps have been used to describe incidents and their circumstances, to capture causal factors, or to create new models or methods. They go on to assert that “the chief virtue of the AcciMap is that it is relatively easy to use” and that AcciMaps support communication with diverse audiences (Waterson et al. 2017).

AcciMaps have been used to analyze train derailments, ferry incidents, disaster responses, and traffic incidents (Underwood and Waterson 2014; Lee et al. 2017; Salmon et al. 2014; Hamim et al. 2022). AcciMaps have also been applied to events involving active transportation users. For example, Wang et al. (2021) developed an AcciMap of the pattern of e-bicycle collisions in China. As mentioned previously, Stanton and Salmon (2020) applied the AcciMap methodology to a collision involving an Uber vehicle and a pedestrian in Arizona. Through their investigation, they were able to identify international factors that contributed to the fatal crash, such as a lack of technical and safety standards governing the design and operation of autonomous vehicles (Stanton and Salmon 2020).

Thus far, no studies have applied an AcciMap analysis to an e-scooter fatality. This study seeks to create an AcciMap of an “archetypal” e-scooter fatality in the United States to provide a framework for future practitioners to apply to similar events. We combine the standardized AcciMap approach provided by Branford et al. (2009) with a coding scheme adapted from Salmon et al. (2020) to identify potential causal factors and interconnections between these factors contributing to a single fatal e-scooter collision.

Study Objectives

The primary aim of this study was to complete the first AcciMap analysis of a fatal e-scooter collision. Second, it aimed to assess the feasibility and usefulness of applying the AcciMap methodology using limited, publicly available data sources. The purpose of this second objective was to establish the suitability of the AcciMap approach for use in a practical setting. Third, this study aimed to develop a framework for applying the AcciMap analysis to other incidents involving e-scooters, other micromobility devices, and other modes of active transportation, with practitioners, governmental officials, advocates, and other typical safety (e.g., Vision Zero) coalition members in mind. Lastly, the study aimed to identify potential upstream and downstream interventions for preventing e-scooter injuries and fatalities.

Materials and Methods

Case Selection

displays the stages of applying the AcciMap methodology, the first step of which was selecting an archetypal case. After careful consideration of several cases, a fatal 2019 e-scooter incident in Nashville, Tennessee, was selected. We selected a fatal e-scooter collision rather than a nonfatal case because we hypothesized it would receive more extensive media coverage and a more thorough crash investigation and documentation. In addition, a fatal case has fewer privacy considerations than one involving a surviving victim. While this case is not intended to be representative of all e-scooter injuries, a fatal injury represents the worst possible outcome, and is therefore of paramount interest to transportation safety and injury prevention professionals.

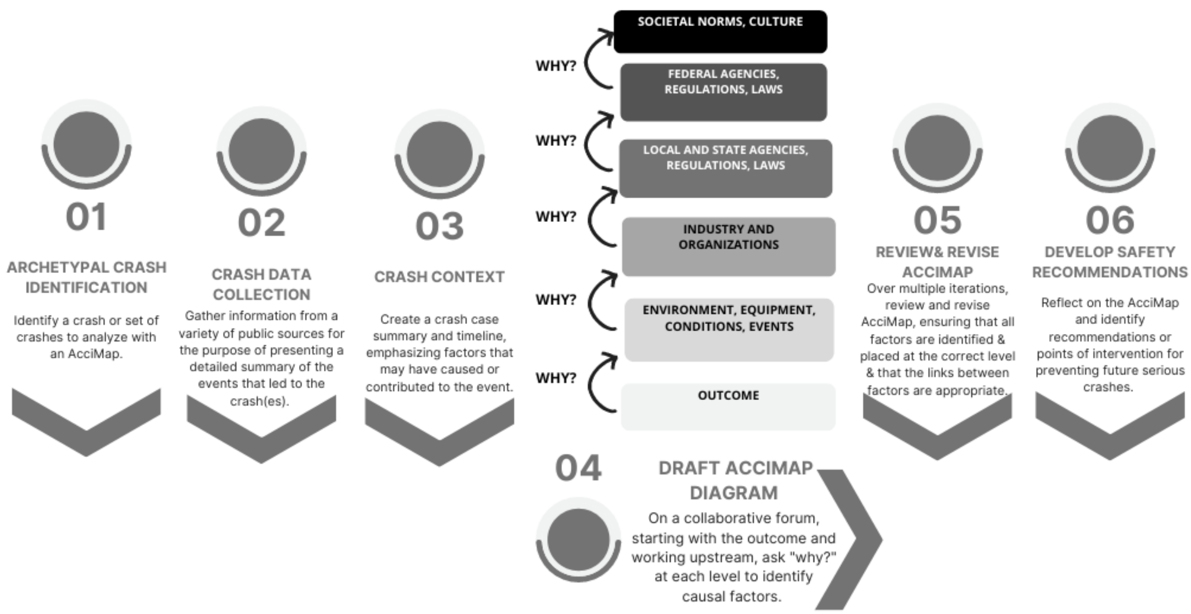

Figure 1. Stages of Developing an AcciMap

Data Collection and AcciMap Creation

Two experts from the University of Tennessee gathered publicly available information from the media, the crash report, and the Fatality Analysis Reporting System (FARS) to understand the sequence of events leading up to the crash, as well as the contextual factors that may have contributed to the likelihood or severity of the incident. These data were presented to a panel of seven experts representing the fields of epidemiology, civil engineering, health behavior, planning, and transportation in a 3-hour virtual session. Then, in a second virtual meeting, a collaborative online forum, Miro (2023), was used to identify and map potential causal factors starting at the most proximal level (environmental conditions, equipment, events) to intermediate levels (industry and organizations, local and state agencies and policies/regulations, Federal agencies and policies/regulations) to the most distal level (societal/cultural factors). The group was instructed to focus on brainstorming and were prompted to ask "Why?" as they progressed up through the next AcciMap level. All initial brainstorming ideas were preserved in an initial copy of the AcciMap to refer to throughout the refinement process.

The Five Whys Method

A common tool to generate a more systemic way of thinking is the Five Whys Method. In short, by repeatedly asking the question "Why?", one can identify the underlying cause of a problem. The following example was adapted from the NHS England and NHS Improvement (2022):

The patient was late arriving to the operating room, delaying the procedure.

1. **Why?**

There was a long wait for a gurney.

2. **Why?**

A replacement gurney had to be located.

3. **Why?**

The original gurney's safety rail was broken.

4. **Why?**

It had not been routinely checked for defects.

5. **Why?**

The hospital did not have a routine maintenance schedule for checking equipment.

Note that the suggested number of five "Whys?" is just that, a suggestion. For this example, we could continue to ask "Why?" and potentially uncover additional failures at higher organizational levels, such as a lack of national guidance pertaining to routine hospital equipment checks and maintenance.

