Collaborative Sciences Center for ROAD SAFETY

FINAL REPORT

Explaining the Rise in Pedestrian Fatalities: A Systems Approach

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16. Abstract

Pedestrian fatalities in the United States increased 48 percent between 2009 (n=4,109) and 2017 (n=6,080). This is particularly alarming after so many years of decreasing pedestrian fatalities nationwide since the early 1970s. Many explanations have been stated for why this increase has occurred. This project was intended to explore some of the possible underlying factors associated with this alarming increase in pedestrian fatalities.

The project first convened a diverse group of cross-sector experts and examined available data sources to explore the underlying and complex factors influencing the national rise in pedestrian deaths. These efforts supported the development of dynamic, testable hypotheses to inform a future research agenda. This project was designed to also demonstrate an application of innovative systems science tools as a means for examining underlying drivers of complex problems. An initial set of systems mapping workshops with diverse stakeholders produced numerous theories involving about 40 key variables and themes related to the rise of pedestrian fatalities, many of which were further substantiated by additional data and literature scans. Additionally, hypotheses about system structures—including balancing and reinforcing feedback loops—thought to be accelerating or mitigating the fatality trends were uncovered.

Many interrelated variables are thought to be contributing to the national rise in pedestrian fatalities, including changes to pedestrian exposure to risk (such as changes in nighttime trip making), demographics, changes in technology use in vehicles, vehicle fleet makeup, new and interacting forms of impairment (including prescription drug impairment), changes in road user distraction, and changes in access to emergency medical services in rural areas. Data needed to further investigate these hypotheses is not easily or universally available, or not currently available at the level (e.g., substate) needed to perform robust analyses. Recommendations are provided for future research areas.

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List of Abbreviations and Acronyms

CLD	causal loop diagram (see definition on next page)
CSCRS	Collaborative Sciences Center for Road Safety
EPA	U.S. Environmental Protection Agency
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
GES	General Estimates System (see definition on next page)
HSRC	Highway Safety Research Center
MVC	motor vehicle crash
NASS	National Automotive Sampling System
NHTSA	National Highway Traffic Safety Administration
SUV	sport utility vehicle
US EIA	U.S. Energy Information Administration
VMT	vehicle miles traveled
WISQARS	Web-based Injury Statistics Query and Reporting System

Glossary of Key Terms

causal loop diagram (CLD): Aids in visualizing how different variables in a system are interrelated. The diagram consists of variables and hypothesized causal links. A positive causal link means the two variables change in the same direction (i.e., if the variable in which the link starts decreases, the other variable also decreases; similarly, if the variable in which the link starts increases, the other variable increases as well). A negative causal link means the two variables change in opposite directions (i.e., if the variable in which the link starts increases, the other variable decreases and vice versa). CLD is also sometimes referred to as systems mapping (see Sterman, 2000 or this website: https://thesystemsthinker.com/causal-loop-construction-the-basics/).

General Estimates System (GES): A nationally representative probability sample of all law enforcement reported crashes, including pedestrian-involved crashes. These data were collected as part of the National Automotive Sampling System (NASS) from 1988 to 2015.

grounded theory: An approach for developing a robust theory from systematically collected data. In this project, multiple CLDs were layered on top of each other, one at a time. Research team members preserved unique feedback loops and hypotheses by considering each CLD one by one and adding unique elements to a synthesized CLD, while attempting not to duplicate previously captured feedback loops.

group model building: A process of developing systems thinking capacity among stakeholders and involving them in the development of systems diagrams.

mental models: Conceptual frameworks that we each hold; they involve our underlying assumptions and understanding of how the world and specific processes work.

system dynamics: According to Richardson (2011), "the use of informal maps and formal models with computer simulation to uncover and understand endogenous sources of system behavior."

systems theory: A multidisciplinary study of systems, or, per Meadows (2009), the "interconnected sets of elements that are coherently organized in a way that achieve something. A system is more than the sum of its parts. It may exhibit adaptive, dynamic, goal-seeking, self-preserving, and sometimes evolutionary behavior."

1.0 Introduction

Pedestrian deaths in the United States have seen a recent surge, with a 48% increase in deaths between 2009 and 2016 (see Figure 1). In 2016, more than 6,000 people lost their lives as pedestrians in the U.S., compared to about 4,000 in 2009. Pedestrian deaths currently represent about 16 percent of all roadway traffic-related deaths.

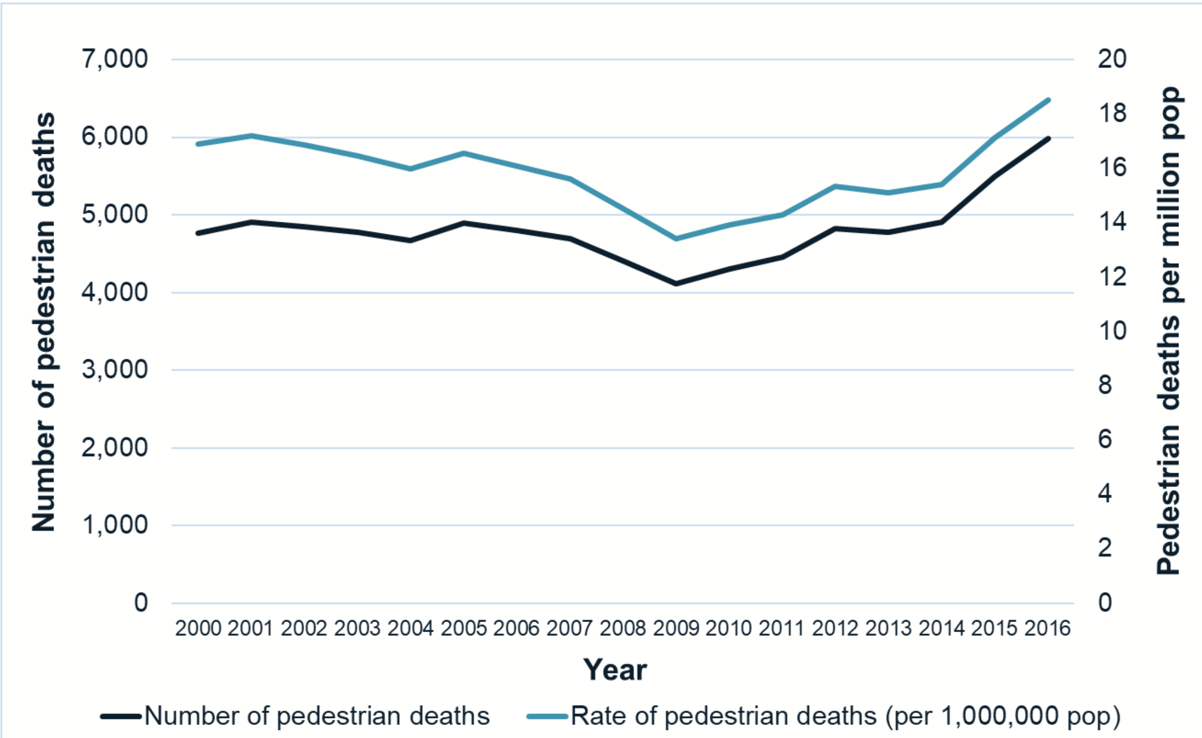


Figure 1 Number and rate of pedestrian deaths, U.S. FARS data, 2000-2016.

Given the increase in pedestrian deaths, media and transportation professionals have presented a number of hypotheses to explain the trend. These include speeding, failure to yield, driver and pedestrian distraction, alcohol or other substance impairment, and vehicle design (Retting, 2018; Hu & Cicchino, 2018). While there are ample hypotheses and studies about the factors associated with pedestrian crashes, rarely do these studies look at the deeper structures of the system that may be underlying these trends. Additionally, most studies to date have been limited to examining only a few sources of data (e.g., crash data and to some degree exposure data) to assess trends and factors.

Much of the pedestrian fatality literature published to date has taken a linear (one way) or reductionist approach, seeking to estimate associations between a finite set of variables included in existing crash data. There is a need for a more systems-oriented approach, which can acknowledge the complexity and dynamics of the problem, focus on the interrelations between many key factors, and expand upon sources of data available to provide insights into the problem of pedestrian fatalities. At the same time, a systems approach can incorporate more diverse perspectives and support broader collaborations needed by Federal, state, and local partners to be able to see the broader set of issues affecting safety and to identify leverage points for pedestrian injury prevention.

1.1 Project Purpose

This project had the following key goals:

1. **Apply systems science tools** to examine factors underlying the rise in pedestrian fatalities and opportunities for intervention:
    - Use systems mapping techniques to identify diverse mental models of underlying system structure and attributes thought to be influencing pedestrian fatality trends.
    - Document key concepts and relationships mapped and illuminate core assumptions, beliefs, uncertainties, and limitations of hypothesized variables, structures, and systems though to explain pedestrian death rates.

2. **Develop and elaborate specific, dynamic, and testable hypotheses** around the increase in pedestrian fatalities, as well as recommendations for data collection and research needs:
    - Explore additional available data and literature sources that may help test systems-level hypotheses generated by the systems mapping technique.
    - Develop recommendations for studies and data needed to support better understanding of pedestrian fatalities and provide a rationale for future research efforts.

3. **Demonstrate the role of systems science** in organizing thinking around complex problems to strengthen policy dialogue and inform future actions:
    - Describe the systems mapping techniques and data analysis methods used and share insights from the process.
    - Engage a national audience on the issue of pedestrian fatalities and methods for taking a systems approach to better understand the pedestrian death trend.

Ultimately, this project was intended to inform future research and implementation efforts to support USDOT, states, and local communities interested in utilizing a broader array of policy levers to advance pedestrian safety goals, putting innovative systems science tools and theory to work.

In the next sections we describe the study methodology applied to achieve the goals above as well as the research findings.

2.0 Study Methodology

Systems science approaches are generally multidisciplinary in nature and utilize a variety of data sources. Data can include written and numerical data, as well as data held in rich, mental models. Using a systems science technique called causal loop diagramming (CLD), we elicited mental models in a workshop format (see glossary for these and more systems-related definitions). CLD activities, as described in section 2.1, allowed experts from a variety of backgrounds to think deeply about the complexity underlying pedestrian death trends, without being constrained to only consider factors for which we have good quantitative data. Given that many aspects of the pedestrian injury problem have poor data (e.g., pedestrian exposure), allowing participants to think in an unconstrained manner about the factors driving the problem, and the connections between those factors, provided an opportunity to develop thoughtful, detailed, and rich hypotheses. In subsequent steps of the project (see section 2.2), we conducted an environmental scan of available quantitative data sources and prior research to gain an understanding of which hypotheses could be quantitatively tested and to document which would require additional data collection or research. Systems science approaches involve triangulating different types of data and iteratively developing and testing dynamic hypotheses. Below, we describe our approach for synthesizing and gaining insight from different types of data: 1) rich, mental models and 2) environmental scans of the literature and quantitative data currently available. This work sets the stage for subsequent testing of the rich, dynamic hypotheses developed in this project.

2.1 Systems Mapping Workshops

2.1.1 Workshop purpose

To incorporate a diversity of perspectives and insights into systems-level hypotheses regarding the rise in pedestrian deaths, we held two group model building workshops. Group model building is a tool from systems science used, in this application, to both introduce systems thinking to participants and gather their dynamic hypotheses about the rise in pedestrian deaths using systems science tools. In the first workshop, we convened a group of road safety-related academic experts affiliated with the CSCRS. In the second workshop, we expanded the reach of participants to gather a wider range of expertise, including several practitioners. Following the workshops, we compiled and analyzed resulting data (see section 2.1.4).

2.1.2 Workshop participant recruitment

The 16 participants in the first workshop included a convenience sample of associate directors of the CSCRS, researchers from HSRC, and selected affiliates of the CSCRS. The group of participants were mainly university-based transportation safety researchers along with students in planning and public health. Though the first workshop was limited in diversity, it included several academic road safety-related experts and also allowed us to further refine the procedure and timing/pacing of activities for the second workshop.

The group of participants for the second workshop resulted from an effort to convene a diversity of expertise and perspectives. We first identified fields to be represented at the workshop. The research team, other colleagues, and invited participants from the first workshop all contributed suggestions on potential participants to invite. We aimed for a mix of perspectives and backgrounds. Additionally, we specifically sought input from fields that are often not considered directly related to pedestrian safety, but from which we believed insight on pedestrian safety issues could be gained. Many of the participants were from North Carolina, due to limited travel funds; however, we did involve a limited number of out-of-state participants. The group of 25 participants featured the following fields: bicycle and pedestrian advocacy, safety advocacy, the automobile industry, child safety, law enforcement, emergency response, homelessness, law, local government, planning, medicine, media, public health, transit, and transportation safety. In addition, the group included researchers that focus on transportation access, injury prevention, human factors, pedestrian and bicycle safety, and transportation planning.

2.1.3 Workshop format and data collection process

Workshops comprised three main parts (an agenda is provided in Appendix A): an introduction to systems thinking; an individual CLD exercise; and a small group CLD exercise. Group reflections followed each diagramming section so participants could share and comment on the maps developed. Initial agendas included time for a final large group diagramming session. The facilitators, however, kept time and ongoing conversations in mind and remained adaptable to the situation during the workshop. As a result, this final planned section (i.e., large group diagramming session) was skipped in both workshops. Facilitators felt that the individual and small group discussions were rich enough that a full group session was not warranted.

Individual CLD exercise: The individual CLD session occurred directly after the facilitators introduced core systems thinking concepts. The facilitators first drew an example of a CLD or systems map, illustrating how feedback within a system of variables can produce a trend over time. The facilitators introduced common CLD notation and walked through how to develop a CLD (Figure 2). (Note: The interested reader can refer to Sterman (2000) for a more thorough discussion of diagramming notation and processes.) Prior to discussing their thoughts on the rise of pedestrian death within the group, participants spent this time drawing their own CLDs. This section was an opportunity for participants to illustrate the variables they understood to be related to pedestrian fatalities, the connections between variables, and the possible feedback loops at play. This also allowed participants to practice diagramming, employing some of the concepts individually before working on CLDs within groups. Early in the workshop planning, the facilitation team determined that we would not provide any background data, save a single national pedestrian fatality trend line, to the workshop participants, in order to avoid biasing their thinking about what might be affecting trends. We reflect on this decision later in this report in sections 4 and 5.

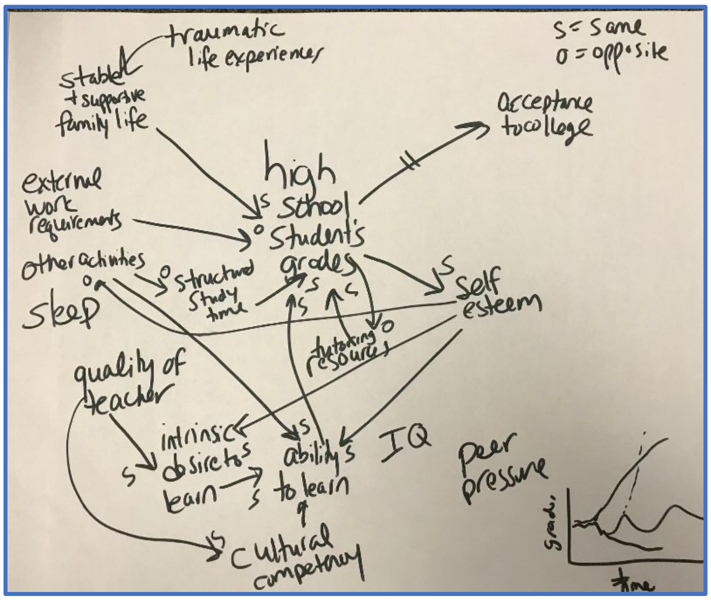


Figure 2 Example of causal loop diagram to illustrate the diagramming process in workshops. Facilitators used an example unrelated to pedestrian deaths (so as not to bias participants' maps) but one that all participants could relate to.

Group CLD exercise: Following individual diagramming exercises, participants then worked within groups of four or five to diagram their group's thinking on the factors influencing the rise in pedestrian deaths. Groups were instructed to first choose a focus variable for their CLD and together diagram key variables and connections surrounding the focus variable, looking at the causes, effects, and feedback loops within the system. We assigned participants to groups prior to the workshop based on both their field and their role within that field. By combining different fields, participants with different backgrounds and expertise could collaborate and bring their different mental models to the group's effort.

Pre- and post-workshop assessment: Prior to beginning the workshop and at the end of the workshop, participants completed short assessments (see Appendix B). Each assessment asked participants to list factors that have contributed to the rise in pedestrian fatalities and what next steps should be taken to reverse this increase. Based on responses to the first workshop's assessment, we altered the assessment for the second workshop for more directed answers on the question about next steps. The second version of this question included prompts to include actions, partners, and the reasoning behind the action. These assessments allow us to explore these workshops as a potential intervention for introducing new ideas or encouraging critical thinking and adaptation of previously held ideas.

2.1.4 Workshop data analysis

The individual and small group CLDs and the pre- and post-workshop assessments provided us with useful data to identify factors and system structures thought to be driving the increase in pedestrian fatalities. Variables from the assessments were key in helping us understand the effectiveness of the workshop as an intervention by showing what changes in thinking occurred by the end of the workshops.

CLD variable analysis: Following the workshops, we listed all of the individual variables from both the individual and small group CLDs. Next to each variable we added each variable that was a direct connection to that variable and included the direction of their interaction (i.e., if one variable increases, then was the connecting variable also hypothesized to increase or decrease). Variables were then deduplicated, so that each variable was only listed once per participant or group. Deduplication resulted in a list of 541 variables listed by individuals and 189 variables listed by small groups. We then categorized the variables into clusters, or common themes, using a web-based sorting tool (see Table 1).

Similar to the CLDs, responses from the pre- and post-workshop assessments required sorting and coding. We coded each question from the assessments separately. Responses were first sorted into groups consisting of similar answers. After sorting, codes were assigned to each of these groups to identify the overall theme. We then calculated the frequency of responses within each coded group and compared the post-workshop frequencies with the pre-workshop frequencies, noting where certain codes were either dropped or added in the post-workshop responses.

CLD synthesis: Individual and group CLDs were separately synthesized and simplified using a grounded theory approach. With this approach, CLDs were layered on top of each other, one at a time. Research team members preserved unique feedback loops and hypotheses by considering each CLD one-by-one and adding unique elements to a synthesized CLD, while attempting not to duplicate previously captured feedback loops. Additionally, detailed notes from the workshops, which were taken when participants described their CLDs to the larger workshop group, were used to help ensure that key hypotheses were captured in the synthesized CLD. Of note, a priority during this process was preserving endogenous feedback loops, given that such closed chains of feedback are generally found to be the primary drivers of persistent problems and are fundamental to systems analyses. While syntheses of individual and small group CLDs were initially conducted separately, we also created a final "working" CLD that included information from both individual and small groups CLDs, pulling in all workshop information. CLDs were simplified and synthesized in Vensim and Kumu software programs (see Figure 4 and Appendices D and E for an example).

