Explaining the rise in pedestrian fatalities, a systems approach (Phase 1)

Examining pedestrian safety impacts of congestion pricing policies using a system dynamics approach (Phase 2)

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Evolution of this Work

- Examining the interconnectedness and complexity potentially generating pedestrian death trends (RR1)
- Honing in on the ripple effects of a specific policy on this trend in a specific geographic area (R21)
  - Understanding the research and current state of the evidence base on this policy (i.e., congestion pricing policies).
  - Model potential policy impacts on pedestrian injuries
Using SD to examine the increase in pedestrian deaths

Pedestrian deaths, US, 2009-2020 (U.S. Fatality Analysis Reporting System)
Walking while drunk fuels surge in US pedestrian deaths

Updated Aug 6; Posted Aug 6

Distracted walking could be a contributor to the nearly 6,000 pedestrian deaths in 2017

UT Police are warning students that texting and walking can be dangerous.

Author: Brandon Bates
Published: 9:51 PM EDT August 27, 2018
Updated: 8:18 AM EDT August 28, 2018

The rise in SUVs is linked to a surge in pedestrian deaths

By Jill Petzinger • May 9, 2018

Where Pedestrian Deaths Are Up, Is Marijuana to Blame?

Marijuana buds being stripped from stalks in Denver. Data from Colorado and other states that have legalized recreational marijuana “is a marker for concern,” the author of a study by the Governors Highway Safety Association said. Photo: David Sorensen for The New York Times.

By Neal E. Boudette
Feb. 28, 2018
What is systems thinking and what are systems approaches/tools?

- Practical, structured inquiry, which...
- Seeks to “see” wholes, and
- Supports development and/or testing of a model (qualitative or quantitative) representing critical components of the system that determine an outcome(s)

https://medium.com/disruptive-design/tools-for-systems-thinkers-the-6-fundamental-concepts-of-systems-thinking-379cdac3dc6a
Some Systems Science Tools

**Qualitative**
- AcciMap
- 5 Rs
- Balance of petals mapping
- Goal and action alignment mapping
- Causal loop diagramming
- Network mapping
- System support mapping

**Quantitative**
- System dynamics simulation (stock and flow simulation)
- Agent-based models & microsimulation
- Network analyses
- Discrete event simulation

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Causal Loop Diagramming and System Dynamics (SD) Modeling

“System dynamics is the use of informal maps and formal models with computer simulation to uncover and understand endogenous sources of system behavior.”

Using SD to examine the increase in pedestrian death rates

- Illuminate core assumptions and uncertainties related to increase in pedestrian deaths
- Enrich our hypotheses. Develop specific, dynamic, and testable hypotheses
- Understand future data collection and research needs
Systems Workshops: Group Model Building

- Group model building workshops, working with a diverse group of experts
- Developed system maps (causal loop diagrams)
- 3 workshops conducted. Attendees represented:
  - Law/ injury claims
  - Transit (local and state)
  - Local and state planners and pedestrian/bicycle coordinators
  - State DOT safety engineers
  - State Department of Health and Human Services
  - Law enforcement
  - Fire department
  - Journalism
  - Medicine/Trauma
  - Researchers (epidemiology, planning, robotics, engineering, child development, economics)
  - Automakers
  - Local elected officials (town council member)
  - Advocacy (injury prevention, AARP, coalition to end homelessness)
From linear thinking to thinking about feedbacks

Real and perceived risk of injury from walking and cycling

Local walking and cycling
From linear thinking to thinking about feedbacks

Number of walking & cycling injuries

Real and perceived risk of injury from walking and cycling

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From linear thinking to thinking about feedbacks
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Local walking and cycling

Number of walking & cycling injuries

Real and perceived risk of injury from walking and cycling

Local walking and cycling

Local sense of security

Presence of people on local streets

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A feedback loop that builds on itself is called a “reinforcing loop”: engines of growth

- They are also called positive feedback loops, virtuous cycles, vicious cycles, bandwagon effects, snowball effects
  - Changing a variable in one direction produces a response in the same direction of that variable
- Drivers of exponential growth

![Diagram showing local walking and cycling reinforcing local sense of security and presence of people on local streets over time.](attachment:image.png)
Balancing loops seek balance or equilibrium: counteract change

• Balancing loops are created when there are an odd number of negative links (or O’s).