Data Cleaning and AcciMap Iteration and Refinement

Once the two AcciMap creation sessions were complete, two people separately applied the coding methodology outlined in Salmon et al. (2011) for coding and grouping potential causal factors across AcciMap levels in a systematic way. Once the individual coding was completed, a group of three people met to consolidate and refine the multiple versions into one AcciMap. This discussion involved identifying differences in the coding, discussing the grouping of concepts, and reaching a consensus on which codes to apply. The cleaned version of the AcciMap was then returned to the entire group for further reflection and refinement of missing pieces or unclear information. Feedback was incorporated into the third and near-final version of the AcciMap. The third version of the AcciMap was shared with the project team for a final time for editorial purposes only. Figure 2 displays the three draft versions of the AcciMap. For full-page visualizations, see the appendices.

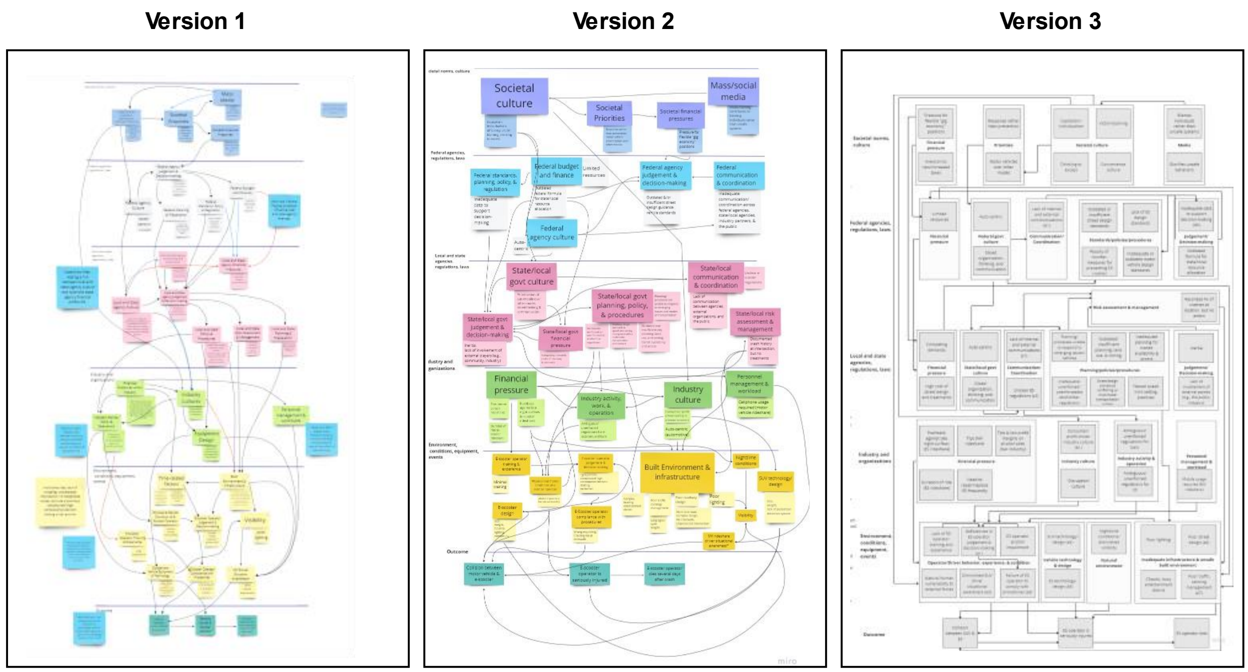

Figure 2. Draft stages of the AcciMap

Analysis and Idea Generation on Potential Interventions

Once the AcciMap was completed, the group identified examples of appropriate countermeasures or interventions based on the causal factors identified. Finally, the group recorded the strengths and limitations of the AcciMap approach as a practical tool to understand the complex systems that produced a fatal e-scooter collision with a motor vehicle in Nashville, Tennessee, in May 2019.

Results

Case Description: Fatal E-scooter Collision, Nashville, TN

The fatal e-scooter collision occurred in Nashville, Tennessee, on May 16, 2019. Figure 3 provides an outline of the events leading up to the collision and death. The intersection where the collision occurred, Demonbreun Street at 14th Avenue South, is a four-way intersection with only two streetlamps and no pedestrian crossing present on the east approach of the intersection.

An Uber driver in a 2017 black Nissan Pathfinder (Vehicle 1) was driving west on Demonbreun Street toward 1505 Demonbreun Street for an Uber pickup. Three people were individually riding on e-scooters eastbound on the sidewalk along Demonbreun Street toward a place of residence at 501 Rep. John Way Lewis South. As Vehicle 1 approached the four-way intersection of Demonbreun Street and 14th Avenue South, with a green light, the middle e-scooter operator (Vehicle 2) followed the first e-scooter rider and turned right off the sidewalk into the roadway. A collision occurred between Vehicle 1 and Vehicle 2 at 10:14 pm. Emergency Medical Services (EMS) responded promptly at 10:19 pm, with the victim arriving at a local hospital at 10:27 pm. The victim died several days later at 1:27 am on May 19, 2019.

The e-scooter operator was intoxicated (BAC of 0.198%) at the time of the collision, and the Nashville police recorded the cause of the collision as “the victim recklessly operated a Bird scooter while under the influence of alcohol.”

At the time of the crash, several relevant e-scooter policies were active in Nashville. For one, e-scooter rideshare operators were required to limit the top motor-powered speed of their e-scooters to less than or equal to 20 miles per hour. In addition, e-scooters (referred to as Shared Urban Mobility Devices in the Nashville Regulations for Shared Urban Mobility Devices (2019)) were not permitted on sidewalks in the business district and were required to yield to pedestrians when operating on sidewalks in permitted zones. However, e-scooter riders were permitted to operate their devices on sidewalks in other locations throughout the city. When riding in the street, e-scooters were required to follow the rules of the road as if they were motor vehicles. Further, while helmet use was encouraged, it was not a requirement when operating an e-scooter. E-scooter rideshare companies were responsible for educating e-scooter users on all laws and regulations applicable to operating the device and instructing users to comply with these laws and regulations.

