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Integrating complex systems science into road safety research and practice, Part 2: Applying systems tools to the problem of increasing pedestrian death rates

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Abstract

Objectives: To provide a specific example of how systems dynamics tools can increase understanding of stakeholder “mental models” and generate robust systems-based hypotheses about the escalating problem of rising pedestrian death rates in the U.S.

Methods: We designed and facilitated two group model building (GMB) workshops. Participants generated causal loop diagrams (CLD) individually and in small groups to explore hypotheses concerning time-dynamic interacting factors underlying the increasing rates of pedestrian deaths. Using a grounded theory approach, research team members synthesized the structures and hypotheses into a single CLD.

Results: CLDs from the 41 participants indicated four core factors hypothesized to have a direct impact on pedestrian fatalities: pedestrian-vehicle crashes, vehicle speed at the time of the crash, vehicle size/dimensions, and emergency response time. Participants diagrammed how actions and reactions impacted these proximal factors over time and led to ripple effects throughout a larger system to generate an increase in pedestrian deaths. Hypothesized contributing mechanisms fell within the following broad categories: community responses; research, policy, and industry influence; potential unintended consequences of responses to pedestrian deaths; and the role of sprawl.

Conclusions: This application of systems science tools suggested several strategies for advancing injury prevention research and practice. The project generated robust hypotheses and

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advanced stakeholder communication and depth of understanding and engagement in this key issue. The CLD and GMB process detailed in this study provides a concrete example of how systems tools can be adopted and applied to a transportation safety topic.

Keywords

systems science; injury prevention; road safety; system dynamics; pedestrian

INTRODUCTION

This is the second paper in a two-paper series that illustrates the use of complex systems science tools in road traffic injury prevention research and practice. The two papers (1) discuss how a systems thinking approach can provide new insights into the field of road traffic injury prevention and (2) provide an example of how specific systems science tools can deepen understanding, and inform strategy, with respect to an escalating problem in the field, namely, the increasing rate of pedestrian deaths.

In the first paper of this series, we discussed road traffic injury as a complex problem, with a focus on pedestrian injury. We provided an overview of how complex systems science approaches can augment established public health and injury prevention frameworks (e.g., social-ecological model, Haddon matrix), while overcoming some important limitations. Finally, we provided an overview of some common systems science tools. In this second paper, we illustrate use of some specific systems science tools: causal loop diagramming and group model building (GMB), used here to describe and synthesize stakeholder "mental models" and generate robust systems-based hypotheses.[1,2] Causal loop diagrams (CLD) are diagrams that illustrate hypotheses about the causal mechanisms at play in a system using arrows to diagram cause and effect mechanisms.[1] GMB is a structured group technique for involving diverse stakeholders in the development of systems diagrams, through forums such as facilitated workshops.[2] The application of these tools provide the foundation for many system dynamics-based projects and can lay the groundwork for formal model testing with simulation.[1]

Using system dynamics tools to examine the complex problem of pedestrian death

Between 2009 and 2017, pedestrian deaths in the U.S. increased 45%, from 4,109 to 5,977 deaths per year (Figure 1).[3] In response to the rapid increase, researchers, media, practitioners, and others have posited diverse hypotheses, including changes in technology use and distraction, impairment, economic factors, and vehicle type distribution on the roadways.[4–8] Some have hypothesized that the increase can be isolated to the effect of single risk factors acting in an independent manner. In contrast, our underlying supposition was that a set of interacting factors have contributed to this increase through multiple dynamic and complex pathways, as further discussed in the first paper of this series. This framework also suggests that contributing factors likely interact through feedback loops (e.g., reinforcing processes involving car-centric road design and culture, balancing processes of brief periods of targeted enforcement in response to crash events) and recognizes that some underlying changes in factors have occurred quickly (e.g., increasing trends in impairing substances) while others have operated more slowly (e.g., dissemination of advanced safety features in vehicles on the road) over time. Our motivation is that an understanding of the structure and strength of such dynamic interactions can ultimately inform more effective action within the system driving these problems.[1,9,10]

This paper describes how our research team sought to advance understanding of rising pedestrian death rates using a particular set of complex systems science tools. We used systems mapping techniques (i.e., CLD) within a GMB context to identify a wide range of "mental models" of the dynamic relationships between factors that are believed to have produced the observed rise in pedestrian deaths, illuminating core assumptions and uncertainties.[1] We emphasize that a significant and vital piece of this work was the participatory nature of the project, which was implemented using GMB. Participatory approaches allowed our team to integrate a wide range of stakeholder perspectives with the overall goal of enriching the holistic examination of this issue. GMB processes engage practitioners and stakeholders involved in decision making in directly shaping the topics and focus of future research and action agendas. This can both deepen stakeholder understanding of a topic and improve uptake of findings by practitioners and stakeholders.[2]

METHODS

Research Design and Data Collection

To elicit and synthesize diverse stakeholder hypotheses about factors and processes leading to the national increase in pedestrian deaths, the research team designed and facilitated a structured and iterative GMB process. We designed two GMB workshops, drawing from and adapting scripts documented in Scriptapedia (including, Causal Mapping in Small Groups, Initiating and Elaborating a 'Causal Loop Diagram,' and Model Review).[11] Scriptapedia is a repository of scripts or structured small group exercises that can be used to support GMB.[11] The scripts and exercises we used provided opportunities for participants to share their individual perspectives, build from each other's knowledge, and practice reflecting their perspectives using system dynamics diagramming conventions. The first workshop included multi-disciplinary researchers affiliated with a National University Transportation Center led by the University of North Carolina at Chapel Hill, which includes researchers from five universities across the United States (n=17). To expand representation of practice-based perspectives, our team recruited diverse stakeholders from across North Carolina for the second workshop (n=24). We made a concerted effort to seek input from "non-traditional" fields that are often not included in discussions and examination of road safety issues but should be. To do this, we created a list of the topic areas and types of expertise needed, incorporating insight from the research team, other colleagues, and invited participants from the first workshop.