Pre- and post-workshop assessment: By having participants complete pre- and post-workshop assessments, we aimed to better understand: 1) the core underlying hypotheses of a diverse range of participants on the rise in pedestrian deaths and 2) whether the workshop also operated as an intervention to introduce participants to different explanations for the increase in pedestrian deaths. Assessments allowed participants to list up to three hypothesized reasons per question (i.e., concerning factors that contributed to the rise in pedestrian deaths and strategies to address the issue). Assessment responses from each workshop were listed and combined into a single spreadsheet. Individual dummy IDs were used for each set of responses to compare individual responses between the pre- and post-workshop assessments while retaining participant anonymity.

For a measure of the change in responses, we used an online sorting tool to group similar responses into categories. We then calculated changes in the frequency of response categories and documented whether categories were added or dropped in the post-workshop survey.

2.2 Additional Literature Scan and Data Analysis

To complement the group model building, we performed a brief scan to identify relevant literature and data sources available to support or further examine hypotheses that arose from the workshops. Based on the final list of CLD variable categories, we identified a selection of topics to identify current data sources and data needs. For each category, we performed a scan of literature to find data sources pertaining to this category and whether previous research had explored trends related to the category. In doing so, we acknowledge previous research in these factors while identifying gaps in research and data needs. To the extent possible when key data were available, we also performed preliminary temporal and spatial analyses. These analyses were descriptive in nature and utilized the following sources of publicly available data:

Fatality Analysis Reporting System (FARS): FARS is a national database, operated by the National Highway Traffic Safety Administration (NHTSA), containing information on all US motor vehicle traffic crash fatalities, including pedestrian fatalities, from 1975 to the present. FARS collects >100 data elements from all 50 US states, the District of Columbia, and Puerto Rico. States obtain these data elements from a variety of primary sources, including law enforcement crash reports, death certificates, coroner/medical examiner reports, hospital records, etc. Statistics are available at the person and crash level. FARS posts publicly available data sets online annually. The most recent year available is 2016 (National Center for Statistics and Analysis, 2018a).

Web-based Injury Statistics Query and Reporting System (WISQARS): WISQARS is an online database of fatal and nonfatal injury data. These data are curated by the National Center for Injury Prevention and Control and are collected from a variety of sources, such as the National Vital Statistics System (NVSS), the National Electronic Injury Surveillance System – All Injury Program (NEIS-AIP), and the National Violent Death Reporting System (NVDRS). For all fatal injuries, including fatal pedestrian injuries, these web-based reports provide information describing the decedents' age, race/ethnicity, metro/non-metro area of residence, and Years of Potential Life Lost. The fatal injury reports are available at the aggregate state, regional, and national level from 1981 to the present. Statistics are available at the person level, only (i.e., not at a crash level). The most recent year available is 2017.

In addition to the fatal injury reports, WISQARS contains nonfatal injury reports based on national estimates of injuries treated in US emergency departments (2000-2016) and cost of injury reports for injury-related emergency department visits, hospitalizations, and deaths (2010). Both the nonfatal and cost of injury reports are available at the national level, only.

General Estimates System (GES): GES is a nationally representative probability sample of all law enforcement reported crashes, including pedestrian involved crashes. These data were collected as part of the National Automotive Sampling System (NASS) from 1988-2015. The GES database contains a larger variety of variables describing the circumstances of the crash and the persons involved. Unlike FARs and WISQARS, GES contains information on crashes with minor and no injury involvement (i.e., property damage only) as well as crashes involving more severe injuries and fatalities. Statistics are available at the person and crash level. In 2016, GES was replaced by the Crash Report Sampling System (CRSS), according to NHTSA (National Center for Statistics and Analysis, 2018b).

The data sources outlined above were used to generate summary statistics. In addition to counts and proportions, crude incidence rates were calculated using the following formula:

$$\frac{Number\ of\ pedestrian\ fatalities\ (or\ injuries)\ during\ specified\ period}{Total\ person - time\ (or\ vehicle\ miles\ traveled)} x\ 10^n$$

For the calculation of motor vehicle crash fatality rates, the following denominators were used:

Vehicle Miles Traveled: The Office of Highway Policy Information of the Federal Highway Administration (FHWA) releases monthly and annual reports estimating the vehicle miles traveled (VMT) by state and several functional classes of roads. These estimates refer to miles traveled by motor vehicles, only. Comparable estimates for pedestrians (i.e., pedestrian miles traveled) are not widely available at the national level; therefore, VMTs were used for the calculation of motor vehicle crash fatality rates.

US Population Estimates: US population estimates were used as the denominator in all pedestrian fatality rate calculations. These estimates were developed by the US Census Bureau in association with the National Center for Health Statistics (Centers for Disease Control and Prevention, 2018). These population estimates are released at the midpoint of each year (July).

Maps in Motion: In addition to the descriptive statistics described above, we created a series of “Maps in Motion” designed to address spatial and temporal changes in pedestrian fatalities at the state and county level. These maps display frequencies, rates, three- and five-year moving averages, kernel densities, and other metrics. These maps were packaged as PNG files and Microsoft PowerPoint presentations for the purposes of posting and sharing with partners. See section 3.1 for more on the research findings we drew from these maps.

3.0 Research Findings

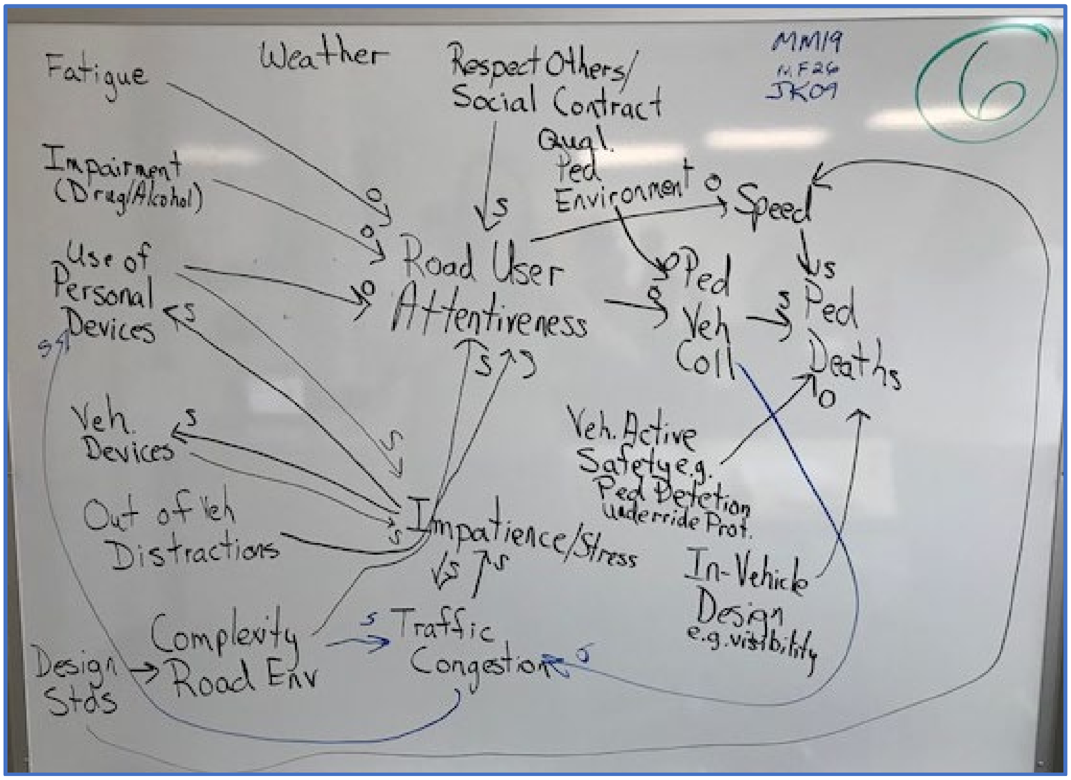
This section describes the findings from this project in two parts: Section 3.1 covers the findings related to the study goals 1 and 2, highlighting the results of the systems mapping exercises in terms of identifying variables, relationships or system structures, and mental models thought to be influencing the rise in pedestrian fatalities, as well as findings from the subsequent data and literature scan.

Section 3.2 describes the results associated with goal 3 of the study, sharing qualitative insights from and impacts of the application of a systems mapping process.

3.1 Dynamic and Testable Hypotheses Regarding Pedestrian Fatalities

3.1.1 Individual variables and themes identified through the system diagram, or CLD, exercises

Workshop participants from the two workshops produced a total of 40 individual maps and 10 group maps (for examples of group maps, see Figure 3).



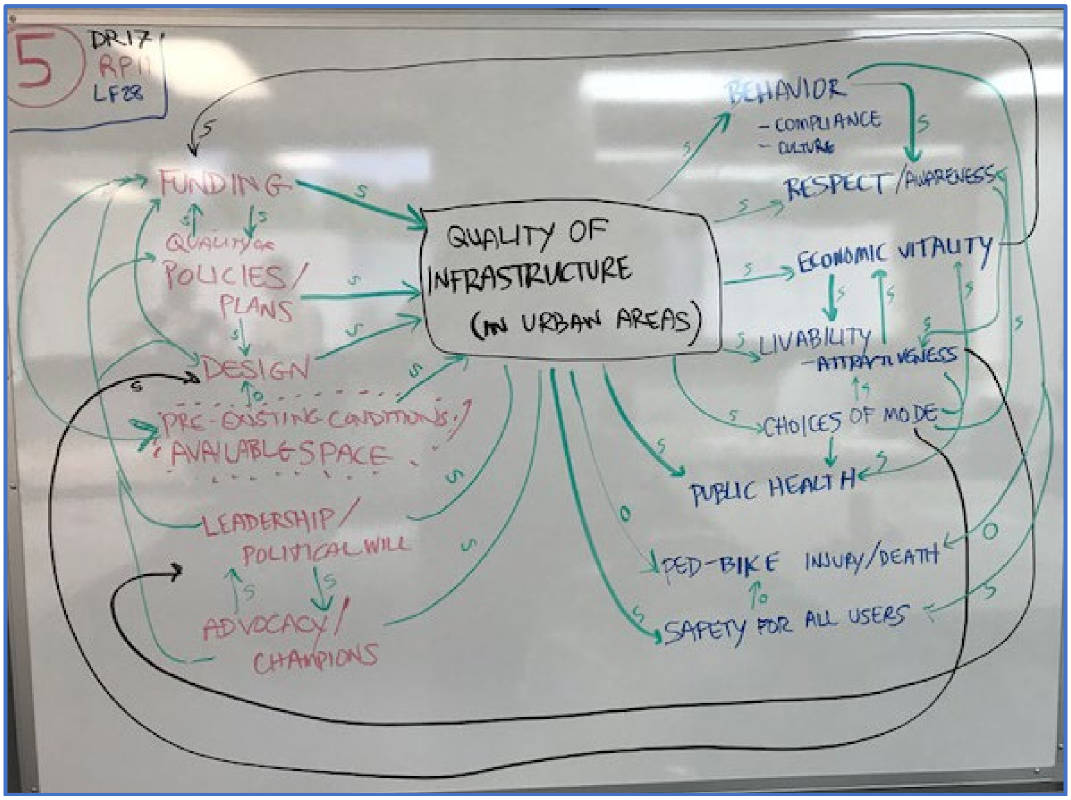


Figure 3 Two group model building system diagrams (or CLDs) produced by participants.

As shown, each individual and group map, or CLD, produced a large set of interrelated variables thought to be affecting pedestrian fatalities either directly or indirectly. Individual variables could hold varying amounts of "weight" in diagrams, meaning that a variable appearing in one diagram could be a central variable that was involved in multiple hypotheses and feedback loops, while in another diagram, the same variable might play a minor peripheral role. Because of this, it can be hard to specifically quantify the importance of particular variables or categories across all individual and small group diagrams created in the workshops. However, the research team's observations throughout the workshops and during the analysis following the workshops (as described in Section 2.1.4) provided an overall sense of at least 28 categories or themes that were most frequently discussed. These included: attentiveness (i.e., pedestrian or motorist distraction), car use (vehicle exposure), measures of the U.S. economy, measures of police enforcement, impairment, infrastructure, injuries/deaths, number of pedestrians (i.e., walking exposure), policies, vehicle speed, and technology use (see Table 1 for the complete list). Many of these themes are further expanded upon in the discussion in Section 4. Appendix C provides a table showing the frequency in which these individual variables arose in the individual and group mapping exercises.

Table 1. Categories and example variables identified in individual and small group diagramming exercises from two pedestrian systems thinking workshops.

Category	Examples of variables
Advocacy	demand for safer roads; survivor advocates
Attentiveness*	distraction; alertness; fatigue
Car safety technology	vehicle safety devices; new technology; safety features
Car use	vehicle miles traveled; vehicle exposure; number of trips by car
Car-pedestrian conflicts	pedestrian-motor vehicle conflicts; interactions with vehicles
Community characteristics	homeless population; income inequality; land use; sprawl
Congestion	congestion/traffic; travel delay; traffic level/speed
Demographics (individuals)	age; race/ethnicity; socioeconomic status
Desire for mode*	social desire to drive; fear of walking
Economy	job availability; gas prices; GDP; unemployment
Education*	drunk driving education; heads up/phones down education
Emergency services	emergency response time; trauma center density
Emotional impacts	friends/family impact; social toll
Enforcement	enforcement of pedestrian safety; inequitable police action; investment in enforcement; effectiveness of enforcement
Funding*	infrastructure funding; money; fewer resources
Health	poor health; physical condition; healthy lifestyle
Impairment*	alcohol; drug use; self-medication; addiction; intoxication; substance abuse
Infrastructure*	design speed; car centric design; road characteristics; land use; traffic separation; high visibility crosswalk
Norms/culture*	media coverage; public perception; cultural values; victim blaming; safety culture; equity mindset
Pedestrian injury/deaths	fatalities; deaths; injury; severity
Pedestrians (walking)	exposure; walking; pedestrian miles; pedestrian volume
Personal financial impact	medical costs; insurance rates; financial repercussions; lawsuits
Policies and regulations*	laws; licensure; insurance; development codes; quality of policies/plans
Public transportation	transit; public transportation access; lack of transit investment

Category	Examples of variables
Speed	vehicle speed
Support for mode*	focus on safety; leadership/political will; priority on pedestrian infrastructure
Technology use	cell phone use; distracting in-vehicle technology
Yielding*	crossing; yielding
Other	weather; data; industry reactions; knowledge of what works; vehicle weight/size

*separately classified for drivers/driving and pedestrians/walking

3.1.2 System dynamics theories identified through mapping/CLD exercises

While the team sought to document the individual variables in the system (described in the previous section), we also sought to preserve the relationships between variables identified. As described in section 2.1.4, the team synthesized the maps and identified a number of compelling and recurring stories, or structures in the systems that were mapped. Figure 4 shows the full system map produced by the group map synthesis. See Appendix D and E for highlights of key structures within the map, which are further described below.

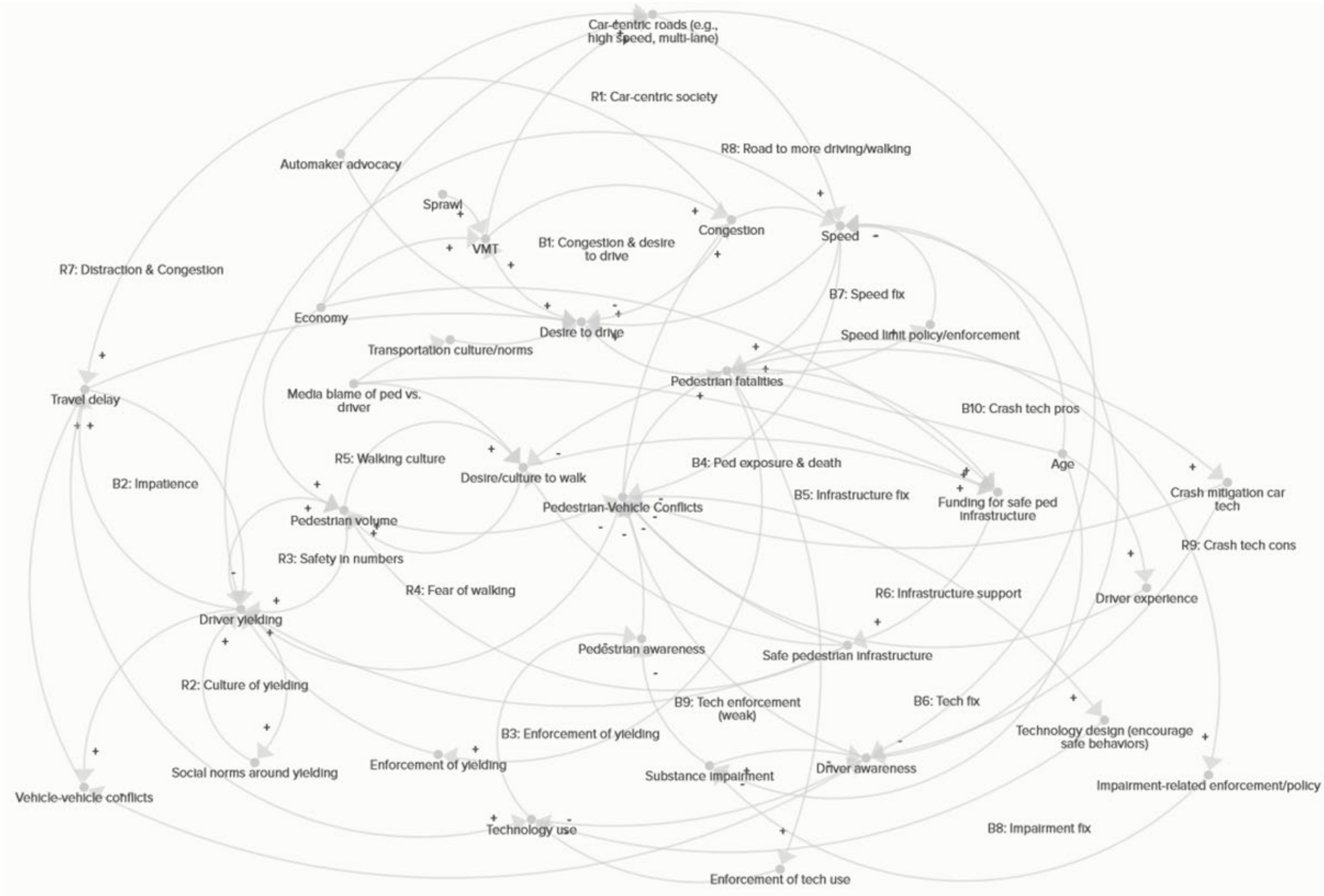

Car-centric roads (e.g., high speed, multi-lane)
R1: Car-centric society
R8: Road to more driving/walking
Automaker advocacy
Sprawl
VMT
B1: Congestion & desire to drive
Congestion
Speed
R7: Distraction & Congestion
B7: Speed fix
Economy
Desire to drive
Speed limit policy/enforcement
Transportation culture/norms
Pedestrian fatalities
Travel delay
Media blame of ped vs. driver
B10: Crash tech pros
R5: Walking culture
Desire/culture to walk
B4: Ped exposure & death
Age
B2: Impatience
B5: Infrastructure fix
Funding for safe ped infrastructure
Crash mitigation car tech
Pedestrian-Vehicle Conflicts
Pedestrian volume
R3: Safety in numbers
R9: Crash tech cons
R4: Fear of walking
R6: Infrastructure support
Driver experience
Driver yielding
Pedestrian awareness
Safe pedestrian infrastructure
R2: Culture of yielding
B9: Tech enforcement (weak)
B6: Tech fix
B3: Enforcement of yielding
Technology design (encourage safe behaviors)
Social norms around yielding
Enforcement of yielding
Substance impairment
Driver awareness
Vehicle-vehicle conflicts
Impairment-related enforcement/policy
B8: Impairment fix
Technology use
Enforcement of tech use

Figure 4 Synthesized systems map.