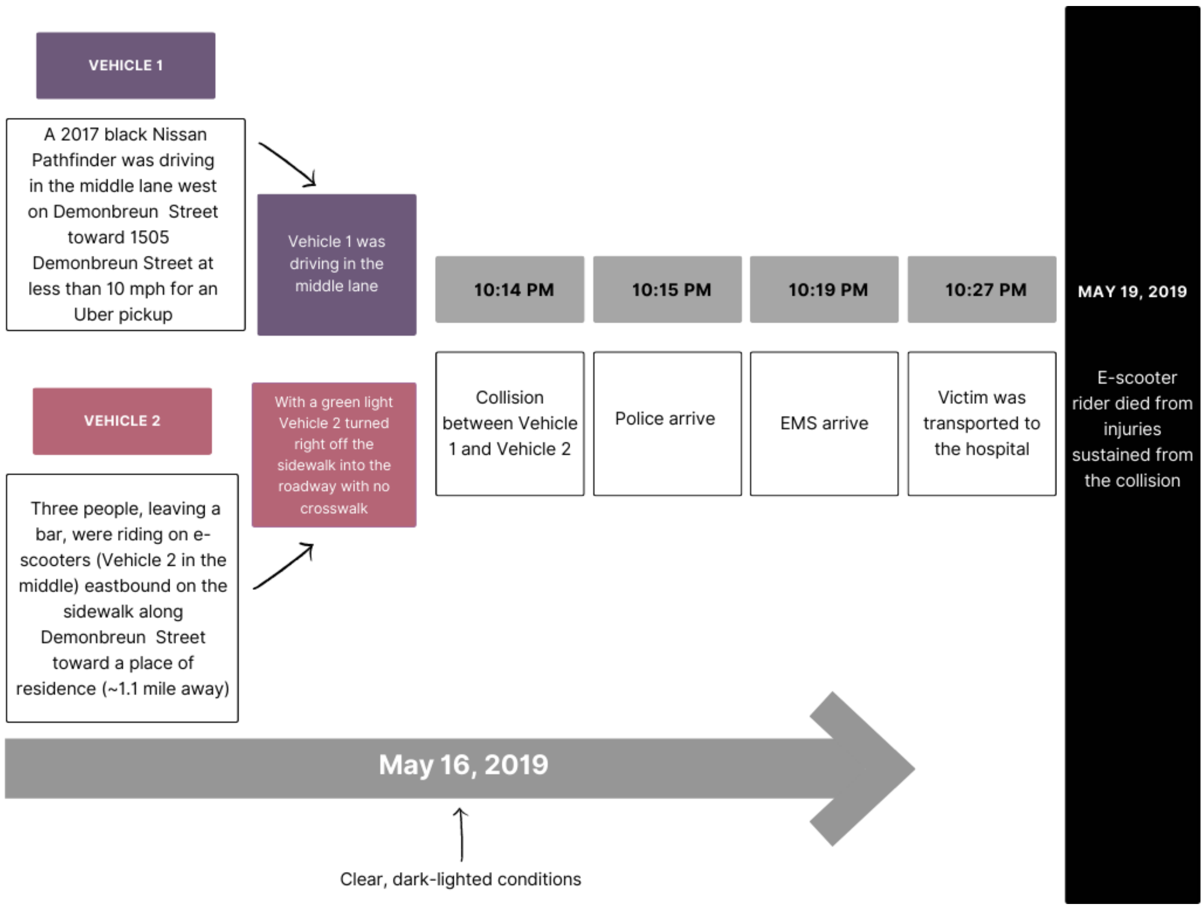

Figure 3. Proximal events leading to the fatal e-scooter collision in Nashville, TN

AcciMap Output: Fatal E-scooter Collision, Nashville, TN

displays the completed AcciMap. For optimal viewing, we recommend viewing the AcciMap at the following online location: https://miro.com/app/board/uXjVPh4AfPw=/, where you can zoom in to view individual levels or factors within the map or zoom out to view relationships across levels. In total, we identified 57 factors across five organizational levels: environment, conditions, equipment, events (13); industry and organizations (8); local and state agencies, regulations, laws (15); Federal agencies, regulations, laws (12); and societal norms, culture (9). Rather than describing all contributory factors resulting in the fatal e-scooter collision, we will focus on one causal pathway and apply the Five Whys Method, as an illustrative example.

At the base level (outcome) is the chain of events that directly resulted in the e-scooter fatality (collision between SUV and e-scooter → seriously injured e-scooter operator → death of e-scooter rider). If we ask, "Why did this fatal collision occur?", one explanation is that the e-scooter rider made a righthand turn into an intersection with no crosswalk, in front of an SUV with a green light and the right-of-way. Since this factor ("failure of e-scooter operator to comply with procedures") involved the e-scooter operator, it was placed in the most proximal organizational level, "environment, conditions, equipment, events." In addition to factors related to the decedent and SUV driver, this level also includes elements related to the natural environment, vehicle design and technology, and the physical infrastructure.

If we return to our Five Whys Method and follow the causal pathway of impaired driving to ask, "Why did the e-scooter operator fail to comply with procedures?" an explanation is that the decedent displayed poor decision-making ("deficiencies in e-scooter operator judgement and decision-making"). If we ask, "Why" once more, we can hypothesize that the rider displayed poor decision-making skills partially because he was under the influence of alcohol ("e-scooter operator alcohol impairment"). In the crash report, the investigating law enforcement officer noted that the cause of the crash was that the decedent was operating the e-scooter in a reckless manner due to alcohol impairment. The officer did not document any systemic issues that contributed to the event; however, through the AcciMap approach, we can determine that alcohol impairment was just one step in the causal pathway that led to the fatal incident.

Therefore, if we continue along the causal pathway and ask, "Why was the e-scooter rider alcohol-impaired?", one possible explanation is that a bartender overserved the decedent because of the server's reliance on tips for income. Since this factor involves a commercial establishment, it is placed in the level "industry and organizations" directly above the environment level. It should be noted that we were unable to collect any supporting evidence that the victim was knowingly overserved at the bar he visited prior to his death; however, overserving is a common occurrence in U.S. alcohol establishments (Toomey et al. 2016) and servers may be concerned about losing tips due to restricting patrons' intake (Ecklund et al. 2017). One issue with relying on publicly available sources for information is that many important details are missing. This, in turn, leads to a significant amount of conjecture, especially for factors at the higher organizational levels. In addition to factors related to the alcohol establishment, the industry level contains factors involving the private companies responsible for managing the e-scooter and motor vehicle rideshares.

If we ask, "Why did the alcohol establishment overserve the e-scooter rider?", a conceivable explanation is that the laws regulating alcohol sales are insufficient or unenforced ("inadequate/ unenforced/ unenforceable alcohol/bar regulations"). Since this is a local/state issue, we proceed to the next level, "local and state agencies, regulations, laws." While Tennessee has a state law prohibiting the sale of alcohol to intoxicated persons (Mosher et al. 2009), these laws have not been shown to be effective in reducing alcohol-related harms (Task Force on Community Preventive Services 2011) and are rarely enforced (Schriemer et al. 2023). As well as local and state laws pertaining to alcohol sales and the regulation of alcohol establishments, this level includes other relevant local/state regulations and laws, as well as local/state governmental processes and practices that failed to prevent the fatal e-scooter collision, such as the lack of communication and collaboration between local/state government and external partners (e.g., industry, community members), as well as inadequate resources to develop a safe, multimodal transportation system in Nashville, Tennessee.

If we ask, "Why?" again, we find a lack of system thinking around alcohol impairment and its role in traffic safety at the Federal level ("Federal agencies, regulations, laws"). Historically, most efforts to reduce overconsumption of alcohol have focused on enforcement and individual-level interventions rather than more systemic approaches, and few programs have been implemented (and even fewer have been evaluated) for use with nonoccupants (Venkatraman et al. 2021). While enforcement has a role, a multipronged approach is necessary for reducing alcohol-related harms (McGill et al. 2021), such as implementing policies that can reduce alcohol consumption (e.g., increasing alcohol excise taxes) (National Academies of Sciences Engineering and Medicine et al. 2018; The Community Guide 2018). Other factors identified at the Federal level include financial pressures, an auto-centric government culture, and a lack of sufficient vehicle and roadway design standards, among other factors. Taking a system-thinking approach to the intersection of alcohol impairment and traffic safety "requires the breakdown of silos between the fields of public health, workplace safety, urban planning and road safety" (Salmon et al. 2017).