The workshops were structured to include three main segments. First, participants were provided an introduction to systems thinking, system dynamics, and CLD conventions. Participants were then given an opportunity to individually draw their own CLDs to illustrate potential interacting factors and feedback loops they believed were contributing to the increasing trend in pedestrian deaths. They shared their CLDs with a partner before reporting out to the larger group. Lastly, participants were given a second opportunity to draw CLDs in small groups of 4–5 participants to collaboratively refine their mental models with others, again sharing results with the larger group. The research team collected participants' individual CLDs, and documented group CLDs with digital photos. The research team supplemented CLDs with detailed notes taken during large group discussions and CLD share outs. Following each workshop, the research team met to consolidate notes and summarize pertinent insights to aid the data analysis process. The University of North Carolina at Chapel Hill's Institutional Review Board reviewed and approved this research.

Analysis

To develop a comprehensive understanding of the diverse stakeholder perspectives in the workshops and the systems hypotheses generated, two research team modelers used a grounded theory approach to integrate and synthesize the structures reflected in the 41 individual CLDs and 10 group CLDs. They reviewed each diagram and noted the narrative themes and feedback loops included. Through an iterative process of constant comparison, the two modelers each created an integrated CLD using Vensim PLE, one creating a synthesized version of all individual CLDs and the other of all group CLDs.[12] Variables and relationships in each diagram were compared with those in previous diagrams and synthesized to create an integrated CLD of hypothesized structures. The two research team members then synthesized the CLDs they generated separately, after reconciling differences, and ensured the fully synthesized CLD included the main list of themes noted in the first step of the process. The synthesized CLD was further revised for clarity in two iterations of model critiques with the larger research team.

RESULTS

Workshop Participants

A total of 41 stakeholders participated in the two workshops (n=16 in the first and n=25 in the second), which both took place in April 2018 in Chapel Hill, North Carolina (USA). Participants identified with diverse fields, bringing a range of unique perspectives pertaining to pedestrian safety. Participants represented: pedestrian and bicycle advocacy, law enforcement, automobile industry, academia/research, health department, medical professions, local government, city planning, transit department, department of transportation, and social services. Participants readily applied systems thinking and CLD concepts and notation to develop rich, individual and group CLDs.

Overview of Causal Loop Diagrams

Diagrams principally included four core factors with a direct impact on pedestrian fatalities: pedestrian-vehicle crashes, vehicle speed at the time of the crash, vehicle size/dimensions, and emergency response time. In their individual and group CLDs, participants diagrammed and hypothesized about how individuals' (re)actions impacted these factors over time, and the key factors that triggered them, to create the increase in pedestrian deaths. The supplement contains the full, synthesized CLD. Figures 2–4 unfold specific feedback loops and hypotheses articulated within GMB sessions, with Table 1 providing further description of each feedback loop.

Community Responses to Pedestrian Fatalities

Participants diagrammed several ways that increases in pedestrian deaths moved communities to take action (Figure 2; Table 1). Community responses to pedestrian deaths were intended to reduce further deaths, represented through balancing feedback loops. The most common response reflected in participants' diagrams and in group discussion was increased police enforcement of vehicle speed (B1& B2) and pedestrian behavior (B3) immediately following a pedestrian death. These loops, while quick to set in action, were also described as short-lived, due to the lack of resources for and desirability of continuous enforcement and challenges implementing enforcement.

Pedestrian deaths were also described as triggering support and political will for more resources for pedestrian infrastructure in a community (B4). However, participants noted disparities in the activation of this loop, sharing the perspective that deaths of individuals from low-income or homeless communities would be less likely to generate political will for intervention. Some communities were described as becoming motivated to respond when they became aware of the number or increase in pedestrian fatalities from surveillance data (B5). Due to delays in data collection and reporting, this loop was described as slower moving than the B1–B4 loops.

The impacts of loops B4 and B5, although slower to observe, were considered to be more effective in the long-term since resulting actions included strengthened policies or improved infrastructure. Moreover, these loops stimulated two other reinforcing loops: infrastructure availability encouraged more pedestrian trips, generating a larger base of support for additional pedestrian safety infrastructure (R1), and more pedestrian trips were hypothesized to increase drivers' expectations of pedestrians and attentiveness, reducing the probability of a crash and increasing pedestrian trips due to increased perceived safety (creating a safety in numbers effect for pedestrians) (R2).