• “Goal seeking”
Post-Workshop Insights

• Perspectives on the nature of the issue and potential solutions changed after the workshop

• Acknowledged & recognized the limitations of existing data in telling the full story and in identifying solutions

• Appreciated the complexity of the issues more and the chance to think more deeply about the issues; the mapping approach was a thought-provoking way to generate and inspire research ideas

• Some participants (from non-transportation fields) reported better seeing how their work relates to pedestrian safety

• New collaboration opportunities emerged

Source: www.pedbikeinfo.org/Dan Gelinne
Synthesizing the Data: Community-level System Structure

Synthesizing the Data: Factors Outside of a Community

Synthesizing the Data: Factors Related to Regional Growth and Vehicle Miles Traveled

More information....


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- Examining the interconnectedness and complexity potentially generating pedestrian death trends (RR1)
- **Honoring in on the ripple effects of a specific policy on this trend in a specific geographic area (R21)**
  - Understanding the research and current state of the evidence base on this policy (i.e., congestion pricing policies).
  - Model potential policy impacts on pedestrian injuries.
Honing in on the system and dynamic complexity affecting pedestrian safety in NYC

• Congestion pricing policies (CPPs) are a travel demand management strategy designed to reduce peak-period traffic volumes by financially encouraging road users to use alternate transport modes, eliminate trips, or travel at different times.

• Several U.S. cities are considering CPPs, and New York City (NYC) plans to implement a CPP in 2022.

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Bibliometric analysis of congestion pricing policy research

- Prioritized references for manual screening using a two-phase, automated approach that relied on semi-supervised learning and machine learning.
- Networks were constructed using the VOSViewer application, based on available data fields in the four databases.
- Network maps describing:
  1. distribution of and relationships between key terms
  2. frequency of publications and collaborations between authors
  3. authors’ countries from which the research originated.

![PRISMA Flow Diagram for Congestion Pricing Bibliometric Analysis](image-url)

*Modified for a bibliometric analysis with no screening of full-text studies.
Seven clusters were identified

3 largest clusters are distinguished by blue, green, and red.

Blue focuses on a range of structural implementation terms and policy types, including terms such as ‘high occupancy toll’, ‘facility’, ‘lane’ and ‘peak period’.

Green cluster includes terms that focus on transportation modeling methods and characteristics, including ‘network’, ‘algorithm’, ‘dynamic,’ ‘link,’ ‘formulation.’

Red includes terms related to population perceptions of congestion pricing policies, such as ‘attitude’, ‘acceptability’, and ‘support’, and effects relevant to perception such as ‘pollution’ and ‘external costs.’

A general shift in terminology from terms related to implementation in the early 2000s toward terms related to acceptability after 2010.
Top countries represented in the literature were the US (n=439), China (n=265), the United Kingdom (n=154), Sweden (n=86).

The UK had an average publication year of 2005. By 2009, publication patterns shifted to include the US, the Netherlands (n=77), Canada (n=51), and Hong Kong.

Sweden and Australia (n=59) gained greater representation, on average, in late 2011 and early 2012, after which patterns shifted to include China, Iran (n=22), Spain (n=33), Germany (n=23), and Switzerland (n=17).

Most recently, research representing countries such as Indonesia (n=9), India (n=7), Puerto Rico (n=3) and Qatar (n=2) have also started to appear in published research.
Key takeaways

• Number of publications grew significantly between 1956 and 2015, with annual research output increasing from just 1 in 1956 to 122 in 2015.

• Wide variety of topic areas were studied: congestion pricing implementation logistics, public perception and acceptability, and network algorithms.

• Country representation revealed notable shifts in research output across the globe as countries explored policy implementation with early research productivity in the UK, moving to the US (and other countries such as the Netherlands, Canada, and Japan), and eventually countries such as China, Germany, and Iran.

• Several topic gaps were identified in this analysis. Terms related to equity and impact were only in a small proportion of titles and abstracts. Also, terms relevant to specific road user types and modes (e.g., pedestrian, motorcycle[ist], bicycle[ist]) and terms related to safety were extremely sparse in titles and abstracts.