Balancing Feedback Loops

Balancing feedback loops are a key feature of complex systems and are thought to stabilize changes happening in the system, resisting change in one direction by producing change in another. An aim in identifying balancing loops is to help unearth underlying goals driving the balancing process, to identify the equilibrium that the system is seeking. Recognizing balancing loops can also help to identify corrective actions needed or approaches to manage the time delays in adjusting or finding the appropriate balance.

Table 2 describes the balancing feedback loops we extracted from the synthesized system model. Images highlighting these loops (found within Figure 4) are provided in Appendix D.

Table 2. Description of balancing feedback loops thought to affect pedestrian fatality trends.

Loop #	Name	Description
B1	Congestion & desire to drive	With more vehicle miles traveled (VMT) and cars on the road, there is more congestion, causing a lower desire to drive, and a reduction in VMT (as more people are able to use alternative modes of transport such as walking, transit, or forego trip-making). Alternatively, as VMT and congestion decrease, desire to drive may increase again, the well-known and documented phenomenon of latent demand.
B2	Impatience	In certain areas (e.g., with marked midblock crosswalks at unsignalized locations), more drivers yielding to pedestrians can cause more travel delays for drivers behind them. With more travel delay, these drivers may be less inclined to yield to pedestrians (and may demonstrate other unsafe behaviors, such as passing stopped vehicles or running red lights).
B3	Enforcement of yielding	With a rise in the frequency of pedestrian crashes, and resulting fatalities, there is an increase in advocacy and support for finding safety “fixes.” One of these fixes could be enforcement of yielding to pedestrians, which may, in the near term, lead to improved yielding to pedestrians and a decrease in pedestrian-vehicle crashes. It may be part of a bigger balancing loop described in B2.
B4	Pedestrian exposure and death	With an increase in pedestrians and walking trips (particularly at high-risk times such as at night or in unexpected locations), there are more crashes and more pedestrian fatalities. The increase in fatalities could cause a decrease in the desire to walk (due to perceptions of danger) and therefore a decrease in the number of pedestrians walking or trips made.
B5	Infrastructure	As pedestrian fatalities increase, there could be an increase in advocacy and calls for safer pedestrian infrastructure. This could lead to increases in funding and, over time, investment in pedestrian-supportive infrastructure, which could in turn decrease conflicts, crashes, and fatalities.
B6	Overall Technology	With more pedestrian crashes (and fatalities), there could be an increase in advocacy and calls for improved technology that could encourage safer driving around pedestrians (e.g., systems to prevent calls during driving or designed to reduce looking down while driving).

Loop #	Name	Description
		This could lead to increases in driver situational awareness and decreases in pedestrian-vehicle conflicts.
B7	Speed	As pedestrian fatalities increase, there could be an increase in advocacy and calls for more solutions and policy fixes, including speed limit reductions and/or increased speed enforcement. This could lead to decreases in pedestrian-vehicle conflicts, crashes, and fatalities.
B8	Impairment	This loop involves two sub-loops, one related to driver impairment and the other related to pedestrian impairment. As pedestrian fatalities increase (assuming some are related to impaired drivers or pedestrians), impairment-related enforcement increases. This is thought to decrease impaired travel by road users, which may lead to greater attentiveness and a decrease in crashes and fatalities.
B9	Enforcement of distraction	As pedestrian fatalities increase, some due to driver distraction, there may be greater advocacy for distracted driving enforcement. This has a low level of effectiveness (because these laws are hard to enforce) but may lead to a small decrease in driver technology use, which may increase driver situational awareness and decrease pedestrian crashes and fatalities.
B10	Vehicle technology	As pedestrian fatalities increase, there may be a push to develop more and better vehicle technologies that can help avoid pedestrian collisions (e.g., detection and crash avoidance systems). As more of these vehicle technologies (e.g., autonomous vehicles, electric vehicles) enter the vehicle fleet, there may be a decrease in pedestrian-vehicle conflicts and fatalities.

Note that these system dynamics theories are still in a very early stage of development. Group model building best practice involves several sessions and iterations of working with stakeholders and different types of data in order to assess, test, clarify, expand, or even eliminate certain theories. The goal of this initial exercise was to capture an initial, rich set of dynamic hypotheses. Moving forward with future analysis and iterations of these hypotheses, it will be important to continue using systems approaches to explore the inherent goals and underlying assumptions in these balancing loops. For example, several loops appear to demonstrate an underlying demand for convenient auto-oriented travel (B1, B2, B7), while others emphasize a demand for safe nonmotorized travel (B3, B5, B6, B7, B8, B9, B10). Still others (B4, B6, B6) indicate that there may be an element of risk homeostasis in the system (as perception of danger increases, safety behaviors adapt). Examining hypotheses around pedestrian fatalities through the systems lens may allow for deeper insights to emerge.

Reinforcing Feedback Loops

In contrast to balancing feedback loops, reinforcing feedback loops destabilize the system and can lead to the acceleration or continued growth (or decline) of a trend. Reinforcing loops that lead to positive outcomes are often called “virtuous cycles” while reinforcing loops contributing to negative outcomes are called “vicious cycles.”

Understanding reinforcing loops in a system can be helpful in identifying policy solutions; for example, we may want to look for ways to “break” vicious cycles so that it is no longer self-reinforcing, or to sustain or enhance virtuous cycles before limits to growth or balancing efforts kick in.

Table 3 describes the reinforcing feedback loops we extracted from the synthesized system model. Images highlighting these loops (found within Figure 4) are provided in Appendix E.

Table 3. Reinforcing feedback loops thought to be related to pedestrian fatalities.

Loop #	Name	Description
R1	Car-centric society	More pedestrian fatalities reduce the desire to walk (see B4 loop) and increase the desire to drive, which increases VMT. This, in turn, increases support for more car-centric infrastructure (e.g., multilane, higher speed roads), which further reduces pedestrian safety around these facilities and desire/ability to walk.
R2	Culture of yielding	As drivers more often yield to pedestrians at marked crosswalks, a culture and social norm around yielding to pedestrians will build, which in turn leads to more yielding by other drivers.
R3	Safety in numbers	As more pedestrians use the roads (specifically, marked crosswalks), drivers become accustomed to seeing and expecting pedestrians and may be more likely to yield right of way. This, in turn, may lead to more pedestrian activity, as they feel safe crossing the road.
R4	Fear of walking	With more pedestrian fatalities, desire to walk decreases, resulting in fewer pedestrians on the road. With fewer pedestrians, there may be less motivation for drivers to yield (unaccustomed to seeing and stopping for pedestrians), which may increase pedestrian crashes and subsequent fatalities.
R5	Walking culture	With more pedestrians using the roads, a culture of walking can grow and engender more support for walking, which can lead to more people choosing to walk.
R6	Infrastructure support	When there are more pedestrians walking and a greater culture around walking, there may also be increased support/advocacy for funding pedestrian infrastructure. With increased funding, there are more investments in safe infrastructure, leading to more people able to walk safely.
R7	Distraction and congestion	More vehicle crashes lead to more congestion and travel delays, leading to more people feeling pressure to (or enabled to) use technology in vehicles, which leads to decreased awareness and results in more crashes.
R8	Road to more driving/walking	Closely related to R1, more driving and VMT can lead to more funding/support for car-centric infrastructure and roads, which leads to faster driving speeds and shorter vehicle travel times, resulting in an increase in desire to drive and miles traveled. Ultimately, this vicious cycle gets limited by available roadway capacity (see B1). Alternatively, this could be framed in relation to R5 as a virtuous cycle, whereby cities reduce car-centric roads, reducing speeds and increasing congestion, which leads to a reduced desire to drive (due to inefficiencies), which leads to reduced VMT and cars on the road, which may lead to increases in walking culture and pedestrian safety.
R9	Technology failures	With more pedestrian fatalities, there is a push to develop more technologies on vehicles to help avoid pedestrian collisions. With

Loop #	Name	Description
		more of these technologies available, drivers become dependent on them and driver situational awareness decreases. If the technology fixes are imperfect or rely on driver partnership, then there may be more pedestrian fatalities.

From the above, several potentially vicious and virtuous cycles were hypothesized to be affecting pedestrian fatality trends:

- Vicious cycles: R1 (car centric society), R4 (fear of walking), R7 (distraction and congestion), R8 (in one direction, more driving), and R9 (technology failures)
- Virtuous cycles: R2 and R5 (culture of yielding and walking), R3 (safety in numbers), R6 (infrastructure support), R8 (in one direction, more walking)

As noted above, these are preliminary concepts that merit further expansion, clarification, and testing to ensure that they are well-grounded in logic, theory, and, ideally, data. Additionally, these loops represent an initial collection of hypothesized feedback loops with no specific city, state, or region in mind. It is likely that some of these loops operate to different extents in different geographic locations, and some may not operate at all in specific areas.

3.1. 3 Variables Identified in Other Data Analysis and Additional Literature Scan

The group mapping workshops identified variables and interactions to highlight potential underlying system structures contributing to the rise in pedestrian deaths. The workshops were held in one location with mostly local participants. Though we attempted to reach a broad range of disciplines, there are potentially other variables and perspectives that warrant exploring. Recognizing these limitations, which are explained in further detail in section 5.2, we performed a data analysis and literature scan to complement the findings from the workshops.

Descriptive Analyses and Data Visualization

As mentioned in Section 2.2., we performed descriptive and spatial analyses (e.g., “Maps in Motion”) to complement the systems mapping workshops and exercises. Data visualization provides a clear picture of how the frequency of pedestrian fatalities are changing in different regions of the country over different time periods. Figure 5 displays the frequency and percent change in the number of pedestrian fatalities over 2012-2016. Over this period, the states of Vermont, Nebraska, and New Mexico had the largest percent increase in the frequency of pedestrian fatalities while the states of North Dakota and Rhode Island and the District of Columbia had the largest percent decrease in pedestrian fatalities.

In addition to temporal and spatial changes in the frequency of pedestrian fatalities by state, we were interested in trends related to fatal pedestrian crashes that involved alcohol (motor vehicle driver *or* pedestrian), unmarked crosswalks at non-intersections, and middle-aged pedestrians (40-64 years of age). Over 2002-2016, we found a significant decrease in the proportion of fatal pedestrian crashes involving alcohol, a significant increase in the proportion of fatal crashes occurring at unmarked crosswalks at non-intersections, and a significant increase in the proportion of fatal crashes involving middle-aged pedestrians. Not all U.S. geographic regions appear the same, however. The Rocky Mountain and Midwest regions had the highest proportion of pedestrian crashes involving alcohol, the South and Midwest regions had the highest proportion of fatal crashes at unmarked crosswalks at non-intersections, and the South and Pacific Coast regions had the highest proportion of crashes involving middle-aged pedestrians. These results highlight the need to consider differences in system structures and dynamics in relation to pedestrian fatalities by city and/or state.

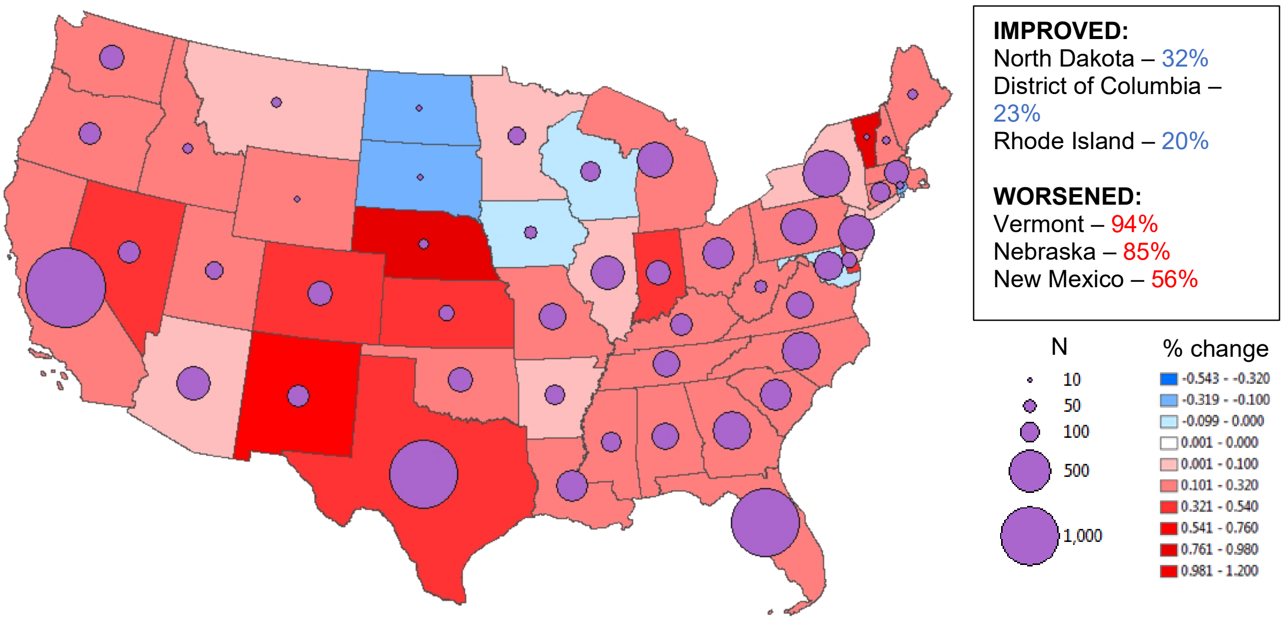


Figure 5 Frequency and temporal changes of all pedestrian fatalities in roadway crashes in the contiguous United States, 2012 – 2016 (N=29,353).

3.2 Systems Tools Applications

Beyond gaining insights into the nature of pedestrian fatality trends described above, the project team also sought to document lessons from systems tool applications as part of Goal 3: "Demonstrate the role of systems science in organizing thinking around complex problems to strengthen policy dialogue and inform future actions." One hypothesis was that a systems-oriented workshop might serve as an intervention in and of itself, bringing together diverse partners to think about pedestrian safety issues in a new way.

We measured the impact of these workshops primarily through the pre- and post-workshop evaluations described in section 2.1.3 (questionnaires provided in Appendix B). We also gathered qualitative information, informally, in subsequent interactions with workshop participants.

3.2.1 Systems mapping activities as thought influencers

The pre- and post-workshop assessments provide insight into employing a systems mapping workshop as a potential intervention for researchers and practitioners to explore their own mental models and incorporate new concepts into their thinking about this issue. The first question of the assessments asked participants to list the three most important contributors to the rise in pedestrian fatalities. In the second question we asked participants to list the three most important next steps, which may include strategies, interventions, or research needs. For many of these questions, we saw evidence of shifts in thinking among participants (see Table 4). For example, fewer participants cited individual characteristics or demographics as factors driving the trend. However, the number of participants citing underlying cultural factors/norms and enforcement inadequacies/biases increased post-workshop, demonstrating an increase by some participants to explore deeper system structure attributes that might contribute to the problem.

Table 4. Pre- and post-workshop opinions on the factors driving the increase in pedestrian fatalities.

Factor	Pre-Workshop	Post-Workshop
Distraction (driver or pedestrian)	15	17
Infrastructure inadequacies	11	12
Individual characteristics (attitude, stress, impatience, risk-taking, etc.)	8	2
Demographic factors (age, race, income, etc.)	6	0
Change in pedestrian numbers/exposure	5	4
Impairment	4	6
Vehicle speed	3	4
Cultural factors/norms	2	4
Increase in driving, VMT	2	2
Transportation policy	1	0
Enforcement inadequacies/biases	1	3
Change in safety priorities	1	0
Equity/disparities	0	2

More generally, the workshop participants completing the evaluations noted that they appreciated the complexity of the issues more and the chance to think more deeply about the issues, and that the mapping approach was a thought-provoking way to generate and inspire research ideas. Some participants also later reflected to the project team that they were now thinking differently about the everyday pedestrian safety issues faced by the population they serve.

3.2.1 Systems mapping activities as collaboration catalysts

While resources for the project prohibited an exhaustive data collection effort to follow workshop participant actions, we were able to informally catalog a few additional workshop outcomes and impacts. Most notably, we heard from participants that new collaboration and partnership opportunities emerged as a result of interacting with other workshop participants. For example, a representative of a major automaker reported following up with the police officer that attended the workshop, to learn more about forensic crash investigations, and resulting data that might support opportunities to improve vehicle design for crash prevention. Another collaboration opportunity arose for state and local transportation providers present at the workshop, who have subsequently coordinated to hold “systems” conversations at a statewide conference to further discuss the ways to coordinate action to improve pedestrian safety at bus stops. These examples provide evidence of meaningful change that can result from applying systems-oriented workshops designed to engage diverse perspectives.