Participants also identified two less formal responses to pedestrian deaths. Pedestrian deaths could increase concerns about personal safety, and reduce the number of walking trips individuals make, reducing the overall number of pedestrians exposed to vehicles, and thus, reducing the incidence of pedestrian deaths (B6). Related, as pedestrian deaths create the perception that walking is unsafe, individuals may choose to drive instead of walk, thus, increasing vehicle miles traveled (VMT) and pedestrian deaths (R3).

Research, Policy and Industry Influence

Participants identified two slower feedback loops often operating above the community level. One involved conducting, disseminating, and implementing research around pedestrian safety. Research was identified as improving the effectiveness of pedestrian safety infrastructure (Figure 2, B6). The other involved drafting and passing pedestrian safety-focused laws (Figure 3, B7). In addition to speed limit laws, pedestrian safety-focused laws could aim to control other driver behaviors (e.g., texting while driving) through enforcement (B8); however, law enforcement workshop participants shared several challenges to enforcing such well-intended policies. Participants also diagrammed and discussed feedback loops involving industry. Responding to crashes and driver fears about crash risk from distracted driving and other behaviors, participants described the car industry as developing vehicle-safety technology including auto-emergency braking (AEB) (B9) and designing cars to reduce the severity of collisions (B10). Lastly, over a longer time horizon, increasing pedestrian deaths can raise the threshold for what is “acceptable,” which can slow the motivation to take action (R4).

Potential Unintended Consequences of Responses to Pedestrian Deaths

CLDs can support identification of potential unintended consequences of stakeholder actions. Participants hypothesized that while pedestrian safety-focused laws intend to increase driver attentiveness and reduce distracted driving, the enforcement of these laws could influence some drivers to conceal their texting/cell-phone use, which could further increase distraction and deaths, encouraging more calls for enforcement (Figure 3, R5). As more vehicles are equipped with safety features like AEB and other proximity sensors, over time, some drivers may become less attentive and (over-)confident in relying on the vehicle’s safety features, prompting more dedicated development for a technology-fix to reduce crashes (R7). Similarly, increased pedestrian infrastructure like lighted crosswalks may, over time, reduce drivers’ and pedestrians’ attentiveness as they each expect the other to use the infrastructure appropriately. In communities where the level of infrastructure coverage varies significantly, this was noted as a particular problem (R6).

Role of Sprawl on Pedestrian Deaths

For several participants, the increase in pedestrian deaths could not be understood without taking the dynamics of poorly managed regional growth into account (Figure 4). While the dynamics of sprawl is a system of its own,[13–15] participants described how sprawl-related dynamics interacted with other factors to, in most cases, impede community efforts to reduce pedestrian deaths. Increasing VMT over time can create congestion, which puts pressure on communities to increase road capacity, which may initially reduce congestion (B11) and increase speed (R8, R9). However, these increases also increase the size of the region accessible within a desired travel time, further increasing trips taken and VMT (R11 & R12). This sprawl reinforcing loop increases the vulnerability of pedestrians to crashes through increases in VMT (exposure) and reduces the number of pedestrian trips since fewer destinations are within walking distance in a growing region (R13). When the majority of the population is car-dependent and focused on arriving at destinations faster, addressing congestion becomes the priority, which diverts potential funds from pedestrian infrastructure projects (R10). Moreover, when cars are the preferred trip modality (R19), participants discussed that there is more pedestrian victim blaming, which reduces pressure to allocate resources to take action to address pedestrian deaths. Sprawl also affects emergency response time, with congestion and size of the region increasing the time it takes for first responders to arrive and attend to crash victims, increasing the probability of death (R17 & R18). A growing region further strains (already limited) resources for both pedestrian infrastructure projects (R14) and driver/pedestrian enforcement efforts, since the same resources now must be stretched over a larger area (R15 & R16).

Context Dependent Factors

Workshop participants noted several demographic and contextual factors that might influence specific links and system behavior around pedestrian fatalities in important ways, perhaps triggering stakeholder action or affecting system structure. The age of drivers and pedestrians was mentioned as a potentially important exogenous factor (a variable whose change over time is not explained by or affected by other variables within the CLD). Older adult drivers and pedestrians were described as particularly vulnerable to crashes, and younger drivers were perceived to use technology while driving more than older drivers. Participants' diagrams highlighted pedestrians' race/ethnicity and social status as important factors in determining a community's response (or lack thereof) to pedestrian deaths, with deaths from white and/or middle upper class being more likely to trigger political will for action.

Moreover, participants posited that where deaths occurred also affected the kinds of responses. Participants discussed how budget constraints in certain areas often resulted in inequitable distribution of pedestrian infrastructure, which could leave areas on corridors between city centers the most vulnerable. Deaths in these areas were more likely to trigger the (short-term) enforcement focused responses, as opposed to more effective and long-term infrastructure changes.

Finally, participants expressed that for some communities, increasing prevalence of substance use, especially opioids, could also be an important factor to consider in the increase in pedestrian deaths.

DISCUSSION

The CLD and GMB process detailed in this study demonstrate how systems science tools can be adopted and applied by a diverse group of stakeholders to relay varied perspectives and rich theories on the underlying structure and interactions driving a dynamically complex and persistent problem, namely pedestrian deaths in the US.[9,16,17] This is the first study to use CLD and GMB to begin to explore this increasing trend.