Safety-related congestion pricing studies

- 366 Studies Imported for Screening
  - 104 Duplicates Removed
  - 262 Titles & Abstracts Screened
    - 188 Excluded
  - 74 Full-text studies assessed for eligibility
    - 61 Excluded
      - Reasons for Exclusion:
        1. Not a peer-reviewed or published report (e.g., news, project synopsis).
        2. Not an original study/application (e.g., commentaries, reviews/syntheses).
        3. Does not examine a congestion pricing policy, according to the definition used in this review.
        4. Pertains to non-roadway congestion pricing (e.g., airports).
        5. Does not relate to safety, injuries, etc. at all (not even broadly speaking).
    - 5 studies added from reference screening during full-text assessment

18 Final publications identified and included in completed extraction.
Overall study characteristics and key findings

• Published between 1989 to 2021
• United Kingdom (n=9), other European countries (n=5), US (n=4)
• Mostly examined zone- and cordon-based (n=13) schemes
• Most studied crashes broadly
• Crashes: Estimated reductions of the number of road traffic crashes following policy implementation included 3.6% per year in Stockholm’s’ zone-based charging area and 35% per month in London’s zone-based charging area
• Fatalities: Varied. No observed changes in the three years following policy implementation in Milan to decreases as high as 33% in the two years following implementation in London.
• Injury Crashes: Estimated that through three years post-implementation, traffic changes caused by the London zone-based charging scheme were ultimately responsible for the reduction of 40-70 additional injury crashes per year beyond the crash reductions that were expected to occur as the result of all road safety initiatives and a general declining trend in road traffic crashes. Spain: an area-wide CPP documented increases in observed injury crashes, as a result of traffic patterns shifting to non-tolled areas
Mode-specific findings

• Motorcyclists: a 5.7% increase in total motorcycle casualties (in the year immediately post-CPP implementation, with a 17.3% increase in the number killed or seriously injured). Other estimates: no significant changes in motorcyclist casualties within the London charging zone during the same post-implementation period; however, increase immediately adjacent to the charging zone.

• Bicyclists: Observed and estimated changes in bicycle crashes and injuries varied in magnitude and direction, particularly based on time since CPP implementation. 13.3% increase in bicycle injuries resulting from crashes during the year immediately following London CPP implementation with a decrease several years after implementation in London. Attributed observed increases in the number of bicyclist injuries due to mode shifts and increases in bicycle use.

• Pedestrians: No significant change in the proportion of crashes affecting pedestrians in London (compared to vehicle occupants/riders) in the year immediately following implementation, but then observed increases in this proportion in years two and three post-implementation.
Key Takeaways

• Potential safety benefits for some road users following CPP implementation.

• Benefits may vary by road user type and according to length of time post-implementation.

• Relative paucity of research specifically exploring the safety outcomes of these policies, along with the wide breadth of CPP types, implementation contexts, outcomes measured, and relationships modeled indicate a need for additional research.

• Before implementing CPPs, cities/regions should consider, within the context of their own community, potential mode shifts and safety-related supports for such mode shifts, appropriate revenue reinvestment, and benefits in both short- and long-term time frames.

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Honing in on the system and dynamic complexity affecting pedestrian safety in NYC

• NYC planning to implement CPP in 2022. Facing several unique challenges with respect to mode availability and increasing injury trends, despite infrastructure investments
  • Prior to the COVID-19 pandemic, the bus and metro systems were running at peak capacity in many places and had recently experienced reduced ridership due to slower and unreliable travel times
  • Additionally, beginning in 2014, the city had made significant investments in pedestrian and cyclist infrastructure over the last few years through their Vision Zero initiative.

• Can (and if so, how can) the NYC congestion pricing policy improve safety for road users (and namely, pedestrians), while meeting the intended purpose of reducing congestion and improving alternate travel modes?
Creating a strong foundation of dynamic hypotheses (illustrated through a causal loop diagram)

• Tailored the causal loop diagram to capture mechanisms believed to be strongest and most important for understanding pedestrian injuries over time in Manhattan

• Used an iterative process of systems-based interviewing (n=7), consulting with experts in pedestrian safety, engineering, planning, public health, and advocacy who were from academic institutions, the NYC Department of Transportation, and a NYC-based advocacy organization focused on vulnerable road users

• Asked interviewees to rank and discuss the likely impact of a range of specific feedback loops and dynamics on the overall pedestrian injury trend in Manhattan and set aside those believed to have little to no effect.