4.0 Discussion: Focus Areas for Future Pedestrian Fatality Research

Given that we conducted two workshops, we did not expect to reach a saturation in breadth or depth of hypotheses about the underlying system structure driving pedestrian deaths. Rather, we aimed to gather an initial sample of ideas and perspectives to inform future systems qualitative and quantitative modeling that would allow us to further unpack and test hypotheses and plausible system structures. In future iterations, there are several specific dynamic variables and feedback loops that we would like to explore more, based on what the research team has seen in the data and literature base. These include:

- Changes in pedestrian exposure to risk
- Changes in distraction and technology use in vehicles
- Changes in impairment status and mechanism of pedestrians and drivers
- Changes in funding and support for safe pedestrian infrastructure
- Changes in rural crash response times
- Changes in community demographics and characteristics

The following sections discuss the research findings and key hypotheses about pedestrian fatality trends in the context of additional studies and data identified in the literature scan (described in section 2.2).

4.1 Changes in pedestrian exposure to risk

Data on pedestrian exposure factors

Over the last 11 years, Americans have driven more and more. Despite a plateau in vehicle miles traveled (VMT) coinciding with the Great Recession of the late 2000s, VMT increased by 5% from 2006 to 2016 alongside a recovering economy and lower gas prices (Figure 6). The FHWA anticipates VMT to continue to increase based on economic and population growth models (Office of Highway Policy Information, 2018; US Energy Information Administration, 2018).

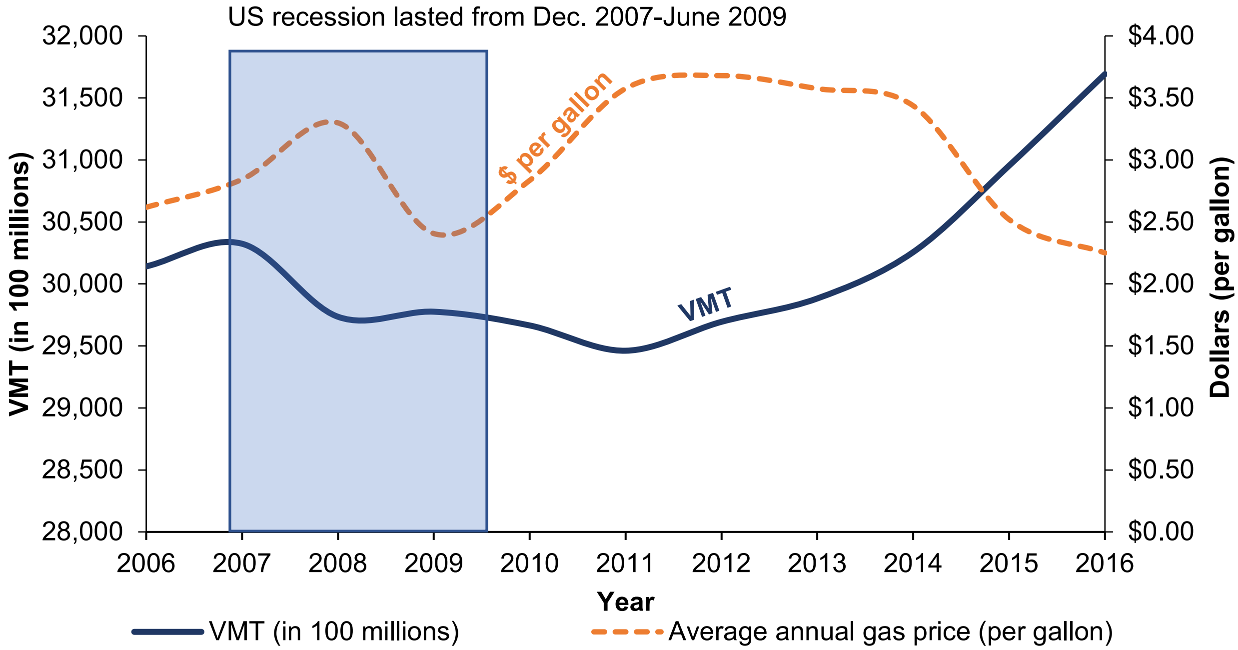


Figure 6 Traffic volume (in 100 million vehicle miles traveled) and average annual retail prices (per gallon)[a]: FHWA & US EIA, 2006-2016 (Office of Highway Policy Information, FHWA, 2018; US Energy Information Administration, 2018)

Abbreviations: FHWA, Federal Highway Traffic Administration; US EIA, United States Energy Information Administration; VMT, vehicle miles traveled; US, United States; Dec., December

[a]Average annual US retail prices; all grades, all formulations.

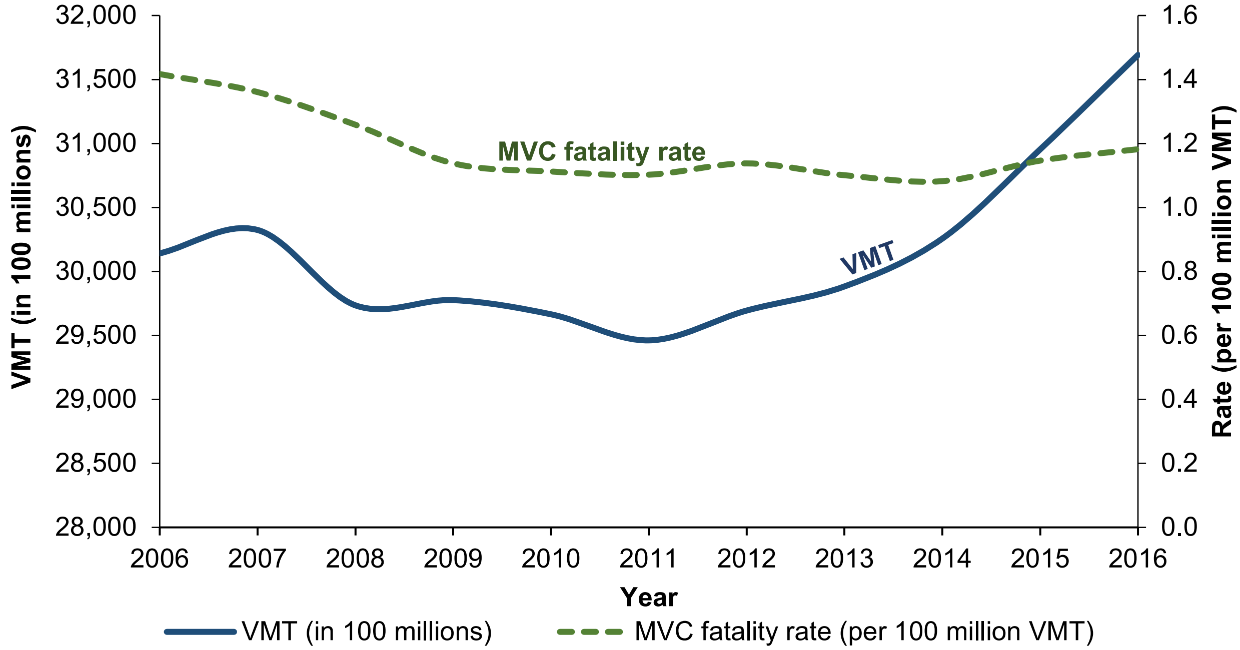


Figure 7 Traffic volume (in vehicle miles traveled) and rate of motor vehicle crash fatalities (per 100 million VMT): FHWA & FARS, 2006-2016 (Federal Highway Administration, 2018; National Highway Traffic Safety Administration, 2018)

Abbreviations: FHWA, Federal Highway Traffic Administration; FARS, Fatality Analysis Reporting System; VMT, vehicle miles traveled; MVC, motor vehicle crash

Overall, the increase in VMT has not been accompanied by an increase in the rate of MVC fatalities. Over this same period, the rate of total motor vehicle crash fatalities (per 100 million VMT) *decreased* by 17% (Figure 7). Such trends do not hold true for all motor vehicle crash victims, however.

Figure 8 displays the MVC fatality rates stratified by person type. Since estimates of miles traveled are not readily available for all categories of person type at the national level, rates are calculated using population denominators. Over 2006-2016, the fatality rate decreased for MV drivers and passengers. However, over the same period, the pedestrian fatality rate increased by 15% from 1.61 to 1.85 deaths per 100,000 person-years.

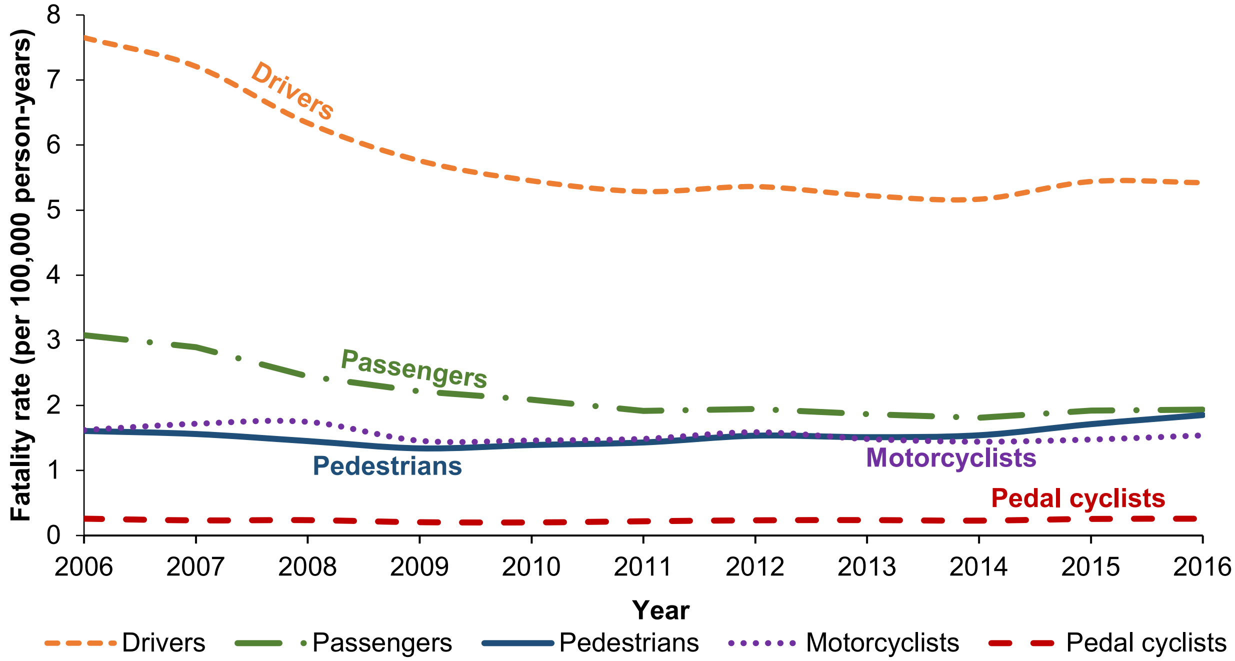


Figure 8 Annual rate of motor vehicle crash fatalities stratified by person type (per 100,000 person-years): FARS, 2006-2016 (National Highway Traffic Safety Administration, 2018)

Abbreviations: FARS, Fatality Analysis Reporting System

In addition to temporal changes, the incidence of pedestrian fatalities varies widely by US state. For example, over the period 2012-2016, the state with the highest rate of pedestrian fatalities (Delaware) had a rate that was over four times that of the state with the lowest fatality rate (Minnesota) (Figure 9).

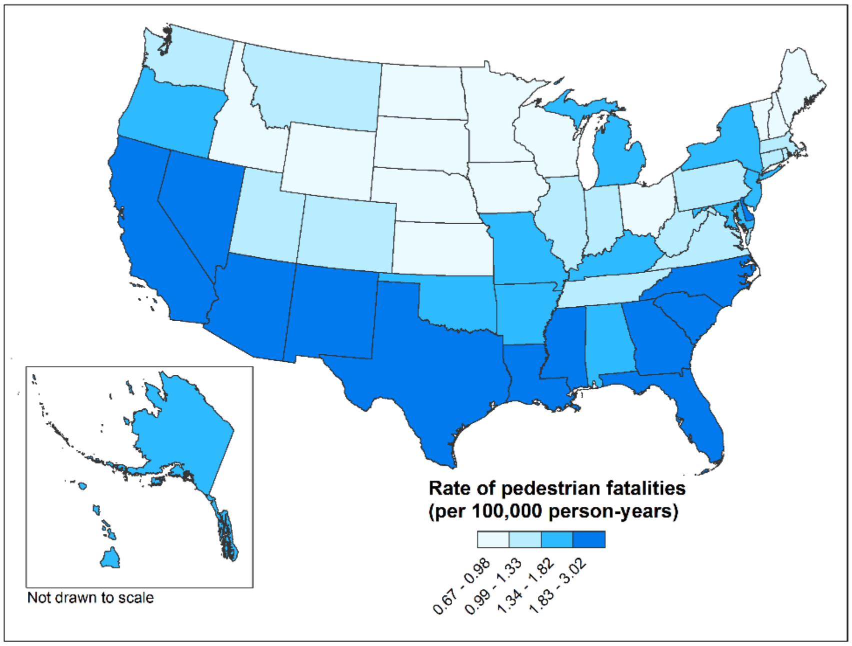


Figure 9 Average annual rates of pedestrian fatalities (per 100,000 person-years) by state: FARS, 2012-2016 (National Highway Traffic Safety Administration, 2018b)

Pedestrian fatality rates also varied by age group. Over the period 2012-2016, seniors ≥75 years of age had the highest fatality rates of any age group (average annual rate of 1.62 deaths per 100,000 person-years). Older pedestrians are at a greater risk of having fatal injuries for several reasons related to the natural aging process. These include an increased vulnerability to sustaining serious injuries and a diminished capacity to recover from said serious injuries (Zegeer et al., 1996). Older adults are also susceptible to declines in cognitive functioning, balance, and mobility that may place them at an increased risk of being involved in a motor vehicle collision (Tournier et al., 2016). Although, seniors ≥75 years of age had the highest pedestrian fatality rate, adults 35-54 and 55-74 years of age had the highest increases in fatality rates over the 2012-2016 period. For both age groups, the fatality rate increased by >25% over the five-year period. On the other hand, the pedestrian fatality rate declined slightly among children, 0-9 years of age, over this same period (Figure 10).

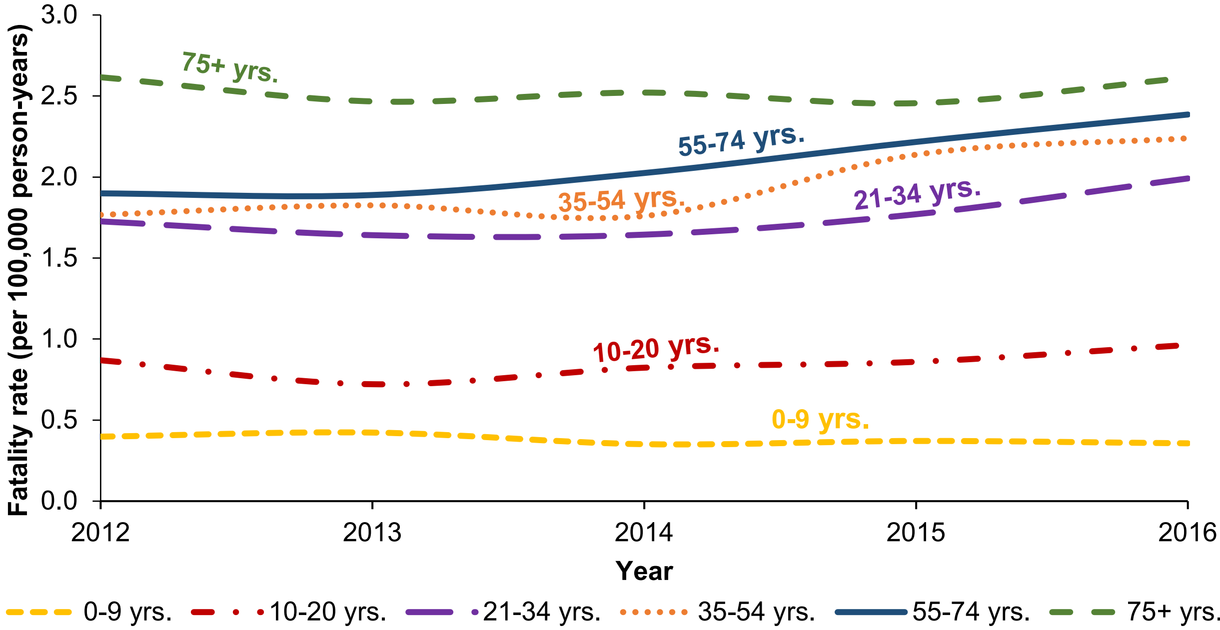


Figure 10 Average annual rate of pedestrian fatalities (per 100,000 person-years) stratified by age group: FARS, 2012-2016

Abbreviations: FARS, Fatality Analysis Reporting System; yrs., years

Another exposure-related factor that may be related to the observed increase in the pedestrian fatality rates over time is vehicle type. Since 2006, the proportion of new vehicles characterized as crossover sport utility vehicles (SUVs) (SUVs built on a car chassis) and truck SUVs (SUVs built on a truck chassis) has increased, while the proportion of new vehicles characterized as passenger cars has decreased (Figure 11) (Office of Transportation and Air Quality, 2018). Prior research has suggested that light trucks (including SUVs and pickup trucks) are 1.5 times more likely to kill a pedestrian per VMT traveled, as compared to passenger cars (Paulozzi, 2005). There are multiple reasons why light trucks are more likely to be involved in fatal pedestrian crashes than cars, including increased vehicle mass, decreased visibility, increased glare from headlights, and differences in front end design, among other factors (Paulozzi, 2005; Bradsher, 1998).