Moreover, this process generated a wide range of insights. Here, we highlight five key observations:

- First, diagramming ***provided a useful forum to describe and discuss competing goals within our transportation systems*** and helped hypothesize about how competing goals drive trends. For example, participants detailed how pedestrian-friendly infrastructure in a community triggers more pedestrian activity, while also discussing mechanisms through which pressure to achieve desired vehicle travel times can undercut pedestrian safety. Participants recognized the vast variability in the strength of these processes across communities.
- Second, workshop discussions and CLDs ***helped participants depict and comprehend variation in speeds of action and reaction within different feedback processes***. These representations fostered a clearer understanding of why many responses take so long to generate change and may be attenuated in

the process by other actions. For example, as cars with newer safety features, like lane departure warnings, enter the vehicle fleet (a slow process), distractions remain prevalent and can quickly change over time, potentially becoming even more dangerous or prevalent.

- Third, the diagrams ***led to important discussions about disparities and the role that systematic bias may play*** in transportation decision-making. Biases and disparities were noted as significant systemic contributors to feedback loops involving the strength of political will, infrastructure placement decisions, and enforcement.
- Similarly, ***feedback structures provided a means to describe and depict processes driving norms and perceptions***, factors that likely play a large role but are often missing from traditional studies. For example, some described mechanisms through which a culture of complacency persists or grows, in which people come to expect a consistent and almost acceptable level of road traffic-related deaths. As another example, many stakeholders described enforcement as an effective "go to" lever to reduce distracted driving. Hearing the enthusiasm for the ability of this balancing loop to help control outcomes, law enforcement stakeholders were able to question this perception and explain real-world challenges with detecting and proving distracted driving, fundamentally limiting the ability of enforcement to effectively counter pedestrian deaths.
- Finally, the CLDs helped participants ***appreciate the complexity of the issue overall***, including a realization that the problem is likely generated by no one factor, and illuminated limitations of our current data systems in "seeing" the whole system.

While CLDs provide numerous benefits, and in some cases can serve as a final project goal (e.g., to increase stakeholder communication and collaboration), they often serve to establish a foundation for further hypothesis testing.[1,9] CLD creation within a GMB setting provides an opportunity to free participants' thinking from constraints around the extent and strength of specific data sources, allowing stakeholders to explore the complexity of a problem and inspire ideas on the deeper mechanisms generating the problem. However, subsequent steps generally include triangulating "mental model" information with written and numerical data sources.[12,18] Structured and systematic approaches exist to incorporate findings from the scientific literature into CLDs, documenting evidence on which relationships and feedback loops have support and in which contexts.[19–21] In addition to identifying where empirical support exists and may be lacking within a systems diagram, this triangulation can also help inform parametrization of quantitative models to test hypotheses. System dynamics simulation modeling, using available (though potentially fragmented) data, provides a means to test dynamic theories and examine the relative effectiveness of potential policies and interventions.[17,22–25] Many tools and approaches exist to integrate uncertainty analyses within system dynamics simulation modeling, recognizing that potentially important relationships and feedbacks may be lacking effect estimates from the scientific literature base.[1,26]

While this work served as a foundational step in collecting diverse stakeholder hypotheses from a variety of perspectives, there are also limitations. First, there is considerable regional and community-specific variation in pedestrian safety, and the dynamic system driving outcomes in different settings might be structurally different or might be different in terms of feedback strength. Given the variation in the context our participants worked in and/or were familiar with, the synthesized diagrams were not context-specific and, therefore, should be thought of as a broad map of several potential feedback structures, which are likely not all relevant to any one context. However, the diagram provides a valuable basis for future community-specific work and context-specific testing, including exploring potential system archetypes (or common patterns of behavior identified in system diagramming and modeling) that may drive community-specific trends.[27] Additionally, the CLD process inherently includes stakeholder biases, and these biases would likely differ depending on who participates. Still, understanding the assumptions, beliefs, and values of key stakeholders is a critical piece in uncovering how to effectively drive change within a system. Simulation models can help tease apart the extent to which beliefs and biases contribute to system behavior and/or hinder views of system behavior. Relatedly, some perspectives may have been missing or not represented in the workshops. At the end of the second workshop, we specifically asked participants what perspectives might have been missing, and responses included rural entities, demographers, and trucking/freight-related stakeholders. Additional iterations concentrated on gathering such perspectives could help ensure that important dynamics are not omitted due to stakeholder representation and further test and extend dynamic hypotheses.

Summary

Systems science approaches can advance understanding of dynamically complex road safety problems and may ultimately help inform more effective action and intervention. We used one set of system tools, CLDs within a GMB process, to develop a holistic systems diagram of potential contributors to increasing pedestrian death rates. This process prompted critical conversations on what is known and not, where current efforts are often targeted and why, and the importance of developing a shared vision and path forward. Additionally, this work established a robust foundation of specific, dynamic, and testable hypotheses, laying the groundwork for future simulation testing. These tools represent just a few from the larger complex systems science field,[10,16,17] whose full range of approaches may warrant further consideration as a means to help advance injury prevention efforts.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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KEY MESSAGES:

What is already known on this subject:

- Between 2009 and 2017, pedestrian deaths in the U.S. increased 45%, from 4,109 to 5,977 deaths per year.
- Our underlying motivating supposition was that a set of interacting time-dependent factors have contributed to the increase (rather than a single factor acting in isolation).