If we ask, "Why has the Federal government failed to apply a Safe System approach to alcohol-related harms?", one underlying reason is that drinking to excess is acceptable in the United States ("encourages drinking to excess") (Julian 2021), a contributory factor placed on the highest organizational level in the AcciMap, "societal norms, culture". If we ask, "Why" an eighth and final time, we determine that our U.S. drinking culture is a product of media and advertising ("media promotes/ encourages unsafe behaviors"), among other underlying factors (Sudhinaraset et al. 2016). In addition, to our culture around alcohol misuse, this level also includes factors related to a culture that prioritizes automobiles over other transportation modes, private ownership over sharing, and a tendency to blame individuals rather than systems. While interventions at the societal, or population level, are often the most challenging to implement, such interventions have the benefit of significant downstream effects, preventing far higher numbers of traffic injuries and fatalities than interventions implemented at lower organizational levels.

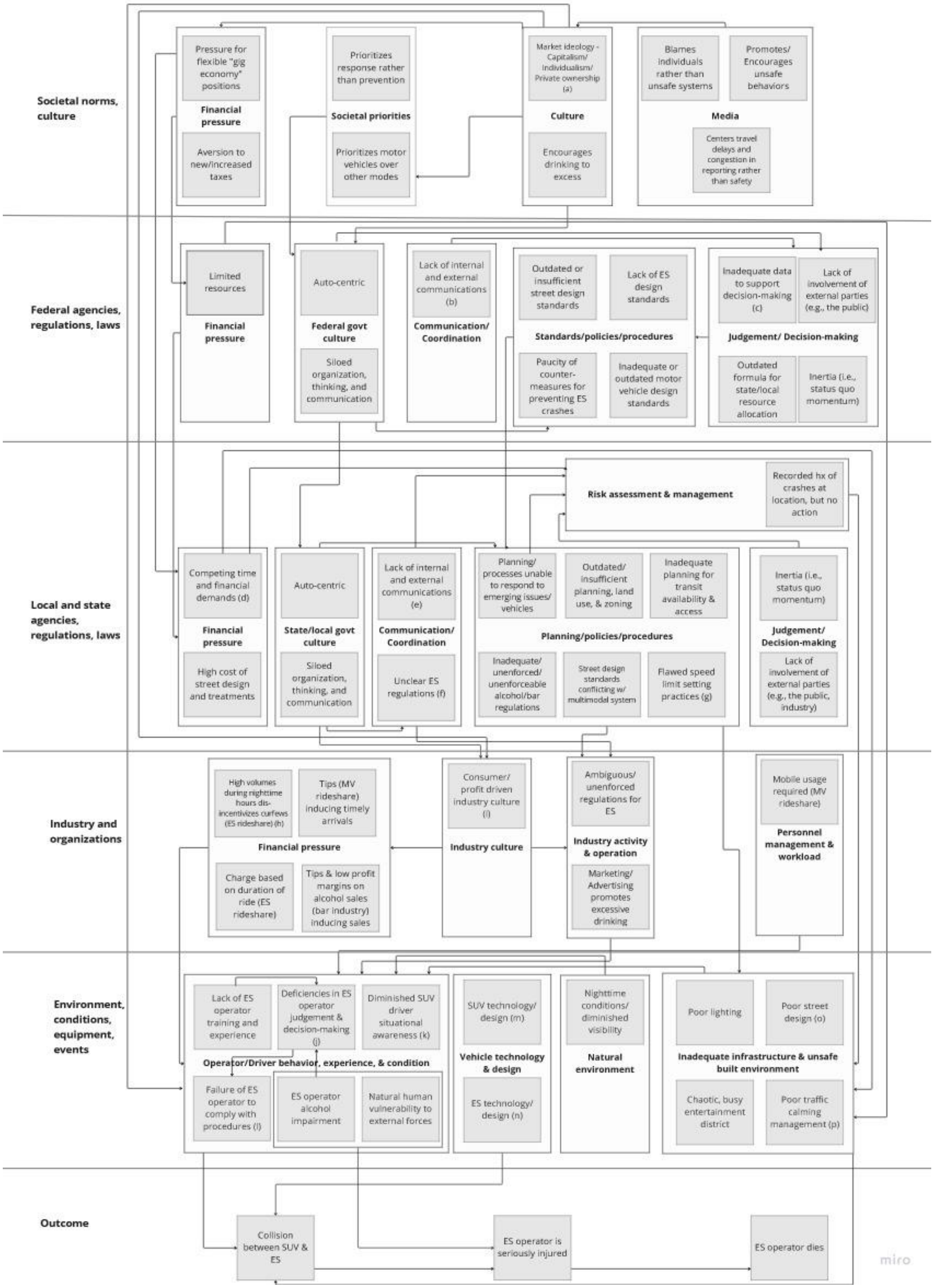

Figure 4. AcciMap representing the various interrelated factors contributing to the fatal e-scooter collision in Nashville, TN

[a] *A culture that centers the self, capitalism, and private ownership of personal vehicles is in conflict with a society that prioritizes safety and the public wellbeing over the private good* (Hall and Gingerich 2009; Kasser and Linn 2016)*.*
[b] *Inadequate communication/ coordination across Federal agencies, state/local agencies, industry partners, and the public.*
[c] *At the time of the fatal incident, the Federal government was not collecting data on e-scooter collisions (including fatal collisions) in a systematic manner.*
[d] *E.g., resource demands contributing to the inability to innovate or move outside of the "status quo" as related to roadway improvement as well as other safety strategies.*
[e] *Nashville residents had vocalized concerns regarding the safety of the crash location as well as e-scooter safety concerns more generally in the period leading up to the collision; however, there was little action preceding the fatal collision.*
[f] *E.g., in Nashville, at the time of the incident, whether sidewalk riding was allowed or prohibited differed by geographic location, potentially leading to operator confusion.*
[g] *Agencies follow Manual on Uniform Traffic Control Devices (MUTCD) guidance for speed limit setting. While the MUTCD recommends a variety of data for consideration in speed limit setting, some agencies may not carefully consider the safety implications of different speed limits and may default to posting speed limits based on 85th percentile operating speeds that are well above human injury tolerance. Differences between local road ownership and legislature-established statutory speed limits also complicate speed limit setting practice* (Federal Highway Administration n.d.)*.*
[h] *Late-night curfews limiting or banning e-scooter rideshare usage are common regulatory responses to perceived deficiencies in e-scooter safety; however, late-night ridership is quite high, especially in cities, such as Nashville, with large, vibrant entertainment districts. Therefore, these measures have historically been met with resistance on the part of e-scooter companies. Nashville enacted an e-scooter curfew after the fatal e-scooter collision* (Gardner 2019)*.*
[i] *A consumer/profit-driven industry culture may discourage safety considerations. E.g., at the time of the event, the e-scooter rideshare industry was an emerging market, with relatively high costs and low profit-margins; therefore, safety may have been a secondary consideration, especially in comparison to market expansion and economic growth* (Button et al. 2020)*. Also, consumer demands may have contributed to SUV size/design/technology that factored into the collision.*
[j] *E.g., wrong-way riding, crossing not at a designated crosswalk, and failing to yield to motor vehicle right-of-way as potential contributors to the collision.*
[k] *The crash report did not provide any suggestion of driver inattentiveness; however, such a condition is common among motor vehicle rideshare drivers due to fatigue, cognitive load, and the necessity of cellphone usage for job.*
[l] *E.g., the implications of high-consequence decision-making in complex environments, "group think" (i.e., following lead e-scooter operator without processing safety risks and conditions), and not wearing a helmet.*
[m] *E.g., SUV size/weight, the lack of a validated pedestrian detection system, and outdated headlight technology as potential contributors to the collision.*
[n] *E.g., e-scooter size, weight, balance, conspicuity, and inadequate lighting as potential contributors to the collision.*
[o] *E.g., more than 2 lanes, an unprotected intersection, and unprotected bike lane as potential contributors to the collision.*
[p] *E.g., long traffic signal lengths as a potential contributor to the collision.*