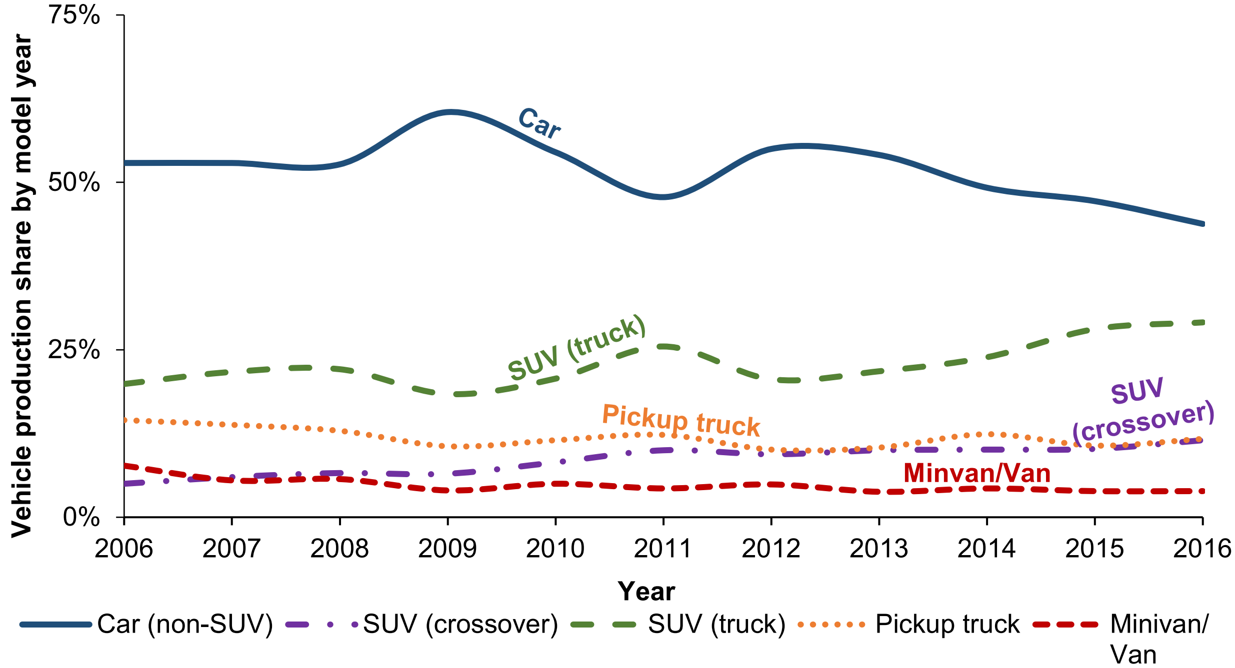


Figure 11 United States vehicle production share by model year: US EPA, 2006-2016 (Office of Transportation and Air Quality, 2018)

Abbreviations: US EPA, United States Environmental Protection Agency; SUV, sport utility vehicle

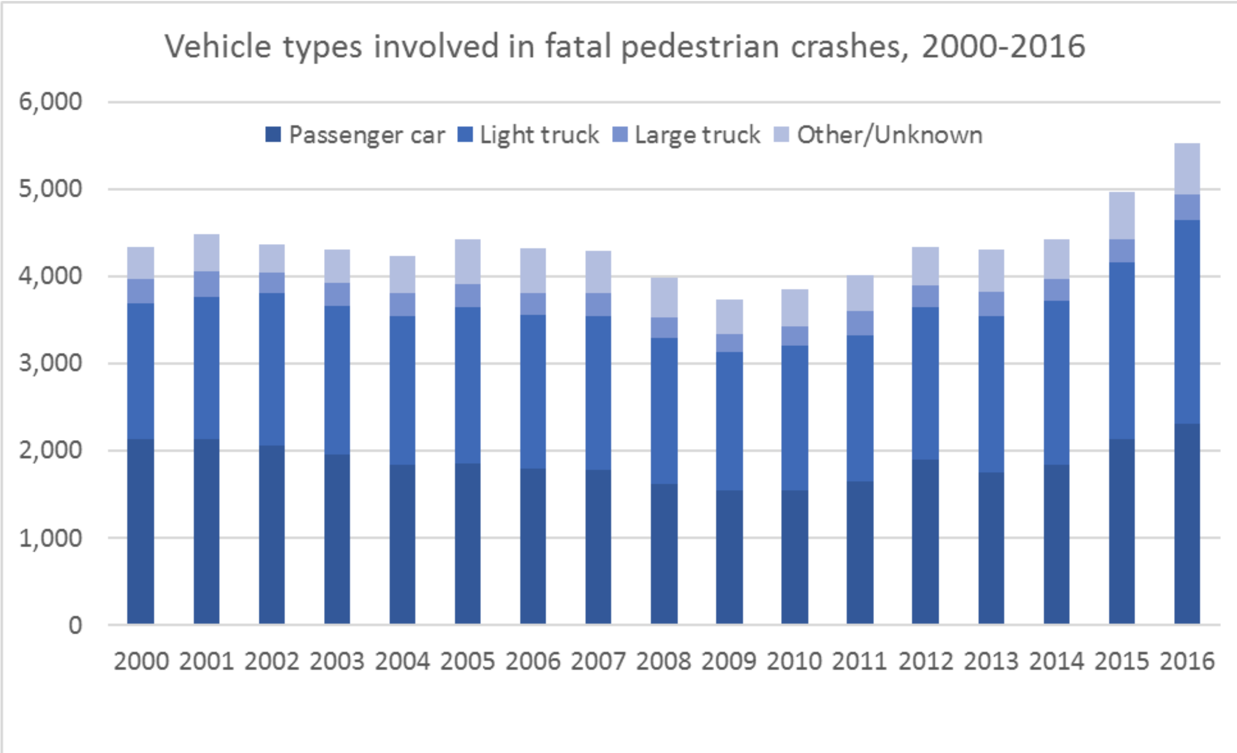


Figure 12 Vehicle types involved in fatal pedestrian crashes, 2000-2016.

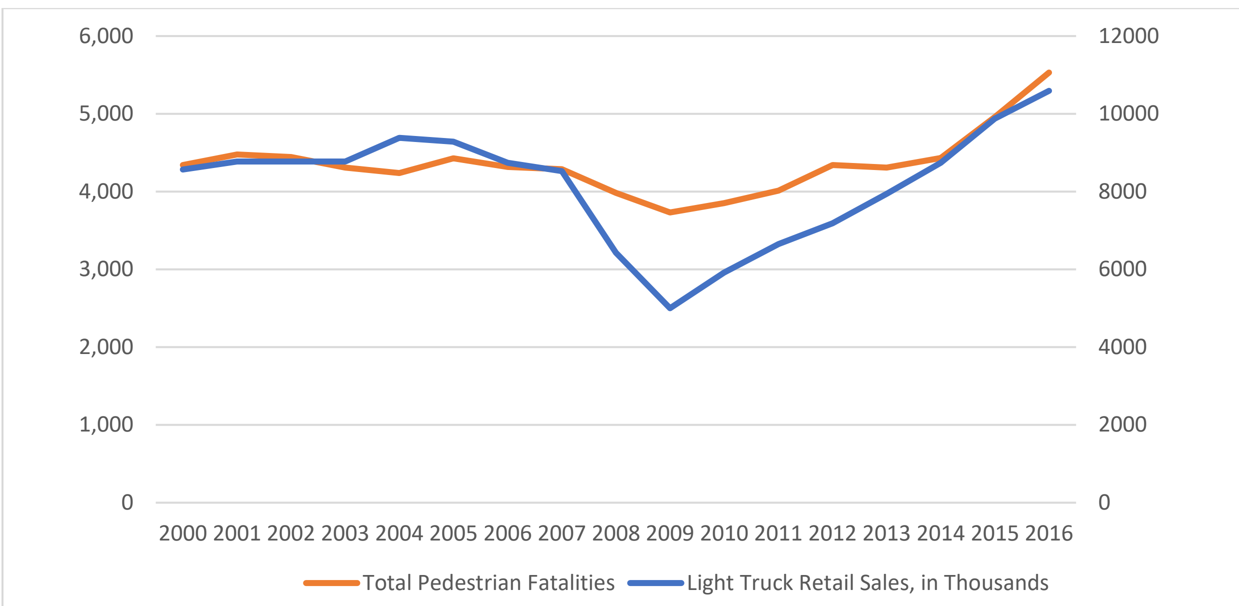


Figure 13 Total pedestrian fatalities and light truck sales, 2000-2016.

Pedestrian exposure literature scan

Given the rise in VMT, adding arterial capacity may change congestion and travel speeds. Increasing arterial capacity seems to generate a lagged reduction in VMT in metropolitan areas (perhaps due to shortened trips) with effects being higher in areas that are already less congested (Zolnik, 2018). Lower volumes allow more free-flow speed conditions which could affect pedestrian fatality risk over time. However, there is not much prior research on the more wide-spread impacts over time of changing roadway capacity and building larger roads in and near urban/suburban centers, although there is considerable evidence that more lanes are associated with increased risk at specific locations. Over time, these risks may deter pedestrians who have a choice from making trips at all, and thus, seem to be associated with reduced fatalities. The impacts may depend on the particular context and communities and populations and their ability to choose other modes.

In addition to VMT changes, pedestrian crash frequencies are also associated with presence of transit stops, transit frequencies, and higher densities of stops (Thomas et al., 2018); however increased transit use has also been associated in some analyses with lower population-wide fatality rates among cities (American Public Transportation Association, 2016). Indeed, both trends could occur, with the increasing risk of fatalities primarily falling on pedestrians accessing stops, while occupants of motor vehicles are at lower exposure-related risk. The largest cities seemed to benefit most from increasing transit according to the APTA analysis. Types of transit provided or access to other modes, land use, and access to stops, roadway designs, traffic speeds and volumes, and populations and behavioral factors all likely interact to affect pedestrian crash and fatality risk. Schneider et al. (2017) compared U.S. metro area pedestrian fatality rates for the periods 1999–2003 and 2007–2011 using data from the National Household Travel Surveys (NHTS) that approximately corresponded with these periods and found that metro areas in the south with less walking trips and amounts tended to have higher pedestrian fatality rates compared to other regions with more walking. The authors performed a qualitative assessment and suggested that metro areas with Walk Friendly designations (suggestive of greater investment in programs and infrastructure) were among those with lower fatality rates. Therefore, more investigation of population and demographic shifts over time may be worth further investigation.

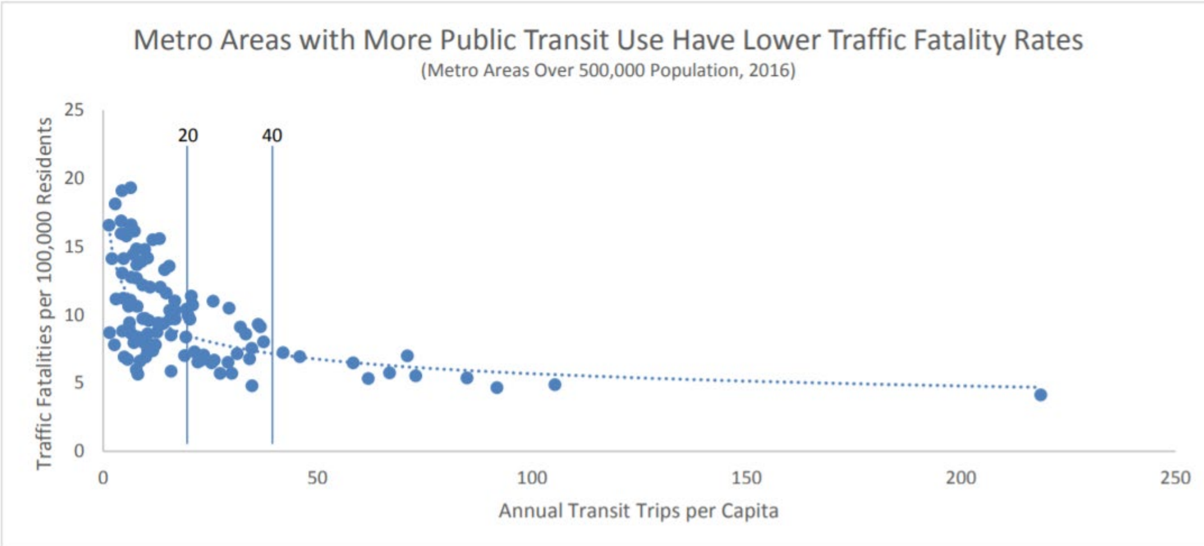


Figure 14 Metro areas with more public transit use have lower traffic fatality rates: APTA, 2016.

Other social factors, such as on-line shopping, and the suburbanization of poverty (see Kneebone & Garr, 2017), may also affect where, by whom, and how far/much people are walking or driving. Lower income populations tend to rely more on transit, and transit may be less available in suburban areas. If transit is provided, traffic speeds may be higher, distances to stops may be greater, while lighting, access and infrastructure provision may be less adequate in these areas. Census and American Community Survey data, which are available at smaller time intervals, among other travel data—such as NHTS, with longer intervals—may be useful to help assess whether shifts in demographics and trip-making by census areas may be contributing to the rise in pedestrian fatalities. Data compiled by transit agencies may also be useful in an assessment of changes in pedestrian crash exposure over time. The Federal Transit Administration provides monthly estimates of transit use by reporting agencies nationwide that could be used in assessments of time-related trends at area-wide spatial scales (https://www.transit.dot.gov/ntd). Local transit agencies also maintain data on routes, transit stops and boarding and alighting data, typically, spatially coded, that could be considered for investigating time-related trends in transit-related exposure at finer spatial scales.

Pedestrian exposure, VMT, and infrastructure were represented in several workshop participant maps and were often described as crucial elements of feedback. Unfortunately, we currently have little information on trends over time and at scales that can help us understand if there are changes in where and when pedestrians are being exposed to crash risks that may increase fatality rates. Motor vehicle volume data, roadway lane miles, and vehicle registration data are required reporting by states to FHWA and are published by FHWA's Policy and Governmental Affairs Office of Highway Policy Information and therefore more widely available than pedestrian volume data, which are not as yet required reporting. However, surrogate measures for pedestrian activity such as land use, transit, and population and employment densities may be useful to account for changes in pedestrian activity levels. Increasingly, jurisdictions are also beginning counting programs, and the CSCRS Safety Data Clearinghouse project (see CSCRS Project R14) has identified and documented sources of pedestrian exposure data that could be considered for use. Pedestrian count data are a relatively recent undertaking in most areas and require more years of collection for trend analyses.

4.2 Changes in distraction and technology use in vehicles

Similar to data on impairment included below, distraction is included in FARS data. Research has explored trends in distraction using FARS data and NHTSA publishes reports on distraction (Stimpson et al., 2013; National Center for Statistics and Analysis, 2018c). Additional sources of data have included the US Consumer Product Safety Commission which reports on injuries related to technology use (Nasar & Troyer, 2013). Studies have also used state phone-use laws as a stand-in for distraction rates to analyze the effects of cell phones on traffic safety (McCartt et al., 2014).

Even when able to explore the change in distraction-related fatalities over time, the use of FARS data leaves many questions surrounding distraction unanswered. Many of these limitations are laid out in NHTSA's Research Note, *Distracted Driving 2016* (2018c). Due to changing definitions of distraction, identifying the nature of distraction is difficult to track over time, limiting the ability to point to cell phone use as a cause of fatal crashes. Furthermore, the data in FARS relies on crash reports which vary in terms of how distracted is identified and often depend on local or state reporting requirements. Though it may be determined that a phone was in use during the crash, it is difficult to definitively label "technology use" as the causal factor. (Of course there are many other causes of distraction, besides use of a smart phone, by pedestrians and motorists, which can cause a pedestrian/motor vehicle crash. In any case, it is difficult to go back post-crash and clearly identify such distraction-related factors, since drivers may be reluctant to admit to their pre-crash behavior, and the pedestrian may have been fatally injured.)

In workshops, several causal loops linked driver stress and technology use. These loops, in taking a systems approach to the problem, look beyond the direct cause of the crash and explore the reasons behind phone use in the vehicle and increased distractions. Stress, which may be related to congestion or may be related to device use itself, is identified as a cause of increased device use which may lead to increased conflicts on the road. In further research these causal factors may warrant exploration to identify societal trends that encourage distracting technology use while driving and intervention points that would reduce or mitigate these distractions.

Data sources that have potential to better expose driver habits with regard to technology are often proprietary. Zendrive is one example of a company obtaining data to analyze safe driving behaviors. The company produces a phone app for use by other businesses that manage vehicle fleets or for insurance companies to monitor driving behaviors and phone use in vehicles. Zendrive has released some data visualizations to show levels of safety among commuters and cell phone use around school zones (Zendrive n.d.; Zendrive 2018). If this data were to be made available, researchers could compile a better picture of technology use, driver behavior, and overall road safety.

4.3 Changes in impairment status and mechanism of pedestrians and drivers

There are a number of impairing substances that might affect trends in pedestrian deaths, namely opioids, alcohol, and marijuana. Synthetic opioid-related deaths (mostly fentanyl-related) have risen 540 percent in just three years and more than 28 states have declared a national emergency related to this crisis (Katz, 2017; Salam, 2017). Much of the impact of the opioid crisis has been felt in states in the Southwest and Appalachia, which is also where pedestrian crashes and fatalities are on the rise. A rise in opioid use could contribute to pedestrian fatalities in a number of ways, affecting both driver and pedestrian abilities. It may also be associated with a rise in people experiencing homelessness and their exposure to vehicles (who might be classified as pedestrians in the event of a crash).

Traditionally, most research on driver and pedestrian impairment relies on data from FARS and focuses on alcohol. Each year, NHTSA releases summary statistics based on FARS data of impairment in fact sheets on alcohol-impaired driving and on pedestrian fatalities (National Center for Statistics and Analysis, 2018a; National Center for Statistics and Analysis, 2018b). Research has documented trends in alcohol levels among fatally injured pedestrians, demonstrating a potential decline in the proportion of alcohol-related pedestrian deaths during nighttime hours but stable proportions for daytime crashes (Eichelberger et al., 2018). Finally, as medical and recreational marijuana has become increasing available in different states, research also has delved into the effects of marijuana use on driving (Salomonsen-Sautel et al., 2014; Santaella-Tenorio et al., 2017).

The reliance on FARS data, while capable of tracking fatal alcohol-related trends over time, still limits the introduction of other causal variables that a systems perspective allows. Future research may explore the role of economic situations in influencing substance use and how this combines with the choice or need to walk or drive to contribute to an increase in serious or fatal crash-related injuries. Additionally, more detailed geographic analyses would help identify regions or types or places that are experiencing a higher level of pedestrian fatalities due to either driver or pedestrian impairment.

4.4 Changes in funding and support for safe pedestrian infrastructure

The *Benchmarking Report* (Alliance for Biking & Walking, 2016) brings together comprehensive data to document support for walking and biking across the U.S. Through an analysis of planning documents and implemented projects, the report identifies the extent of walking and biking support across states. The report also documents state and city-level policies with regard to walking and biking and lists funding for specific pedestrian and bicycle infrastructure projects. Prior research has focused on broad relationships between infrastructure funding and mode shift (Henao et al., 2016), while other studies have honed in on relationships between specific funding types, like the federal Safe Routes to School program, and safety (DiMaggio et al., 2016).

While information is available on funding sources, and reports like the *Benchmarking Report* reveal details on pertinent policies and infrastructure at state and local levels, the trends related to infrastructure funding over time as they relate to pedestrian safety remain to be explored. In our systems workshops, some of the stories that emerged indicated links between rising pedestrian numbers and funding for pedestrian infrastructure, which then leads to more pedestrians and demand for more funding. Previous research does not include the potential cyclical aspect of funding or the causes behind increased funding but rather takes either a linear approach to funding and mode share or a static view of funding and policy support.