What this study adds:

- Systems science tools, such as causal loop diagraming and group model building, can be used to synthesize diverse perspectives on the underlying structure and interactions driving dynamically complex injury problems, such as pedestrian deaths.
- These tools aid in fostering discussions about the competing goals within our transportation systems, disparities in transportation safety, processes driving norms and perceptions, and the overall complexity of injury issues.

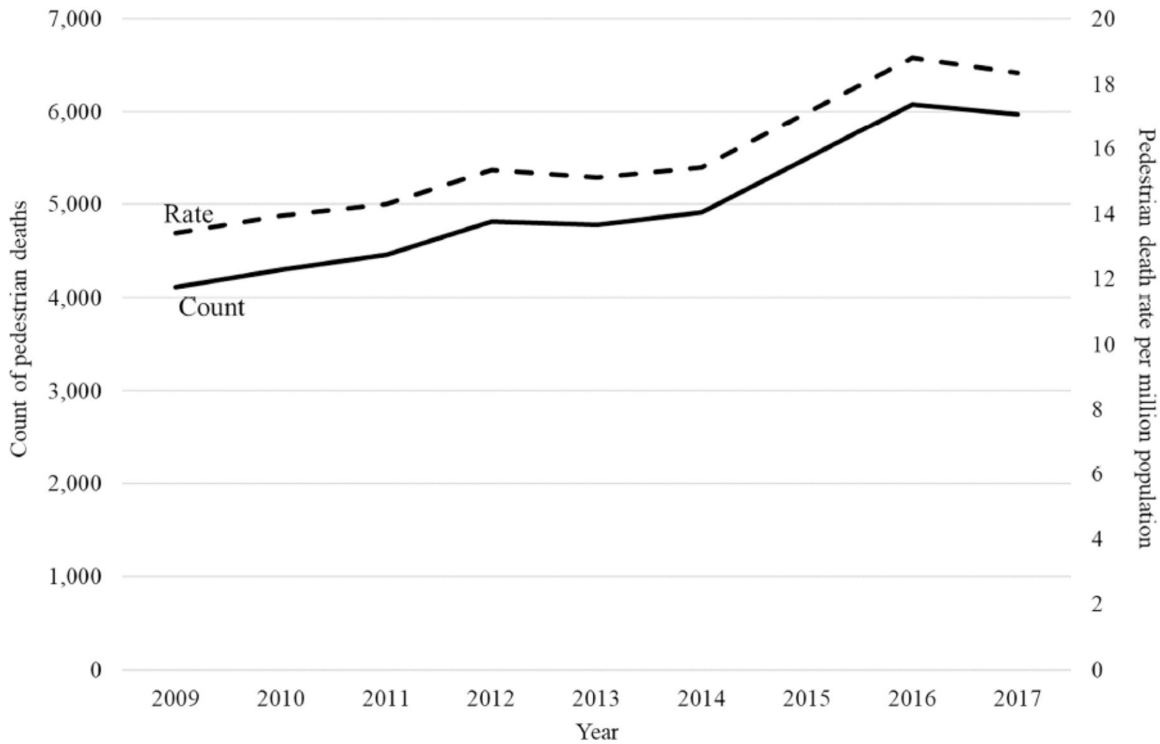

FIGURE 1.

Count and rate of pedestrian deaths in the United States, 2009–2017

Source: National Highway Traffic Safety Administration, Fatality Analysis Reporting System