Recommendations

One of the leading benefits of applying the AcciMap methodology is that, through identifying and organizing potential causal factors according to system levels, one can understand and hypothesize about entire, holistic pathways and mechanisms generating the conditions and decisions that resulted in an event, and avoid placing undue blame on the frontline actors (Hamim et al. 2019; Leveson 2004). As part of a more systemic approach to safety, potential countermeasures can be developed for all levels of the system.

Table 2 displays potential countermeasures collected from participants during the AcciMap workshops and development process. In theory, by intervening on the higher levels of the system, multiple downstream factors can be influenced, thereby maximizing safety benefits across the transportation system. Returning to our example of alcohol impairment discussed in the Results section, one potential countermeasure at the societal level would be the implementation of social norms campaigns to change perceptions around alcohol misuse, an approach that has some supporting evidence, especially among university students (of which the victim was one) (Lewis and Neighbors 2006).

Table 2. Examples of countermeasures/interventions suggested by considering factors at each level and links between factors

System Level	Potential Countermeasures
Environmental, conditions, equipment, events	• Provide alternative forms of transportation for impaired persons, including better/expanded transit options as well as nonprofit or subsidized for-profit rideshare programs • Transition auto-oriented designs and operations (traffic signals) to multimodal designs and operations • Add route detours and signage to encourage crossing at designated (safer) crossing locations • Improve lighting (e.g., adding streetlights, upgrading to LEDs)[a]
Industry and organizations	• Provide partial or full subsidization of e-scooter rideshare program by local government as a means of better integrating e-scooters into the existing transportation system, reaching underserved populations, and improving safety, while still allowing private companies to remain profitable
Local and state agencies, regulations, laws	• Improve coordination and cooperation between state and local agencies to ensure that the design and operations of a state-maintained road in an urban setting is meeting the safety needs of local residents and visitors • Reduce barriers for state and local agencies to quickly respond to changing land use patterns and emerging technologies • Collect better data on e-scooter operatorship, travel patterns, and collisions • Institute more stringent safety audit processes and procedures
Federal agencies, regulations, laws	• Adequately fund safe, multimodal infrastructural improvements • Design and retrofit guidance, standards, and processes • Update New Car Assessment Program (NCAP), include ratings of vehicles' VRU[b] safety performance
Societal norms, culture	• Develop and disseminate recommendations for framing media coverage of e-scooter incidents using a public health lens • Launch wide-scale social norms campaigns to change perceptions around binge-drinking and drinking and riding as norms as well as norms related to safe e-scooter use and active travel

[a]*Light-emitting diode (LED)*

[b]*Vulnerable Road User (VRU)*

Discussion

This study represents the first attempt to analyze a fatal e-scooter collision using the AcciMap approach. In addition, this study is one of the first to prepare an AcciMap using existing, publicly available data sources, highlighting the utility of the AcciMap as a practical tool for systems thinking for the prevention of traffic crashes. Finally, the construction of the AcciMap yielded several possible countermeasures for the prevention of future collisions between motor vehicles and e-scooters, addressing organizational levels from the crash site up through U.S. traffic safety culture.

To date, there have been numerous AcciMaps developed for traffic incidents, especially those involving motor vehicles (Das et al. 2021; Hamim et al. 2019; Hamim et al. 2020; McIlroy et al.

2021; Newnam and Goode 2015; Stanton et al. 2023). Many of these AcciMaps have yielded important transportation safety insights. For example, in an AcciMap developed for a fatal motorcycle collision in the United Kingdom, McIlroy et al. (2021) identified a total of 66 factors that contributed to the incident, 50% of which were immediate/proximal to the crash and 50% that were more distal, occurring at national and international regulatory levels. Through their work, the authors were able to shift misguided blame (consistent with a Safe System approach) from the motorcyclist to more systemic factors, such as the lack of traffic calming features that facilitated the high-speed collision and the regulatory climate that resulted in the unsafe roadway design.

While there are numerous examples of AcciMaps developed for motor vehicles crashes, there are far fewer examples involving active modes of transportation, including micromobility devices. Wang et al. (2021) developed an AcciMap for collisions involving electric bicycles ("e-bikes") in China. In a rather unique approach, the authors developed a generic AcciMap based on a review of public media reports of e-bike collisions supplemented by semi-structured interviews with couriers (riders delivering goods) regarding their activities and e-bike safety concerns. Due to differences in methodology, target population, and case selection, there were few overlapping themes between the AcciMap for e-bike collisions and our AcciMap for the fatal e-scooter collision; however, there were some similarities. Most notably, the authors identified cell phone usage as well as time/financial pressures as contributors to e-bike crashes at the technical operations and management level. Similarly, we hypothesized that such time/financial pressures, cellphone usage, and other factors related to workload may have diminished the awareness of the striking Uber driver. In addition, the authors noted the lack of relevant vehicle design standards at the national level, an issue that we also identified as potentially contributing to the fatal e-scooter collision.

In another recent example, Stanton et al. (2019) developed an AcciMap for a collision involving an automated Uber test vehicle and a pedestrian. Like our study, much of the original "blame" for the event was focused on the pedestrian, who was impaired at the time of the collision and the Uber driver, who was likely distracted in the moments leading up to the crash. However, through the construction of the AcciMap, the investigators were able to determine that additional factors contributed to the event. These included inadequate pedestrian infrastructure (absence of crosswalks and streetlighting) at the environmental level to the deactivation of the vehicle's automated emergency braking (AEB) by engineering staff at Uber at the technical operations level. Similar to our findings, these contributing factors were also related to even more distal causes, namely deficiencies in city planning and company management, respectively, which were in turn related to state, Federal, and international failures. One key area of overlap in Stanton et al. (2019) and our research was the identified need for developing practical, well-developed regulations and vehicle design standards at the Federal level regarding emerging modes of transportation, such as automated vehicles and micromobility devices. Therefore, a growing evidence base suggests the AcciMap approach may be suitable for an enhanced understanding of events involving micromobility devices and active modes of transportation, especially for the identification of underlying safety failures. However, more studies are needed to corroborate this assessment.