• Also solicited feedback on what else was missing

• Finalized within research team
FIGURE. Causal loop diagram of feedback structure contributing to potential congestion pricing policy impacts on pedestrian injury

Arrows with a “+” sign indicate that a change in the originating variable leads to a change in the destination variable in the same direction (e.g., more vehicle trips leads to more congestion or less vehicle trips leads to less congestion), all else held equal. Arrows with a “−” sign indicate that the two variables change in opposite directions (e.g., more pedestrian infrastructure leads to fewer pedestrian injuries or less pedestrian infrastructure leads to more pedestrian injuries), all else held equal. R: reinforcing feedback loop; B: balancing feedback loop.
• Stocks: where systems hold “stuff”
  • Give a system inertia, can be a source of delays, can be basis for action

• Flows: changes in stocks over time
  • Stocks can only change through their flows
  • Rates ("stuff" per unit time)

• Auxiliary/converter variables: functions of stocks and flows
  • Help define stock and flow equations

• Understanding how stocks and flows interact is not intuitive - It’s not easy! Simulation can help

• Nonlinearity: the behavior of the whole is more than the sum of the behaviors of individual parts
  • Can not understand “emergent” behavior from the behavior of each individual piece
System dynamics simulation model construction

- Slow build up feedback loop by feedback loop with many tests (e.g., extreme conditions, variation in functional form describing relationships between variables)
- Acquire as much of information and data points as possible to validate and increase confidence (does it sit well in past data?)
What kinds of data?

- Pedestrian crash and injury data from the Department of Motor Vehicles Accident Information System through the NY State Traffic Safety Statistical Repository
- Several measures tracked through annual NYC Mobility Surveys and Reports, including data on average travel speeds in the central business district, vehicle trips into the central business district, transit ridership trends, and proportions of trips that are made by walking and other modes
- Population data from the U.S. Census and American Community Survey
- Freight vehicle data from the NYC Department of Transportation
- Taxi and for-hire vehicle trend data from the NYC Taxi and Limousine Commission
- Intersection count data from the NYC Pedestrian Safety Action Plan
- NYC Metropolitan Transportation Authority (MTA) data on transit ridership, expenditures and deficits, and average numbers of major delays on transit lines
- Detailed literature reviews were used to help define the functional form of relationships between key variables (e.g., speed and injury risk)
System dynamics simulation model construction

- Slow build up feedback loop by feedback loop with many tests (e.g., extreme conditions, variation in functional form describing relationships between variables)
- Acquire as much of information and data points as possible to validate and increase confidence (does it sit well in past data?)
- Calibration to observed data and policy tests
- Sensitivity analyses (particularly around unknown variables)

- Purpose of the model is to serve as a learning model to explore congestion pricing impacts on pedestrian safety that can illustrate key insights about congestion pricing dynamics and the system dynamics approach
FIGURE 2. Observed vs. simulated data in congestion pricing policy-related system dynamics model
<table>
<thead>
<tr>
<th>Simulated Policy Abbreviation</th>
<th>Simulated Policy Details*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0. CPP not implemented</td>
<td>No CPP implemented but Vision Zero (VZ) investments remain in place and unchanged.</td>
</tr>
<tr>
<td>1. CPP implemented and no other changes in policy</td>
<td>CPP implemented, assuming a $6 charge in each direction for vehicles entering and exiting the congestion pricing zone, beginning in 2022. We assumed for-hire vehicles are not charged under the new CPP. However, they are charged under a previous congestion-related surcharge placed on these vehicles, beginning in 2019. All revenue from the CPP is used to improve the metro system. VZ investments remain in place and unchanged. Assumes that none of the other policy options listed in this table are implemented.</td>
</tr>
<tr>
<td>2. CPP implemented and VZ investments expire</td>
<td>CPP implemented. Assumes consistent investments in improved pedestrian infrastructure which began when NYC adopted VZ in 2014. However, this scenario assumes that political will for VZ-related investments wanes, and while the CPP is implemented, the VZ investments for improving pedestrian infrastructure are removed at the time the CPP is implemented.</td>
</tr>
<tr>
<td>3. CPP implemented and FHVs taxed</td>
<td>CPP implemented and additional taxes placed on FHVs when the CPP begins. The model includes the FHV surcharge placed on these vehicles to mitigate congestion beginning in 2019. This policy scenario assumes that another tax (about $2.75 per FHV trip) is placed on FHV trips when the CPP goes into effect, in an attempt to further reduce congestion.</td>
</tr>
<tr>
<td>4A. CPP implemented and post CPP infrastructure investments funded by CPP</td>
<td>CPP implemented and a small proportion of CPP revenue is used to improve pedestrian infrastructure after CPP implementation, instead of all revenue feeding back into metro improvements. These investments are in addition to the standard VZ-related investments.</td>
</tr>
<tr>
<td>4B. CPP implemented and pre &amp; post CPP infrastructure investments</td>
<td>CPP implemented and additional investments are made to improve pedestrian infrastructure after CPP implementation (like in 4A), as well as in the two years prior to CPP implementation, aiming to prepare for potential mode shifts. These investments are in addition to the standard VZ-related investments.</td>
</tr>
<tr>
<td>5A. CPP implemented with speed reduction</td>
<td>CPP implemented and measures put in place to keep speed consistently low post-CPP implementation, despite congestion being alleviated.</td>
</tr>
<tr>
<td>5B. CPP implemented with speed reduction &amp; post CPP infrastructure investment funded by CPP</td>
<td>Essentially scenario 4A combined with 5A. CPP implemented; measures put in place to keep speed consistently low post-CPP implementation, despite congestion being alleviated; and a small proportion of CPP revenue is used to improve pedestrian infrastructure after CPP implementation, instead of all revenue feeding back into metro improvements.</td>
</tr>
</tbody>
</table>