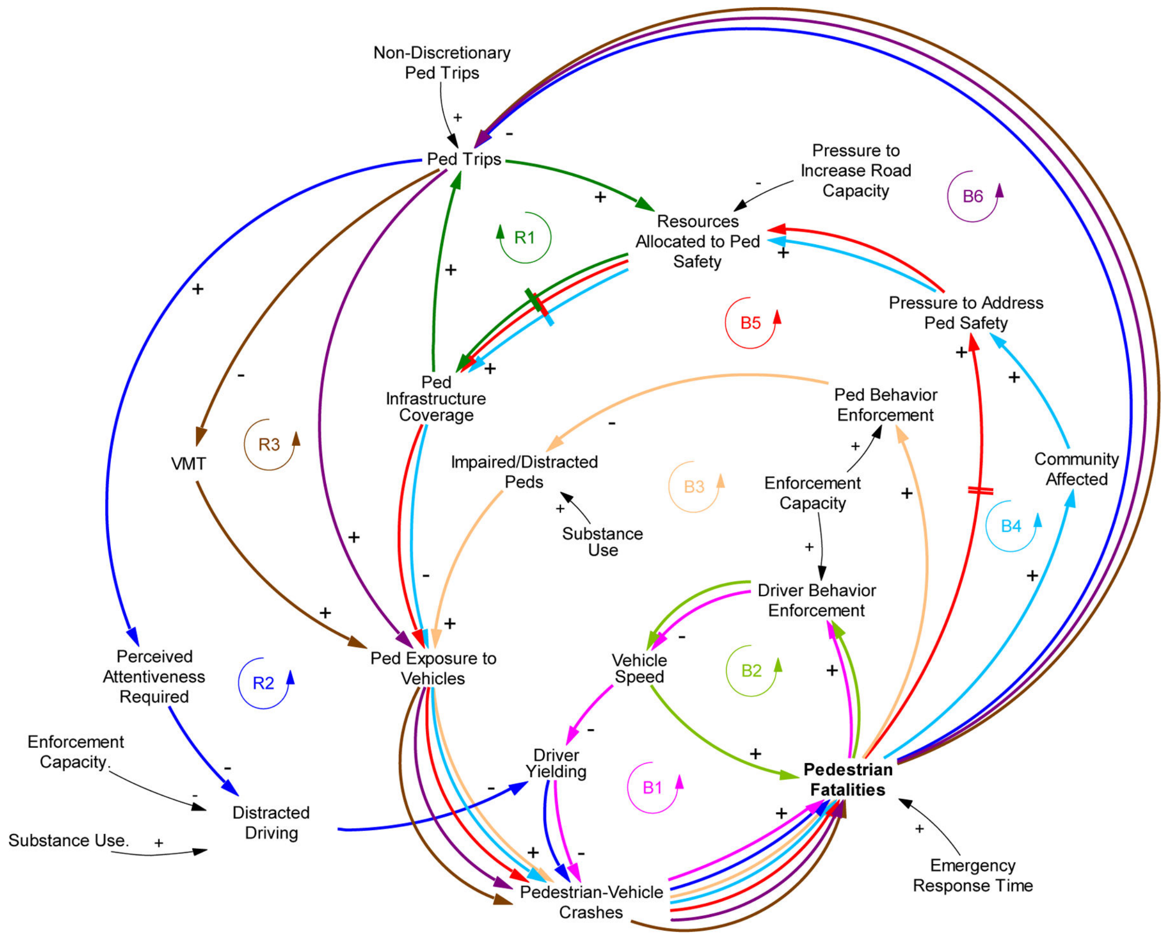

FIGURE 2.

Synthesized causal loop diagram of hypothesized community-level system structure driving pedestrian death rates over time

ped= pedestrian; || represents hypothesized time delay; + represents hypothesis that a connected pair of variables change in the same direction over time (e.g., as one variable increases the other variable increases as well); - represents hypothesis that a connected pair of variables change in the opposite direction over time (e.g., as one variable increases the other variable decreases, and vice versa); B# represent numbered balancing loops; R# represent numbered reinforcing loops.