Many previous applications of the AcciMap approach have characterized events of unusual severity or unusual circumstances due to the large amount of data generated (crash reconstructions, interviews, etc.) (Newnam and Goode 2015; Stanton et al. 2019; Tabibzadeh et al. 2019; Branford 2011; Thoroman et al. 2020; Underwood and Waterson 2014). While these comprehensive investigations are a rich source of data, they are uncommon and are rarely performed for more mundane, "routine" incidents, due to the resources required to perform this scale of data collection and synthesis. In the United States, where tens of thousands of traffic fatalities occur annually (NHTSA 2022), such resources are not available for investigating most traffic collisions, even fatal ones. Therefore, we utilized publicly available resources (crash reports, media reports, etc.) as our data sources for our analysis. While we were able to complete a detailed and comprehensive AcciMap for the fatal e-scooter collision, we likely missed several contributing factors that played significant roles in the collision. In addition, data gaps resulted in a considerable degree of speculation about the role of certain factors, as well as relationships between factors. For example, we could not confirm or deny that the Uber driver had been distracted at the time of the crash, something we may have been able to determine if we had interviewed the driver directly or had access to data from the driver's cellphone, something that is within the scope of a National Transportation Safety Board (NTSB)-style of investigation. However, it should be noted that even AcciMaps resulting from NTSB-style investigations can contain significant data gaps, especially at higher organizational levels (Newnam et al. 2022; Underwood and Waterson 2014). Although most AcciMap examples were produced following extensive primary data collection, we are not the first team to use publicly available data. Two recent studies have also relied on publicly available data sources for the development of AcciMaps, although for different reasons. Hamim et al. (2020) used media reports in their analysis because the incident occurred in a developing country with limited available data. In contrast, Stanton et al. (2023) relied on crash reports for their analysis as a means of engaging traffic safety professionals and in demonstrating the usefulness of the AcciMap approach in generating ideas for potential safety countermeasures.

In addition to the benefits of the AcciMap approach discussed in the preceding paragraphs, we identified several additional strengths, which are listed in Table 1. On the other hand, the reliability of the method refers to the "consistency or repeatability of a method's results" (Branford 2007). The AcciMap method may or may not always have a high level of validity or reliability, meaning that given gaps in data, different groups may come to somewhat different conclusions about potential contributing factors and points of intervention (Branford 2007; Goncalves Filho et al. 2019; Underwood and Waterson 2014; Waterson et al. 2017) However, Waterson et al. (2017) argue that if the purpose of the AcciMap is to analyze and understand an event (hypothesizing potential explanatory factors, developing countermeasures) and expand thinking in a systems-based and holistic manner, then the lack of perfect validity and reliability may not be a major concern. In other words, as with all complex problems, different key factors and opportunities for action may be identified by different groups, which can be seen as a strength, rather than a limitation. The ability to innovate within an AcciMap framework, combined with the accessibility and approachability of the tool, likely overcome potential limitations (Waterson et al. 2017). Still, there are techniques that can be used to consistently work toward improved validity and reliability of the AcciMap approach. These include gathering more data, especially at the higher organizational levels where subjectivity is most prevalent, building a more diverse and multidisciplinary team to expand thinking, performing detailed training of the AcciMap development process, and using taxonomies to classify contributory factors according to specific types, as we did here (Branford et al. 2009; Igene et al. 2017; Salmon et al. 2011; Waterson et al. 2017). Taken together, more research is needed to continually improve the rigor and feasibility of the AcciMap development approach to traffic incidents, including incidents involving micromobility devices.

Table 3. Many of these strengths relate to the utility of the AcciMap method in encouraging systems thinking in a group setting and adoption of a Safe System approach. One benefit of the AcciMap method is the absence of formal training required to perform the activity. While several team members had no experience with the AcciMap method, they were able to assist in the development of the AcciMap diagram following a brief orientation session. In addition, while our team consisted of eight individuals, we felt that it could accommodate a larger group, making it a potentially valuable tool for task forces or community coalitions, such as Vision Zero coalitions (The Vision Zero Network 2023). While several other countries have experimented with applying the AcciMap approach in a practical setting (Igene et al. 2017; Stanton et al. 2023), it has not been widely applied outside of academia within the U.S., opening up an area for further research and application.

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Table 3 also contains several limitations of the AcciMap approach. As mentioned previously, there were considerable gaps in the data that we were able to collect from public sources. In addition, there were concerns regarding both the *validity* and the *reliability* of the AcciMap approach. According to Branford (2007), the validity of a method refers to the extent that a method "does what it is supposed to do". On the other hand, the reliability of the method refers to the "consistency or repeatability of a method's results" (Branford 2007). The AcciMap method may or may not always have a high level of validity or reliability, meaning that given gaps in data, different groups may come to somewhat different conclusions about potential contributing factors and points of intervention (Branford 2007; Goncalves Filho et al. 2019; Underwood and Waterson 2014; Waterson et al. 2017) However, Waterson et al. (2017) argue that if the purpose of the AcciMap is to analyze and understand an event (hypothesizing potential explanatory factors, developing countermeasures) and expand thinking in a systems-based and holistic manner, then the lack of perfect validity and reliability may not be a major concern. In other words, as with all complex problems, different key factors and opportunities for action may be identified by different groups, which can be seen as a strength, rather than a limitation. The ability to innovate within an AcciMap framework, combined with the accessibility and approachability of the tool, likely overcome potential limitations (Waterson et al. 2017). Still, there are techniques that can be used to consistently work toward improved validity and reliability of the AcciMap approach. These include gathering more data, especially at the higher organizational levels where subjectivity is most prevalent, building a more diverse and multidisciplinary team to expand thinking, performing detailed training of the AcciMap development process, and using taxonomies to classify contributory factors according to specific types, as we did here (Branford et al. 2009; Igene et al. 2017; Salmon et al. 2011; Waterson et al. 2017). Taken together, more research is needed to continually improve the rigor and feasibility of the AcciMap development approach to traffic incidents, including incidents involving micromobility devices.