Another story that emerged from the workshops posited that increases in pedestrian injuries and deaths would lead to an increase in funding for infrastructure. As a balancing loop, this would result in fewer injuries or fatalities reducing the demand for continued or increased funding. The snapshot of funding, plans, and policy at a single point in time again avoids the more dynamic picture of how other variables interact to influence support for pedestrian infrastructure.

A final cycle involves the introduction of advocacy work as an intervening variable. Advocacy, sometimes related to the variables mentioned above, may encourage the political will to increase funding towards pedestrian infrastructure. Looking at funding alone may miss this important piece that influences decision making, policies, and the use of funds.

The stories from the systems mapping workshops point to a need to look at the wider system in which policies and funding decisions are made. While research has looked at the funding on its own or the results of increased infrastructure funding, taking a systems approach introduces components that are influenced by and influence infrastructure funding. Future research could explore the influence of increasing pedestrian numbers or worsening pedestrian safety on funding decisions, identifying where and how political will to build or improve infrastructure is generated. Additionally, this research may seek to understand the role of advocates in this system.

4.5 Changes in rural crash response times

In a 2016 study by Kaufman et al., researchers documented increasing hospital closures in rural areas since 2010 with no indication of a slowing trend. Building on this work, Cossman et al. (2017) examined the rural-urban disparity in healthcare access as it relates to mortality. They found a “rural penalty” in terms of mortality for rural residents. For rural residents of color, the penalty was even greater, showing a higher disparity in mortality rates.

While Cossman et al. and other researchers have focused on the link between healthcare access and outcomes, hospital closures and distance also have implications for emergency services (Battista et al., 2015; Mattson, 2011). With an increase in hospital closures, emergency response times following a crash may be impacted, potentially reducing the likelihood of crash survival. Further research is needed to explore the relationship between rural health access and crash responses and the implications that changing access may have for pedestrian fatalities in rural areas.

In addition to the direct relationship between hospital access and emergency response times, further research may also explore the interrelated nature of multiple variables that contribute to the loss of health care access and the need for quicker emergency response. Economic changes in rural areas may have a bearing on the proximity of hospitals but may also warrant consideration for the effect on likelihood of a pedestrian crash. This includes factors such as vehicle types and the safety of the vehicles themselves, access to vehicles and the population of captive pedestrians, as well as alcohol-, recreational-, or prescription-drug impaired walking or driving.

4.6 Changes in community characteristics

Urbanization versus Sprawl

Since the invention of the automobile, the U.S. has focused its mobility infrastructure on vehicle travel. This has resulted in sprawl in many cities but especially suburban and exurban design. More recently however, populations are moving from rural to urban living. In 2015, millennials, those born in the last two decades of the 20th century, represented the largest portion of the

U.S. population, and many tend to live in urbanized areas (McDonald, 2015). Marginalized groups are being pushed out of urban areas through gentrification. This works across demographics class, gender, race, abilities, and age. These groups relied more on transit than more privileged groups, because of the cost of owning an automobile.

Though a lot of literature has addressed urbanization, there is a lack of work on its relationship to crashes. Sprawl and urbanization are polar opposites in terms of land use. There is now a reversal post urban renewal period of the 1950s in the United States. This is leading to the suburbanization of poverty. The characteristics of those in rural and urban areas gives some insight into how to serve them in terms of road safety infrastructure (Census, 2017).

More work on the differences in behaviors within urban and rural spaces would help the thinking into how to solve these issues.

5.0 Conclusions

5.1 Study Strengths

With the understanding that much of the data that may explain the rise in pedestrian deaths does not exist or that more exploration is needed to know which data holds relevance for this issue, this study sought to expand beyond an approach that focuses only on crash data. Crash data provides information on the moment and immediate circumstances of the crash but does little to illuminate the systemic issues that contribute to a crash and to fatalities resulting from crashes. From the systems mapping workshops and our own review of the literature, we expanded the scope of data to include substance use and overdose statistics, information on uptake of technology with potential for creating distractions, vehicle fleet makeup, funding and infrastructure changes, exposure information (VMT), and changes in EMS response times.

This approach to exploring the issue of rising pedestrian deaths considers a variety of data sources, acknowledging the complexity of the issue. We also explored how interrelated factors might contribute to the issue. The systems mapping workshops and resulting maps developed by participants present scenarios that illustrate that variables do not act in isolation. Instead, they rely on each other to determine outcomes. This study demonstrates the interrelated nature of factors that have contributed to the rise in pedestrian deaths through the use of system diagrams and the exploration of common loops within the diagrams. Through this exploration, we identified and documented dynamic theories for the increase, which emerged from the balancing and feedback loops described in workshop diagrams. These loops allow for an examination of the broader system that relates either directly or indirectly to crashes and pedestrian fatalities as well as the interplay between components of the system.

In addition to the insights gained from the products of the workshops, the workshops also broadened the range of partners to consider when studying pedestrian safety. A variety of participants were invited in an effort to bring new, but relevant and rich, perspectives, beyond traditional partners. In doing so, this study benefited from a diversity of viewpoints while also helping professionals in different fields to realize how their work is a part of the system that relates to pedestrian crashes.

Overall, this study demonstrated the value of holding group model building workshops. The workshops brought together multiple perspectives to contribute to thinking about pedestrian fatalities. As a result, new directions for research were examined that consider these different areas of expertise and new data needs and sources were discussed, beyond what is normally analyzed to understand pedestrian safety.

5.2 Study Limitations

The study was limited in its scope by the number of workshops. During this limited time, we convened two workshops and, though we attempted to bring together key partners, some perspectives were still missing from the workshops. As such, these two workshops alone represent a beginning to developing hypotheses for future research, but further, more diverse input would be required. We have planned follow-up workshops on the same topic to add to the findings from these initial workshops to continue efforts to refine the systems maps and focus on bringing in new expertise to flesh out or augment key hypotheses generated in the first workshops.

In each workshop, we employed a “data light” method, where workshop attendees were not provided data other than information about the overall trends in pedestrian fatalities. This approach facilitated exploration of the trends with the hope that attendees would be less focused on individual factors and more on the wider system. This also aided in building hypotheses that indicate future data needs by identifying potential causal factors. However, the approach also led to a lack of context in which participants were diagramming their systems, leading to explanations that looked at sweeping trends. These workshops are part of an iterative process, and future workshops might include data that would complement the analysis and help focus systems mapping. The challenge remains as to what level of data should be included to aid in focusing the conversation while avoiding biasing or limiting the exploration achieved through systems mapping.

5.3 Future Research Needs

We are hypothesizing that the problem (pedestrian deaths) is influenced by many factors; that is, by the underlying structure of a complex system (likely involving many feedback loops). Moving to quantitative SD can help us test the dominance of certain loops at time points, as hypothesized above, but CLDs from only 2 workshops cannot provide the level of inference needed. Additional workshops would allow for the models developed in this project to be refined and adjusted to better capture the system. With future workshops and a different mix of participants the previously diagrammed loops may be altered while new variables may be introduced.

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Appendix A: Workshop Agenda

Reference section 2.1 for detail on systems mapping workshops.

Systems Workshop: "Exploring the Complexity of Pedestrian Fatalities to Inform Action"

Hosted by: Collaborative Sciences Center for Road Safety
Date: Thursday, April 19th
Time: 9:00 am – 1:00 pm
Location: UNC Highway Safety Research Center, 730 MLK, Jr. Blvd, Chapel Hill; Room 318

Agenda

I. Arrival	9:00-9:10 (10 min)
II. Overview, objectives, introductions, mindset	9:10-9:25 (15 min)
III. Pre-workshop reflections	9:25-9:30 (5 min)
IV. Facilitating team presentation on systems thinking	9:30-10:00 (30 min)
V. Individual exercise—system maps	10:00-10:15 (15 min)
VI. Brief reflections on individual exercise	10:15-10:35 (20 min)
Break	10:35-10:50 (15 min)
VII. Introduction to small group diagraming exercise	10:50-11:00 (10 min)
VIII. Small group diagramming	11:00-11:30 (30 min)
IX. Report out from small group diagramming	11:30-11:50 (20 min)
Break and grab lunch	11:50-12:05 (15 min)
X. Working lunch: large group facilitated mapping (as time allows)	12:05-12:40 (35 min)
XI. Post-workshop reflections	12:40-12:45 (5 min)
XII. Summary, next steps & long-term goals	12:45-1:00 (15 min)

Mindset

Mindset is key… Here's what we want to encourage while we're working together:

- I have some information; so do other people.
- Each of us may see things that others don't.
- My organization/agency may be contributing to the problem.
- Differences are opportunities for learning.
- People may disagree with me and have pure motives.

-- Roger Schwarz

Appendix B: Pre/Post Workshop Evaluation Form

Reference section 2.1.4 for details on analysis of data from workshop assessments.

Pre-workshop reflections related to Exploring the Complexity of Pedestrian Fatalities

Please provide the initials of mother's first and maiden names along with the two digit number of your birthday (e.g., Jen Miller, birthday 8th day of the month, would be: "JM08"): _________

Please finish the following statements (*sharing the first thoughts that come to mind*):

- The 3 most important contributors to the increase in pedestrian deaths are…

    1.

    2.

    3.

- The 3 most important next steps that should be taken to reverse the increase in pedestrian deaths include doing __________ with __________ because ________. Please be specific; this could include strategies, interventions, specific research needs, etc.

….. doing ______________	with _________	because _________
1.		
2.		
3.		

Post-workshop reflections related to Exploring the Complexity of Pedestrian Fatalities

Please provide the initials of mother's first and maiden names along with the two digit number of your birthday (e.g., Jen Miller, birthday 8th day of the month, would be: "JM08"): _________

Please finish the following statements (*sharing the first thoughts that come to mind*):

- The 3 most important contributors to the increase in pedestrian deaths are…

    1.

    2.

    3.

- The 3 most important next steps that should be taken to reverse the increase in pedestrian deaths include doing __________ with __________ because ________. Please be specific; this could include strategies, interventions, specific research needs, etc.

….. doing ______________	with _________	because _________
1.		
2.		
3.		

We appreciate what you've contributed today. What, if anything, was most useful to you about this workshop today?

And in order to continue to approve, what thoughts do you have about how we could strengthen sessions like this in the future?

Is there anything else you would you like to share?

Appendix C: Variables in Systems Diagrams and Frequency Referenced

Following is a list of variables included in systems diagrams, showing frequency for both individual and small group exercises. Note that almost all of the diagrams placed “ped injury/death” as the focal point of the diagram, in order to then theorize about contributing factors and consequences.

Variable	Individual diagram frequency (N)	Small group diagram frequency (N)
Ped injury/deaths	49	15
Infrastructure (ped related)	40	14
Car use	35	4
Pedestrians	30	10
Attentiveness (drivers)	28	14
Community Characteristics	26	5
Norm/culture (ped-related)	25	16
Policies and regulations (cars/drivers)	25	5
Technology use	25	14
Economy	20	5
Enforcement	18	6
Attentiveness (peds)	16	2
Impairment (drivers)	15	4
Personal financial impact	15	3
Infrastructure (Car related)	14	11
Car safety technology	13	10
Education	13	4
Other (unclassified)	13	7
Demographics (individuals)	12	4
Speed	11	4
Funding (related to peds)	10	4
Emergency services	9	0
Policies and regulations (peds)	8	2
Public transportation	8	1
Support of peds	8	1
Emotional impacts	6	2
Other personal traits	6	2
Congestion	5	3

Variable	Individual diagram frequency (N)	Small group diagram frequency (N)
Desire to walk	5	0
Health	5	4
Other crash consequences	5	3
Support for cars	5	1
Yielding (peds)	4	0
Advocacy	3	1
Car/ped conflicts	3	4
Desire to drive	2	1
Funding (related to cars)	2	1
Impairment (pedestrians)	2	1
Yielding (drivers)	2	1
Norms/culture (car-related)	0	0

Appendix D: Balancing Feedback Loop "Stories"