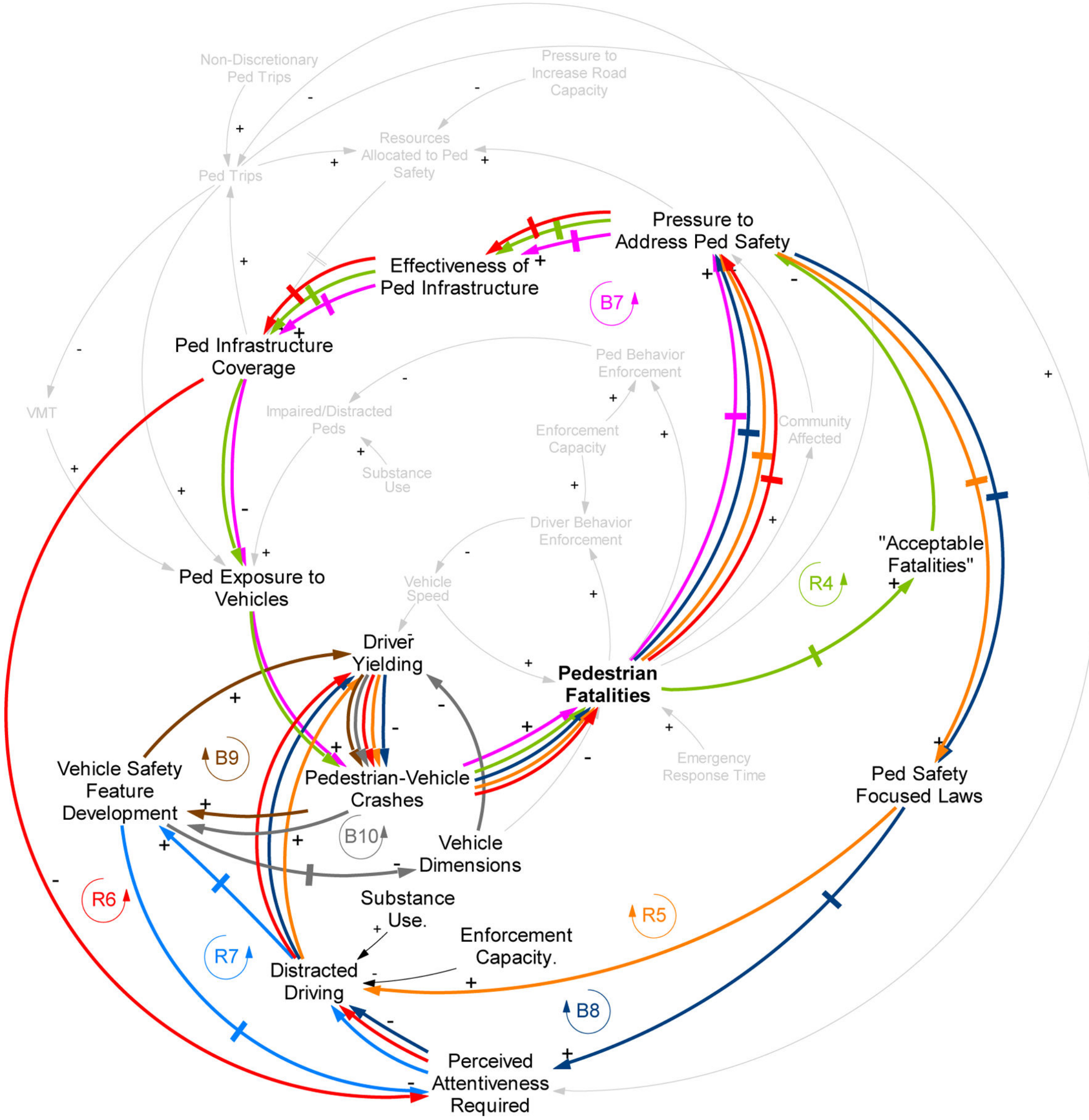

FIGURE 3.

Synthesized causal loop diagram of hypothesized system structure involving factors external to communities that may be driving increases in driving pedestrian death rates over time. B, balancing; Ped, pedestrian; R, reinforcing; VMT, vehicle miles travelled.

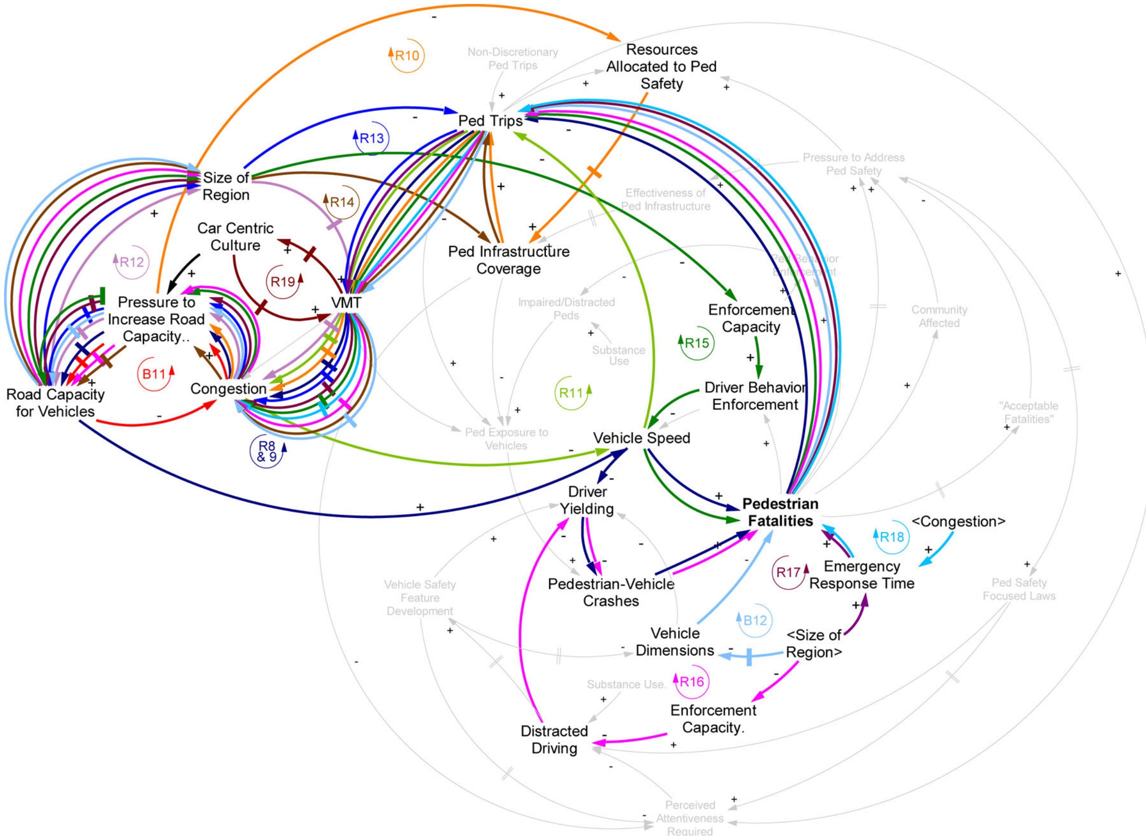

FIGURE 4.

Synthesized causal loop diagram of hypothesized system structure involving factors related to regional growth and vehicle miles traveled (VMT) that may be driving increases in pedestrian death rates over time.

B, balancing; Ped, pedestrian; R, reinforcing; VMT, vehicle miles travelled.

TABLE 1.