Table 3. Strengths/Limitations of the AcciMap approach

Strengths	• Facilitates a more systemic view of traffic safety consistent with the Safe System approach • Facilitates creative, expansive thinking • Facilitates cooperation, accommodates differing viewpoints and perspectives, and is suitable for larger groups; therefore, making it an appropriate tool for task forces, coalitions, and other safety/advocacy groups • Has a low barrier to entry (i.e., does not require specialized analytic abilities) • Has potential as a hypothesis-generating tool • Has the ability to identify a variety of safety countermeasures
Limitations	• Easier to identify proximal (e.g., environmental) as compared to distal (e.g., societal) factors • Easier to apply methodology to recent, as compared to more historical events, due to the lack of easily accessible information • Easier to apply methodology to high-profile (such as the first e-scooter fatality in a city) as compared to more routine events due to the lack of information • Results are influenced ("biased") by the people creating the map, as well as the sources of the data (crash reports, media reports) • Gaps in information can lead to significant conjecture • Sufficiently capturing relationships between factors can be challenging • Does not commonly incorporate feedback between variables to capture reinforcing and balancing forces, as with other systems tools (e.g., causal loop diagramming)

Conclusion

This report describes the use of an AcciMap to analyze a fatal e-scooter collision in Nashville, TN. This project represents the first time this methodology has been applied to a collision involving an e-scooter and the second time this methodology has been applied to an event involving a micromobility device. In addition, this project demonstrates that an AcciMap can be successfully applied using public data sources commonly available to transportation safety professionals, such as crash and media reports. Systems tools provide a set of methods to help tangibly realize a Safe System approach and inform more holistic and systems-based understanding of crash incidents, as well as potential opportunities for intervention.

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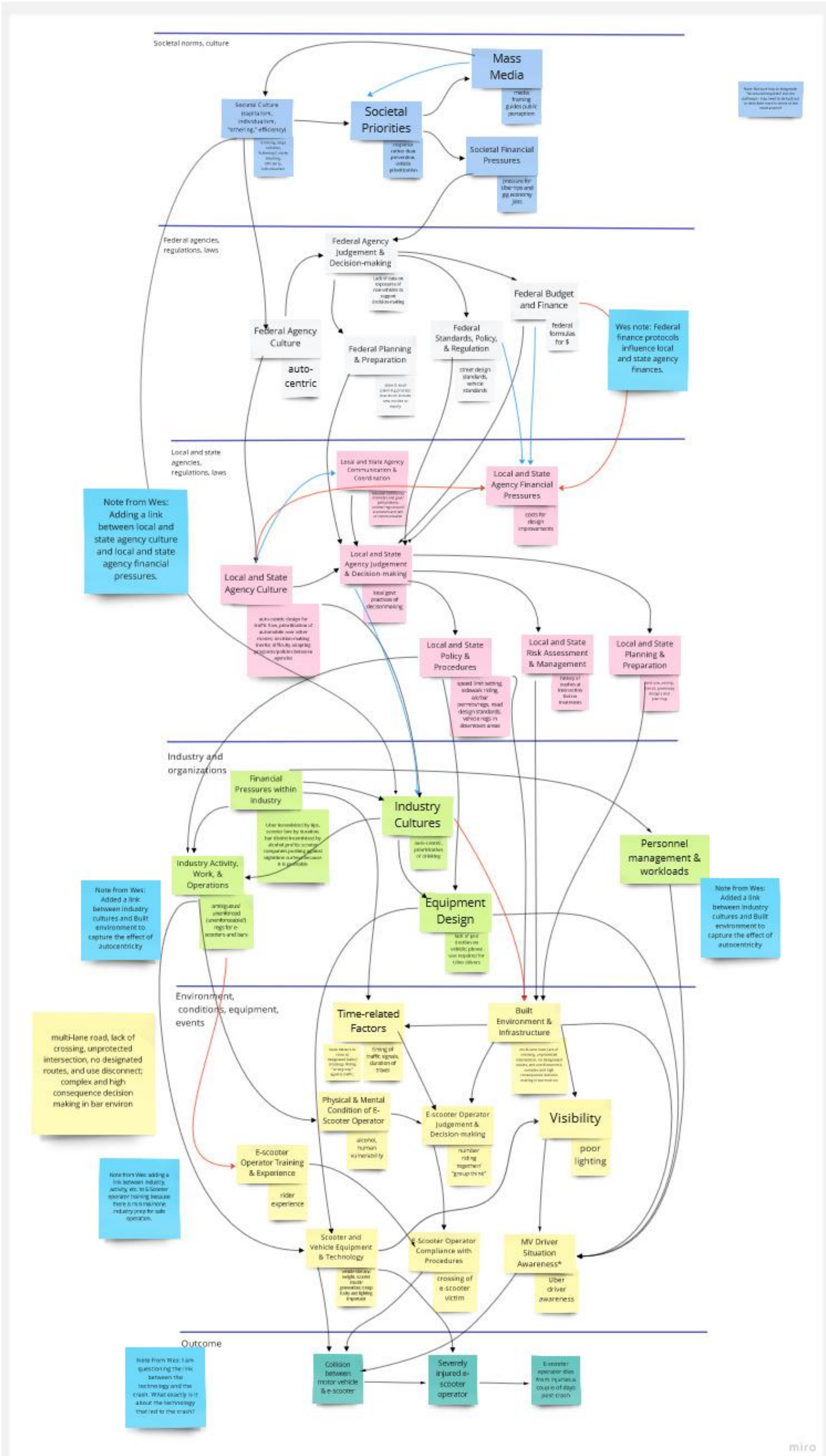
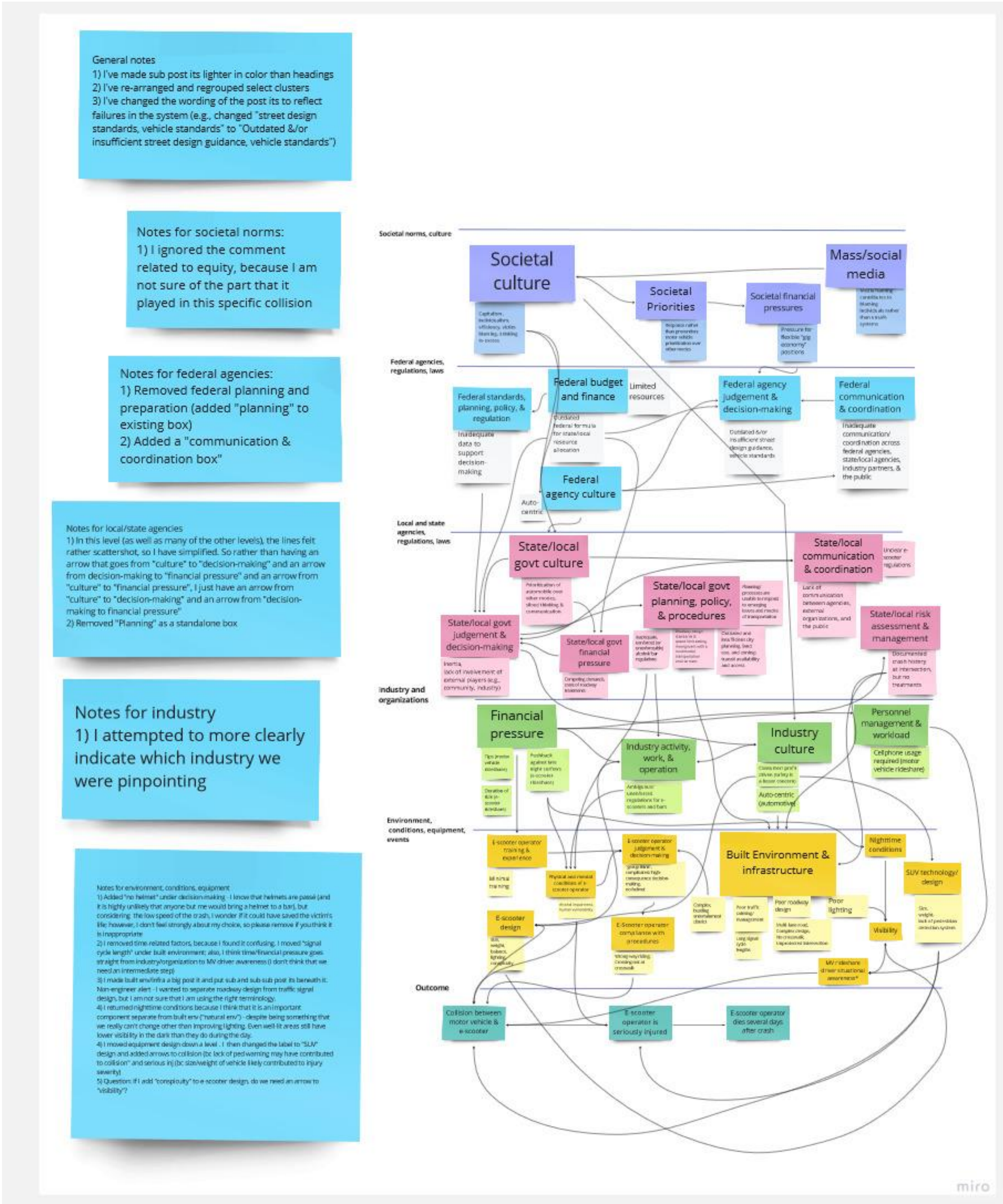
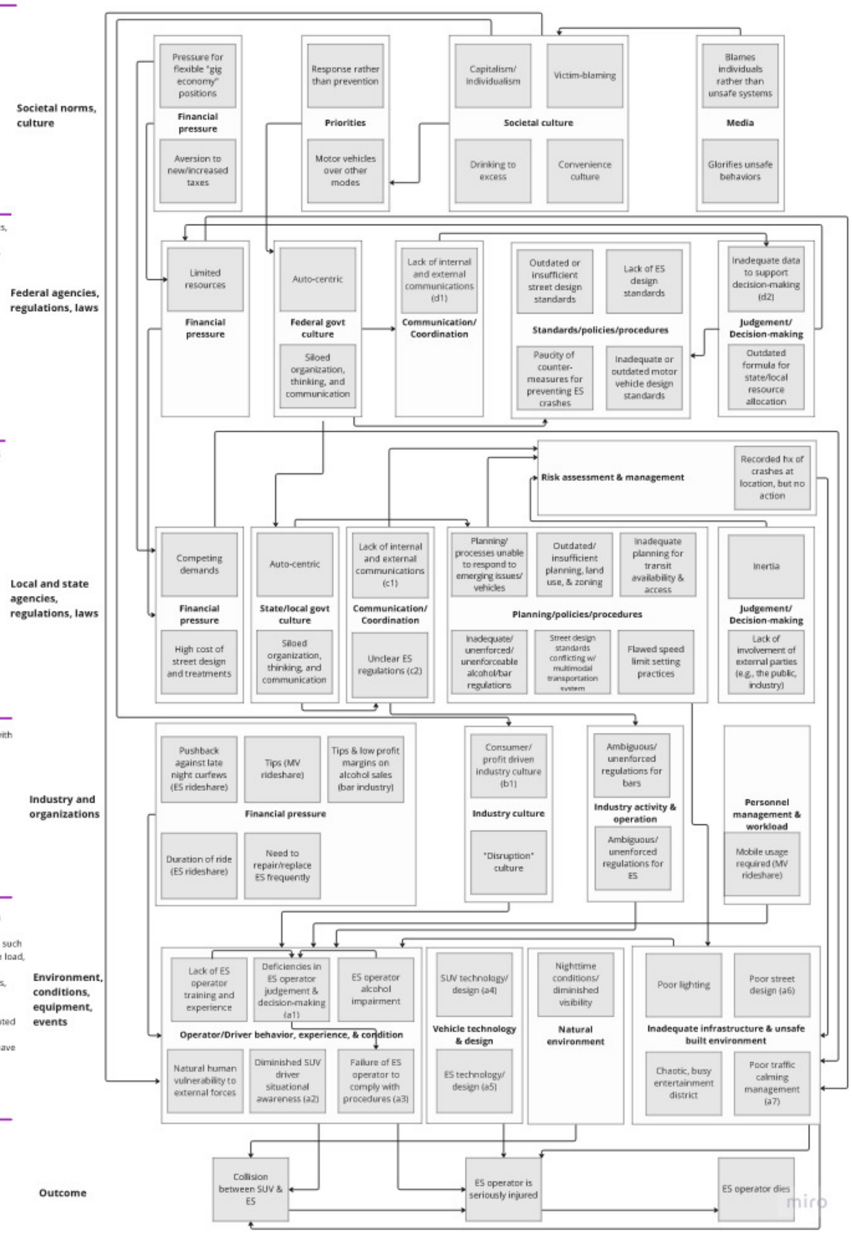
Appendix A: First Draft of the AcciMap