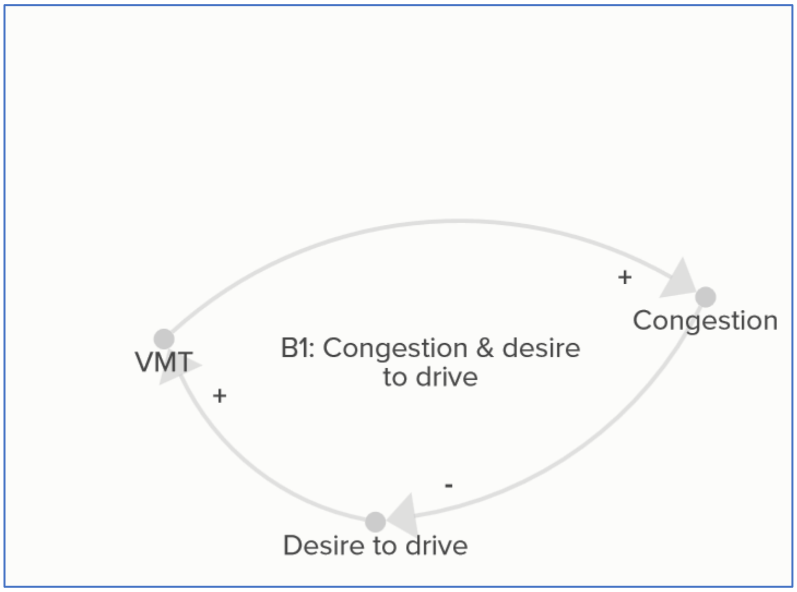

Figure D-1: Congestion and desire to drive

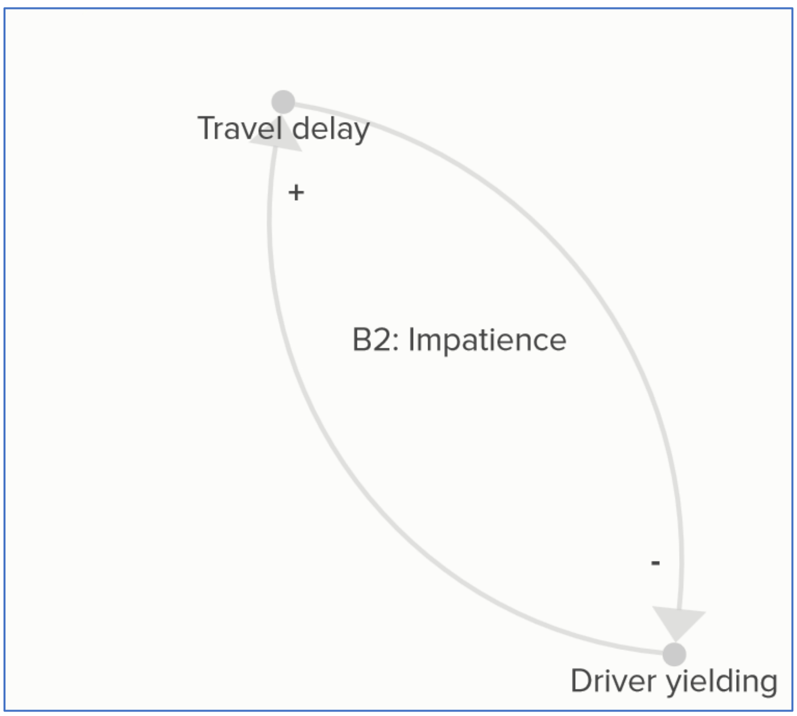

Figure D-2: Impatience

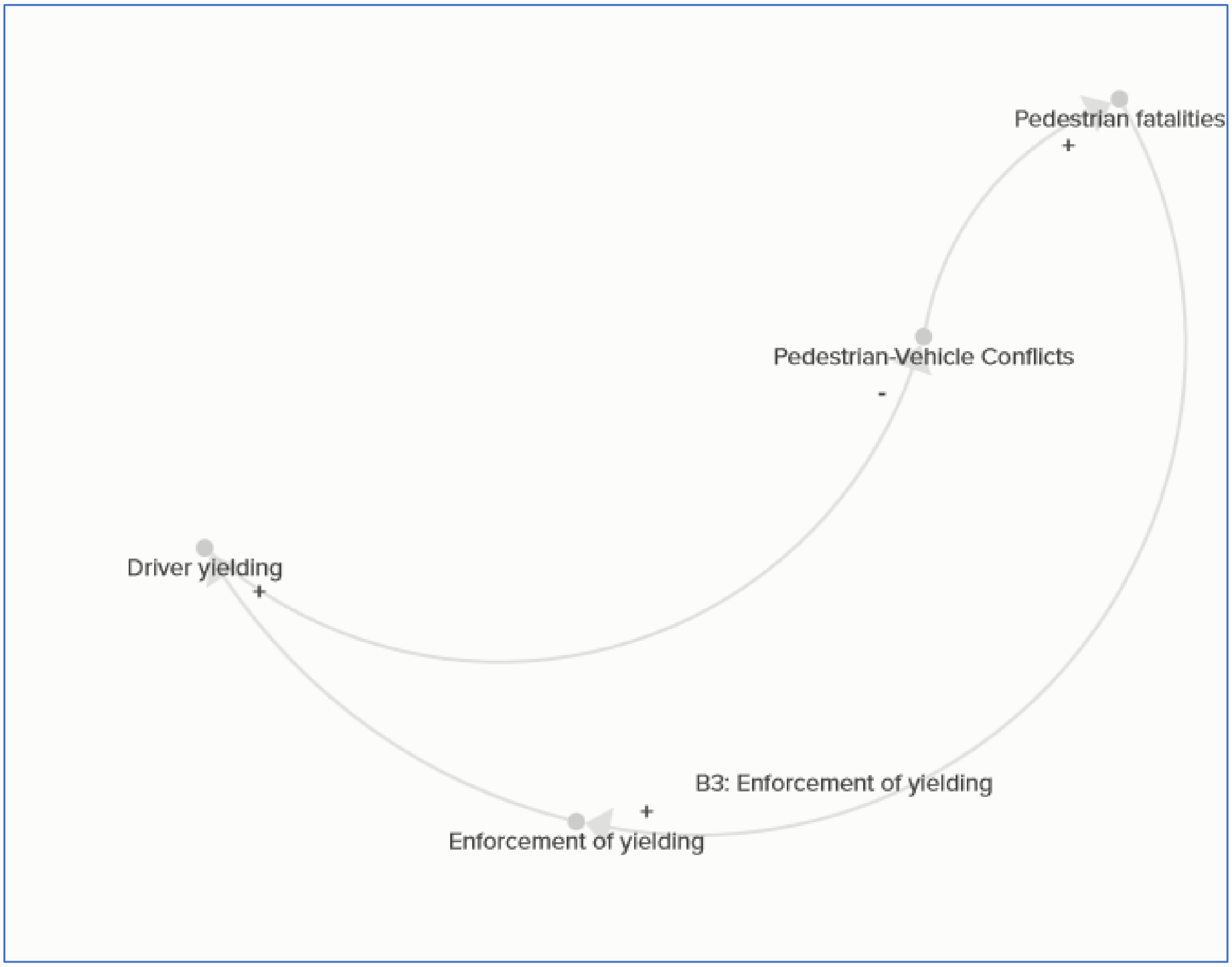

Figure D-3: Enforcement of yielding

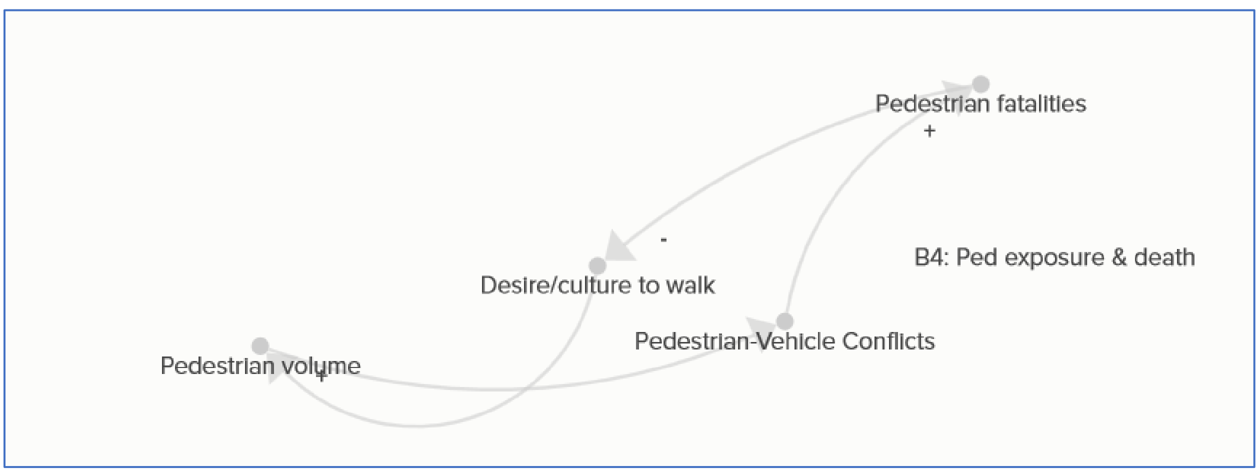

Figure D-4: Ped exposure and death

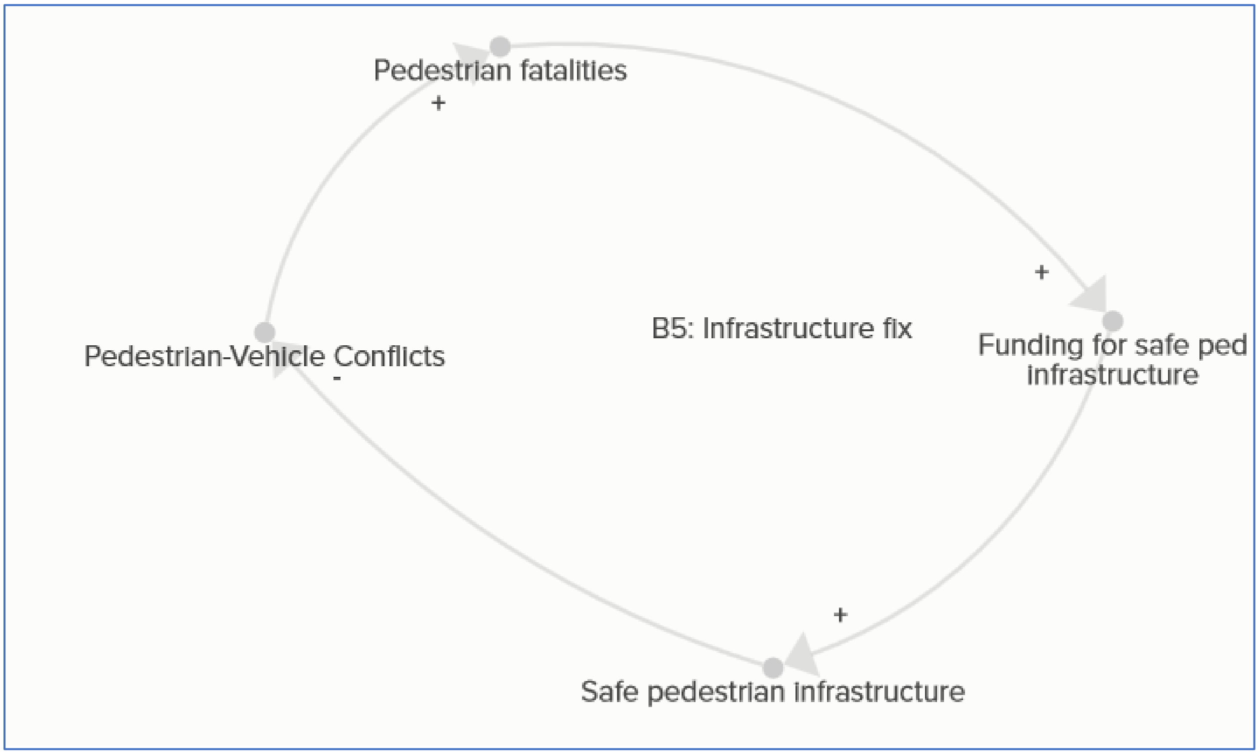

Figure D-5: Infrastructure fix

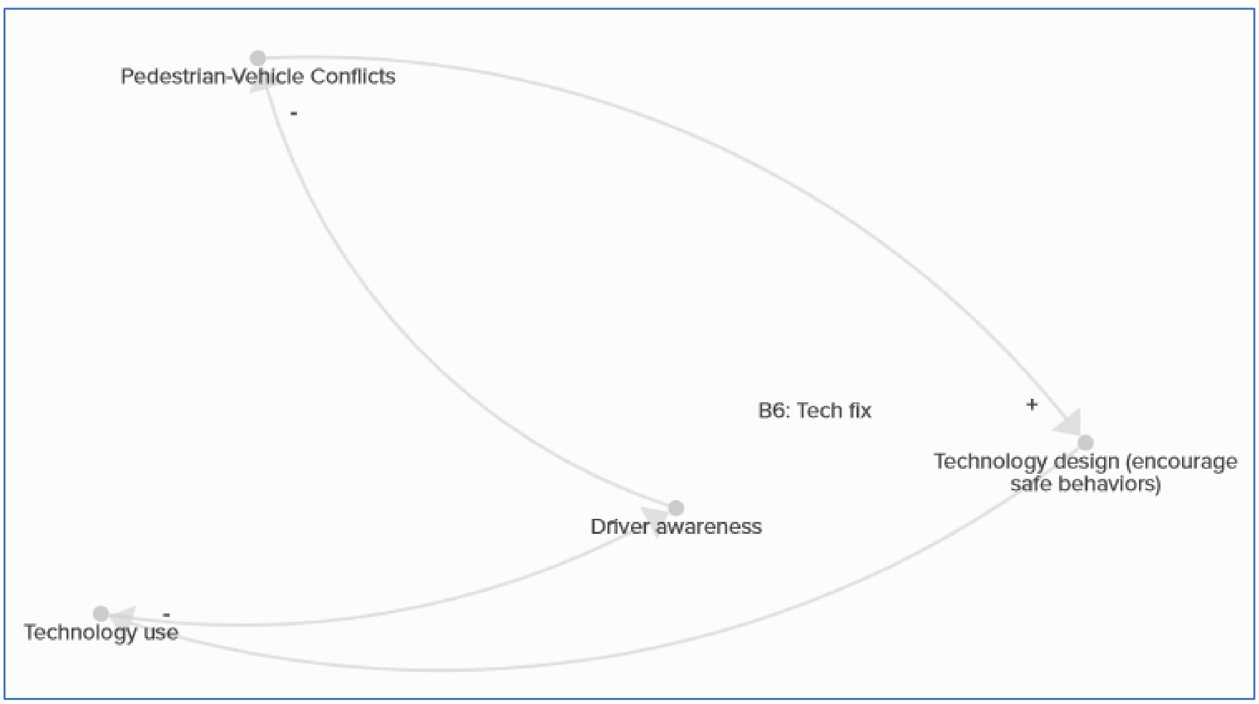

Figure D-6: Tech fix

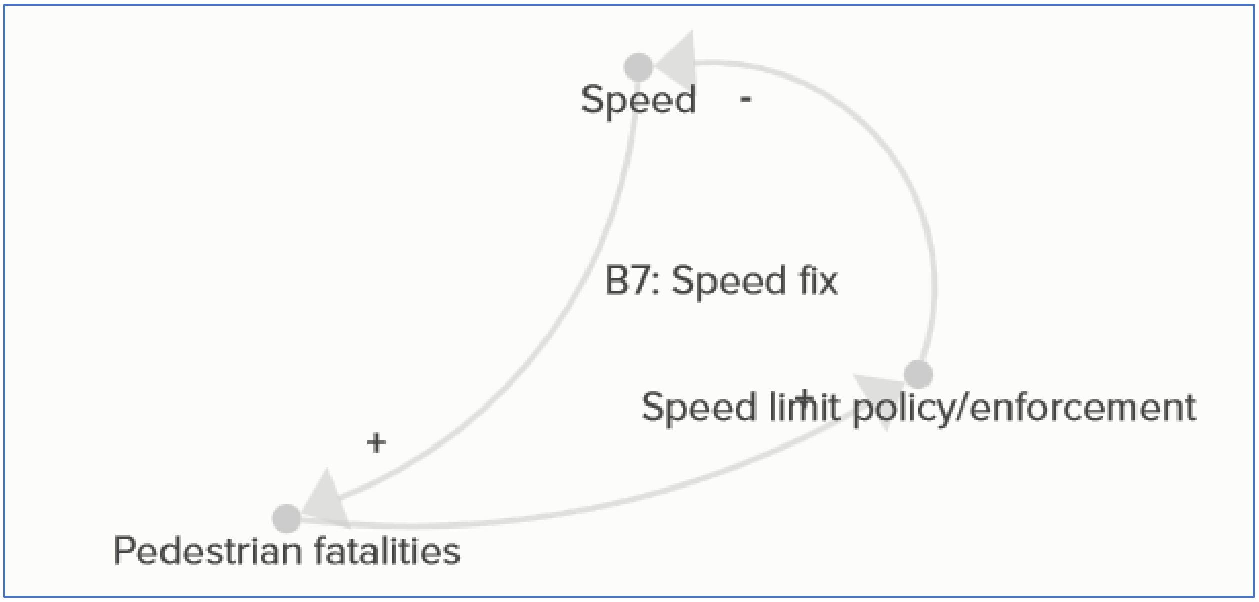

Figure D-7: Speed fix

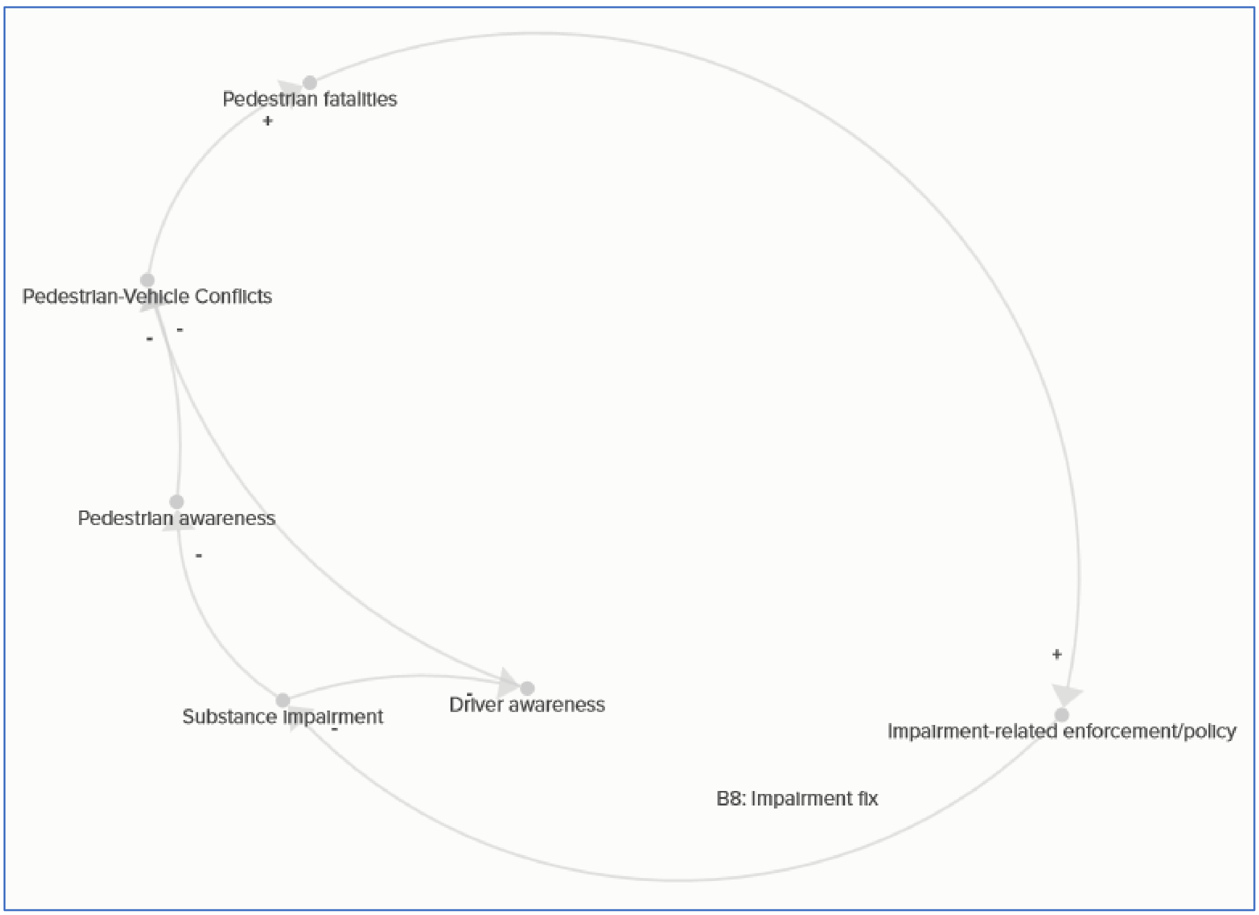

Figure D-8: Impairment fix

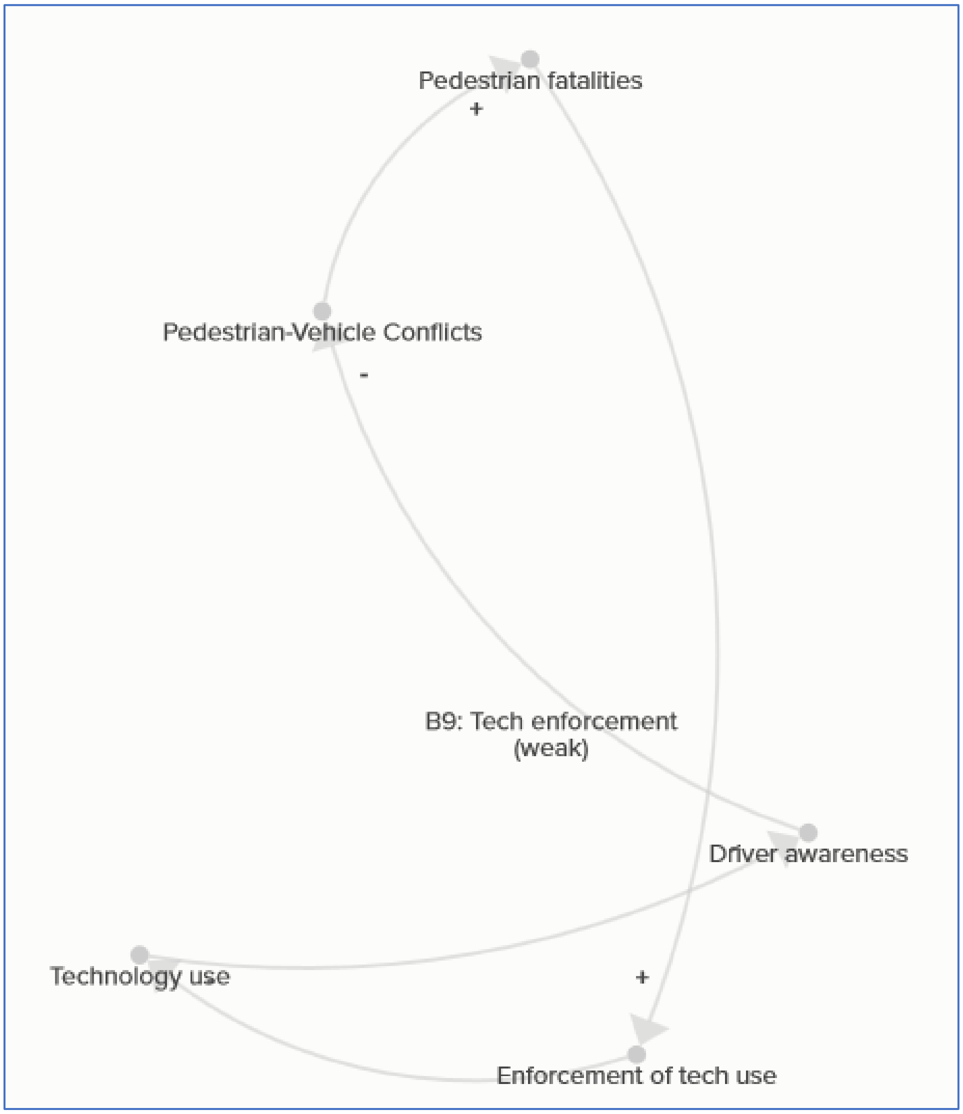

Figure D-9: Tech enforcement (weak)