Reinforcing and balancing feedback loops generated from workshop participants' causal loop diagrams

Label[1]	Name	Short Description
Figure 2		
B1& B2	Band Aid Driver Enforcement	Following a fatality, communities respond by increased enforcement of vehicle speed, which decreases crashes and fatalities, limited by enforcement capacity.
B3	Band Aid Ped Enforcement	Following a fatality, communities respond by increased enforcement of pedestrian behaviors which reduces crashes and fatalities but is limited by enforcement capacity.
B4	Community Response	The families and communities of those killed in pedestrian-vehicle crashes can generate support to address pedestrian safety and infrastructure that protects pedestrians and reduces pedestrian deaths.
B5	Data Driven Advocacy	Data on pedestrian fatalities can also generate support for pedestrian safety and infrastructure, reducing pedestrian vulnerability, crashes, and pedestrian deaths.
B6	(Un)safe to walk	The safer walking appears to be, the more pedestrians will be encouraged to walk, which increases pedestrian exposure to vehicles, and probability of crash and fatalities, and reduces the perceived safety of walking.
R1	Walkability	Pedestrian infrastructure encourages use, which generates a base of support which in turn encourages the construction and maintenance of pedestrian infrastructure.
R2	Safety in Numbers	The more drivers see pedestrians, over time, the more accustomed they will become to seeing them, the more attentive they know they will have to be, preventing crashes and deaths, increasing the number of pedestrians on the streets.
R3	Shift to Reinforcing of Vehicle Trips	More VMT increases pedestrian exposure to vehicles, increasing crashes and fatalities, reducing the perceived safety of pedestrian trips, reinforcing more vehicle trips.
Figure 3		
B7	Improving Infrastructure Effectiveness	Identifying pedestrian safety as an issue encourages research and development of more effective infrastructure to reduce pedestrian vulnerability, crashes, and pedestrian deaths.
B8	Ped Safety Focused Laws	Pressure to address pedestrian safety can also generate support for pedestrian safety focused laws, that reduce pedestrian vulnerability, crashes and fatalities.
B9 & B10	Vehicle Safety Technology Development & Design	In response to distracted driving drivers' concern for safety, the car industry can allocate resources to developing technologies and car design that reduce crashes.
R4	Normalizing Pedestrian Deaths	As pedestrian deaths increase and remain high over time, the norm for what the population perceives as "acceptable losses" or "tolerable" also increases, which reduces pressure to take action, further increasing pedestrian vulnerability.
R5	Distracted by Hiding Distracted Driving	An unintended consequence of pedestrian safety focused policies, drivers try to hide their device cell phone usage, increasing their distractedness, reducing the ability to yield, increasing crashes and fatalities, triggering more pedestrian safety focused policies.
R6	Growing Accustomed to Infrastructure	Ped infrastructure can over time, reduce perceived attentiveness required: drivers are less likely to be attentive to the road (since they are expecting flashing lights and signage to alert them to pedestrians) and pedestrians may assume drivers will stop at marked cross walks. Low attentiveness increases the risk of crashes, and deaths, triggering more allocation of funds to the additional pedestrian infrastructure projects.
R7	Relying on Safety Technology Fixes	Increasing distracted driving encourages the development of vehicle safety technologies, which can relax the attentiveness drivers feel they need to dedicate while driving, reducing their attentiveness and distracted driving behaviors.
Figure 4		
B11	Reducing Congestion	Increasing congestion, triggers pressure to increase road capacity, which reduces congestion in the short term.
B12	Save on Gas	Larger regions over time can influence drivers to choose smaller (more gas efficient) vehicles, reducing probability of a pedestrian death after a crash.
R8 & R9	Speed & Flow	As road capacity increases, vehicle speeds also increase, increasing risk of crashes and deaths, encouraging more driving, and pressure to increase road capacity.

Label[1]	Name	Short Description
R10	Investment Priorities	With increasing congestion and pressure to invest in road capacity, fewer resources are allocated to pedestrian infrastructure, decreasing pedestrian trips, further increasing VMT, and congestion.
R11	Speed Concerns	Faster vehicle traffic decreases the perceived safety of the walking, reducing pedestrian trips, increasing VMT, congestion, pressure to expand road capacity, which can increase vehicle speed and flow.
R12	Sprawl: Expanding Region	Increased road capacity increases the size of region within a desired travel time, increasing the number of cars moving through a region, increasing ped-vehicle exposure, increasing crashes and deaths and reinforcing expansion of road capacity.
R13	Can(not) Walk There	As the region expands, fewer destinations are within walking distance, reducing the pedestrian trips, increasing VMT, and increasing pressure to expand road capacity.
R14	Infrastructure Adequacy	As the region expands, pedestrian infrastructure resources are stretched to cover the area, creating areas with inadequate pedestrian infrastructure, increasing pedestrian vulnerability, and deaths which further discourage pedestrian trips, increase VMT and regional expansion.
R15 & R16	Enforcement Capacity	As the region expands, enforcement resources are stretched to cover the area, reducing enforcement of driver behaviors.
R17	Too Far to Respond	The growing region increases the time for emergency responders to attend to pedestrian crash victims, decreasing the perception of safety of walking and increasing VMT, increasing the pressure to increase road capacity leading to more sprawl.
R18	Too Slow to Respond	Congestion caused by VMT increases the time for emergency responders to attend to pedestrian crash victims, decreasing the perception of safety of walking and increasing VMT.
R19	Car-Centric Culture	As VMT increases, over time, cars become the norm, which increases the number of trips people make by car.

[1]Feedback loops are labeled *R* for reinforcing and *B* for balancing.

Ped, pedestrian; VMT, vehicle miles travelled.