Appendix B: Second Draft of the AcciMap



Appendix C: Third Draft of the AcciMap



d1 Inadequate communication/ coordination across federal agencies, state/local agencies, industry partners, & the public.
d2 At the time of the fatal incident, the Federal government was not collecting data on e-scooter collisions (even fatal collisions) in a systematic manner.

c1 Nashville residents had vocalized concerns regarding the safety of the crash location as well as e-scooter safety concerns more generally in the period leading up to the collision.
c2 E.g., sidewalk riding allowed/not allowed was location specific.

b1 Safety may be a secondary consideration of industry culture, especially if it conflicts with profit margins and consumer demands.

a1 E.g., wrong-way riding, crossing not at a designated crosswalk, and failing to yield to motor vehicle right-of-way.
a2 The crash report did not provide any suggestion of driver inattentiveness; however, such a condition is common among motor vehicle rideshare drivers due to fatigue, cognitive load, and the necessity of cellphone usage for job.
a3 E.g. the implications of high consequence decision-making in complex environments, "group think" (i.e., following lead e-scooter rider without processing safety risks and conditions), and not wearing a helmet.
a4 E.g., SUV size/weight, the lack of a validated pedestrian detection system, and outdated headlight technology.
a5 E.g., e-scooter size, weight, balance, conspicuity, and inadequate lighting that may have contributed to the collisions.
a6 E.g., >2 lanes, an unprotected intersection and, unprotected bike lane.
a7 E.g., long traffic signal lengths.