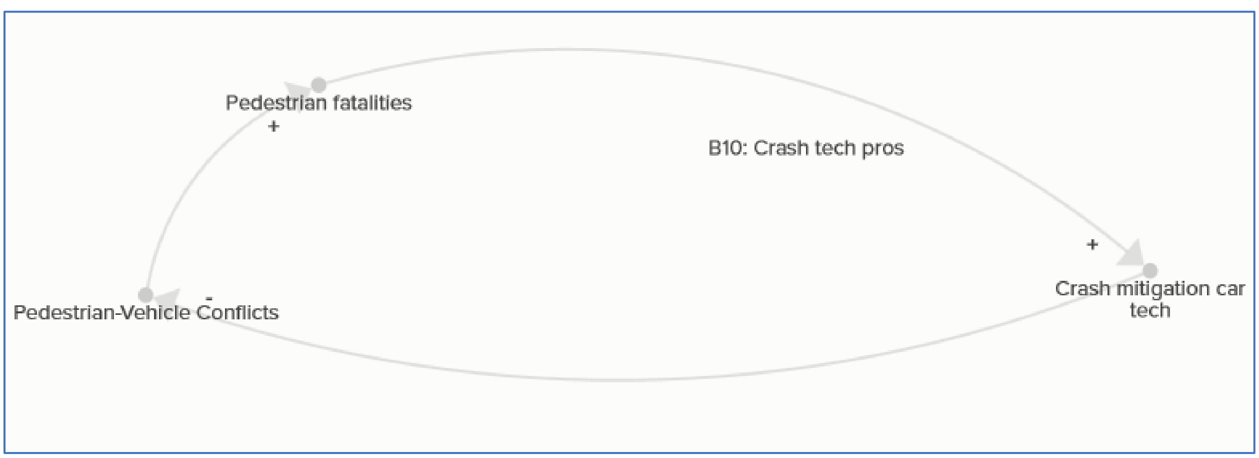

Figure D-10: Crash tech pros

Appendix E: Reinforcing Feedback Loop "Stories"

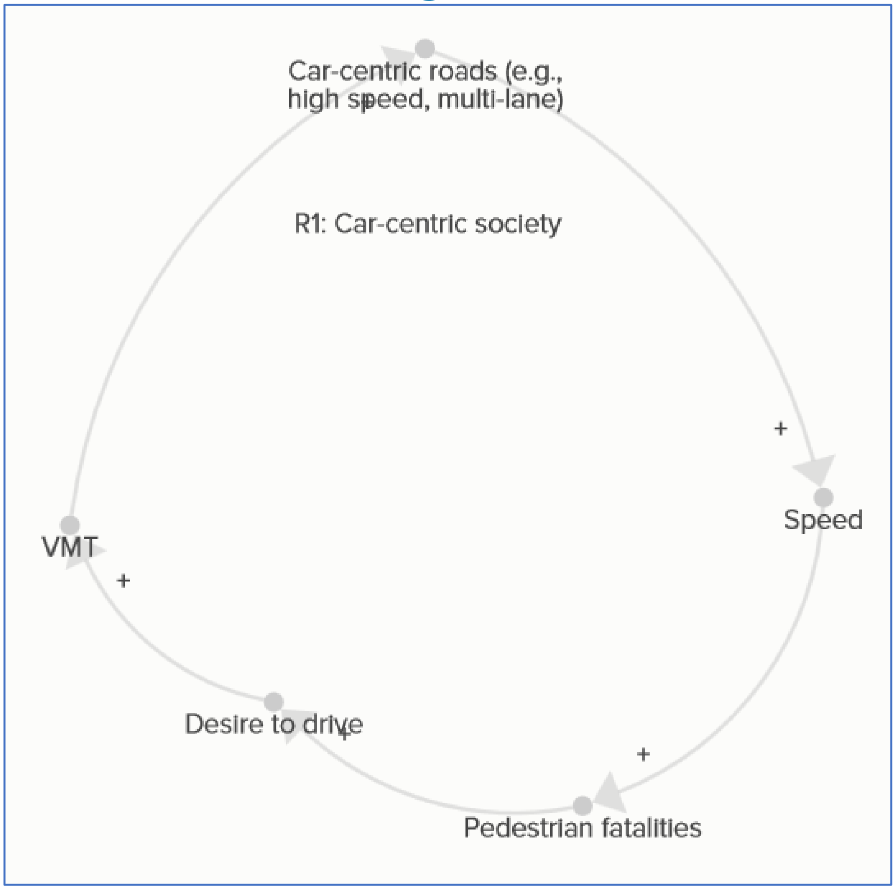

Figure E-1: Car-centric society

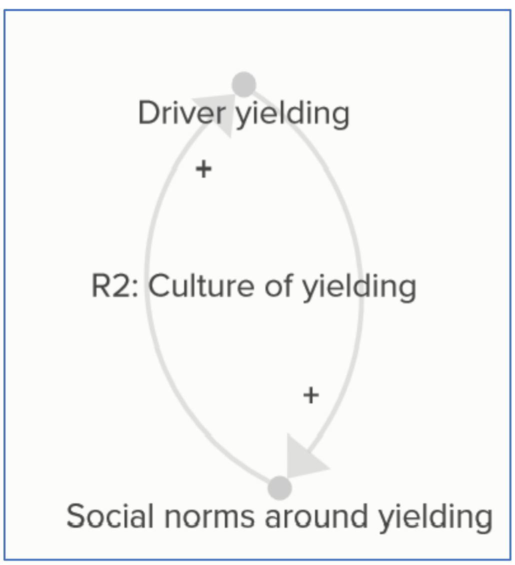

Figure E-2: Culture of yielding

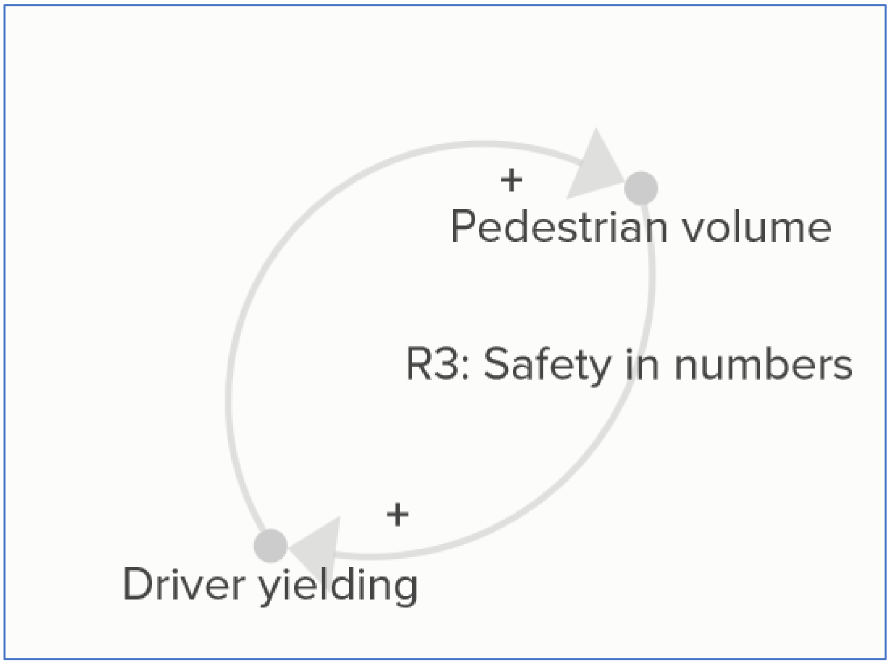

Figure E-3: Safety in numbers

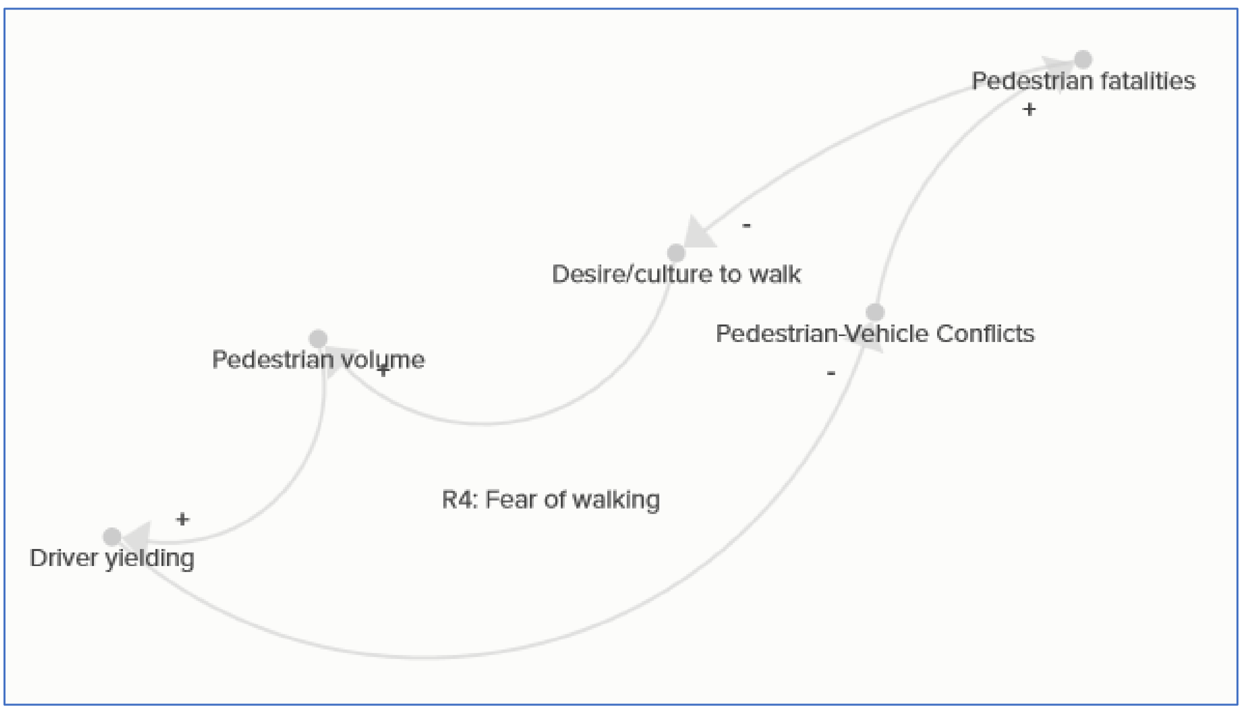

Figure E-4: Fear of walking

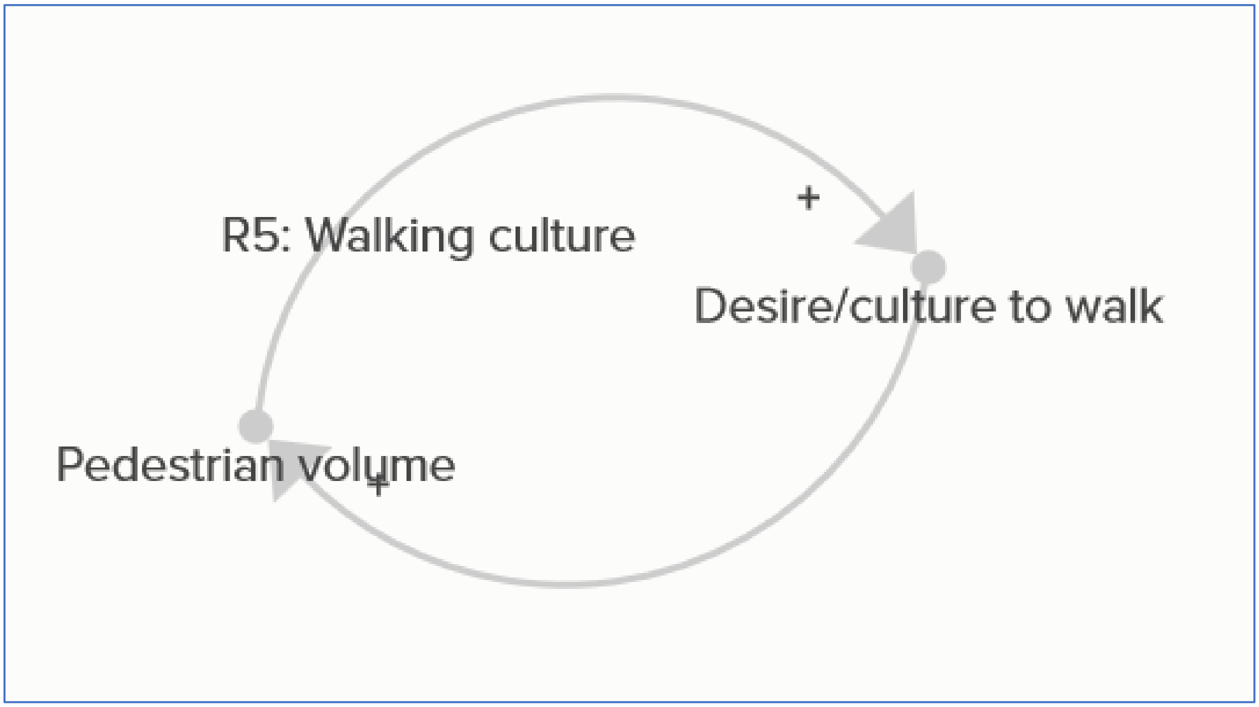

Figure E-5: Walking culture

Figure E-6: Infrastructure support

Figure E-7: Distraction and congestion

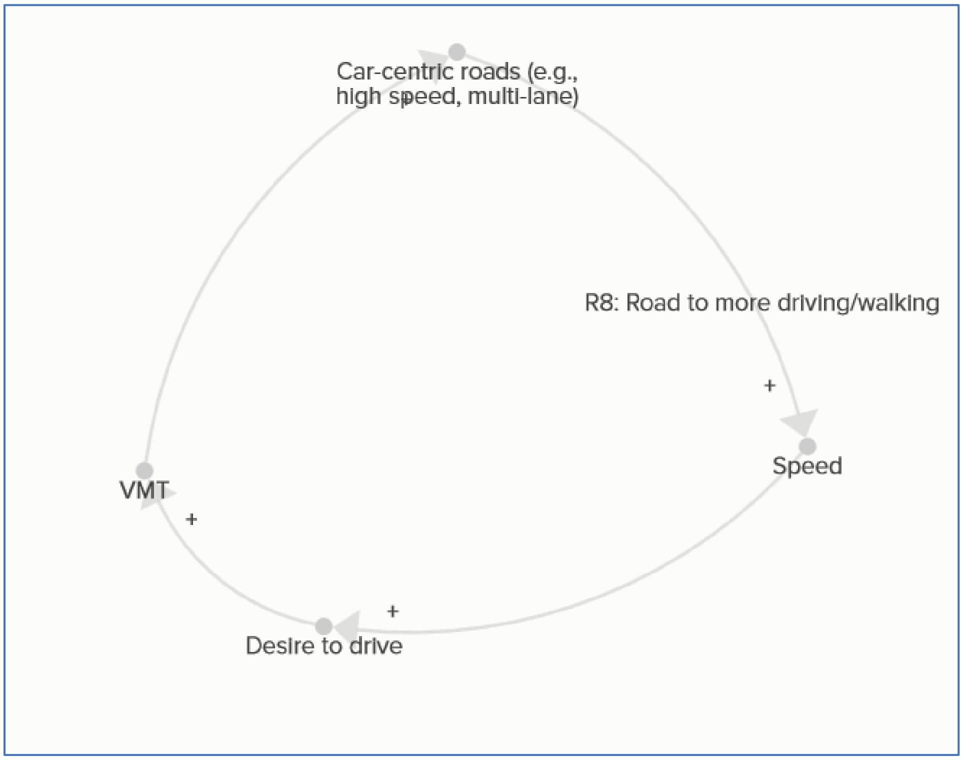

Figure E-8: Road to more driving/walking

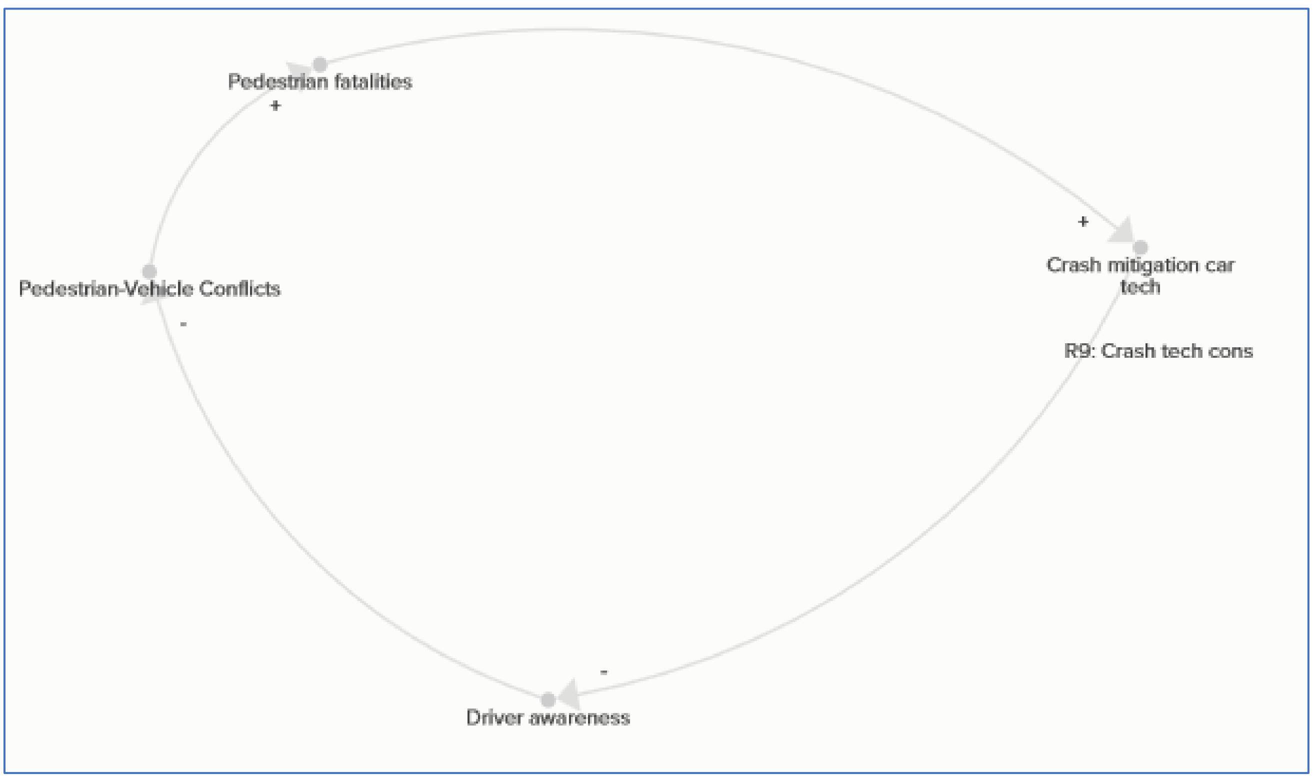

Figure E-9: Crash tech cons