CPP= congestion pricing policy; FHV= for-hire vehicle (such as Uber, Lyft); VZ= Vision Zero

*All models, except for “Vision Zero investments expire post CPP” assume consistent investments in improved pedestrian infrastructure which began when NYC adopted Vision Zero (VZ) in 2014 and that these annual investments continue into the future (i.e., through 2030).
FIGURE. Impact of congestion pricing policy-related scenarios on counts (Panel A) of pedestrian injury

- 0. No CPP
- 1. CPP
- 2. CPP + VZ Investments Expire
- 3. CPP + FHVs Taxed
- 4A. CPP + Post CPP Infrastructure Investment
- 4B. CPP + Pre & Post CPP Infrastructure Investments
- 5A. CPP + Speed Reduction
- 5B. CPP + Speed Reduction + Post CPP Infrastructure Investment

Estimated number of pedestrian injuries per year

Year

2005  2010  2015  2020  2025  2030
A policy simulator to explore effects on pedestrian safety

Policy Simulator Overview
The baseline run (blue line) demonstrates the trend in pedestrian injuries in the Manhattan central business district, assuming congestion pricing policy (CPP) implementation in 2022. The switches below the figure allow the user to layer on policies or remove CPP implementation entirely to explore relative impacts on pedestrian injury trends through 2030. The red line will demonstrate the new trend, under user-specified policies.

Using the "Run" button simulates potential policy impacts under different scenarios, and the "Go Live" button places the simulation in a "live" interacting mode, demonstrating instant updates to the trend line. The "Reset" button resets inputs to the base/default run of CPP implementation alone.

Key takeaways

- Increasing interest over the last several years in CPPs, as major cities struggle with congestion-related impacts of car dependency, including reduced air quality, increases in obesity and other physical health concerns, and reduced quality of life from time spent on progressively congested roadways.

- Absent from much of this research has been a focus on the safety of individuals traveling in and around these cities using different modes, despite worsening fatal and nonfatal injury trends, particularly for pedestrians.

- Found that scenarios involving differences in how the CPP is configured and revenue is invested, and in congruent road safety interventions, resulted in similar congestion reductions (i.e., in average daily vehicles trips in the CPP area).

- However, considerable variation in the pedestrian injury trends by scenario type. Some scenarios had deleterious effects on pedestrian safety, while others offered notable improvements in pedestrian safety, in addition to limiting congestion.

- One important policy take-away from this work is that a CPP combined with other pedestrian efforts has substantial potential for positive gains in public health. On the other hand, adopting CPP and discontinuing infrastructure investments in safety could have a strong negative effect on pedestrian injury.

In summary, systems thinking approaches....

• Teach us to **think differently** about how systems behave (that is, in terms of dynamics, feedbacks, interactions)
• Allow stakeholders to **view the larger system** that a problem is embedded within and **strengthen dialogue** among stakeholders
• Foster development of rich, **hypotheses** that may be driving a persistent problem
• Provide a **framework for integrating** what we know, and determining importance of what we don’t know
• Offer a virtual world in which to “**try out**” and **compare** policies, examining potential **benefits and unintended consequences**