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Autonomous Vehicles and Safety of Vulnerable Road Users: A Systems Approach

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Walkability in the Connected and Automated Vehicle Era: A U.S. Perspective on Research Needs

Elizabeth Shay[*2], *Asad Khattak*[*1], *& Behram Wali*[*1]

**1 University of Tennessee, & *2 Appalachian State University*

- Mobility and Safety of Vulnerable Road Users

Mobility—mode share: walking accounts for 10%-12% of all trips

Safety—out of total of ~35,000 transportation fatalities annually
    ~5,000 peds
    ~800 bicyclists

- Walkability and CAVs—Premise

CAVs will reshape mobility and safety in ways we cannot know with certainty—but can reasonably anticipate will be important

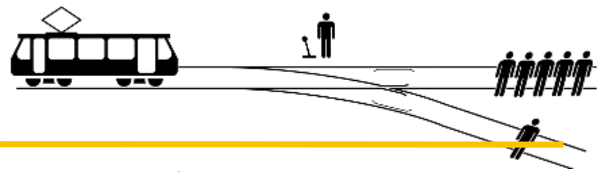
- Walkability and CAVs—Premise

CAVs will reshape mobility and safety in ways we cannot know with certainty—but can reasonably anticipate will be important

Walking (behavior) and walkability (environment) are key elements of sustainable systems—active, accessible, livable, efficient, safe, just

- Public demand for walkability—good for health, households, community
- Economic case for walkability—good for business, property values, growth
- But can CAVs (e.g., ride-hailing) take share away from walking?

- Walkability and CAVs—research issues



Source: Wikipedia

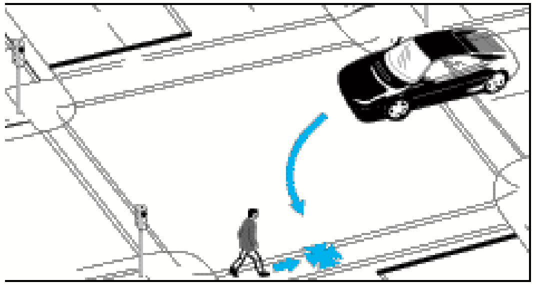
Brave new world? Entering new uncharted territory

- The "Trolley Problem": In unavoidable fatal crashes involving CAVs, will CAV passengers or pedestrians be sacrificed?
- How will CAVs respond to new and changing behavior by pedestrians who anticipate that CAVs will be programmed not to hit them?
    - How will non-CAVs react?

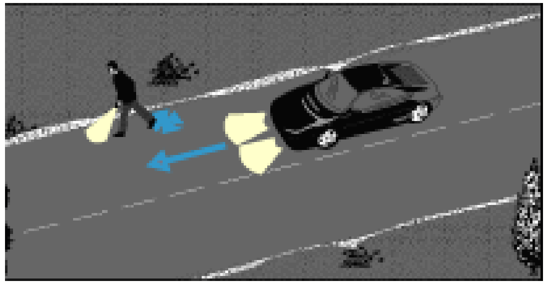
Out of scope: Cyber-security, insurance, attitudes toward automation, encouragement & enforcement

Pedestrian safety studies-FHWA-RD-95-163

Countermeasures:
- Provide exclusive pedestrian interval
- Illuminated No Turn on Red (NTOR) sign

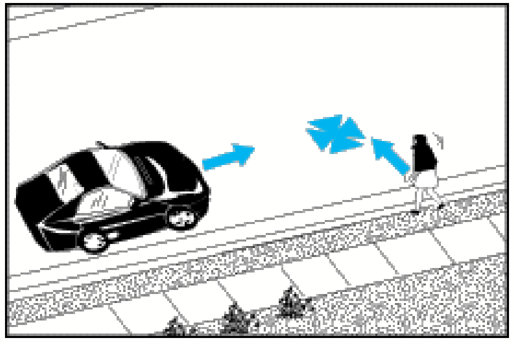


32.2%



7.0%

26.5%



▸ Countermeasure: Increase cycle length for pedestrian crossing

▾ Countermeasure: Install high-visibility crosswalk

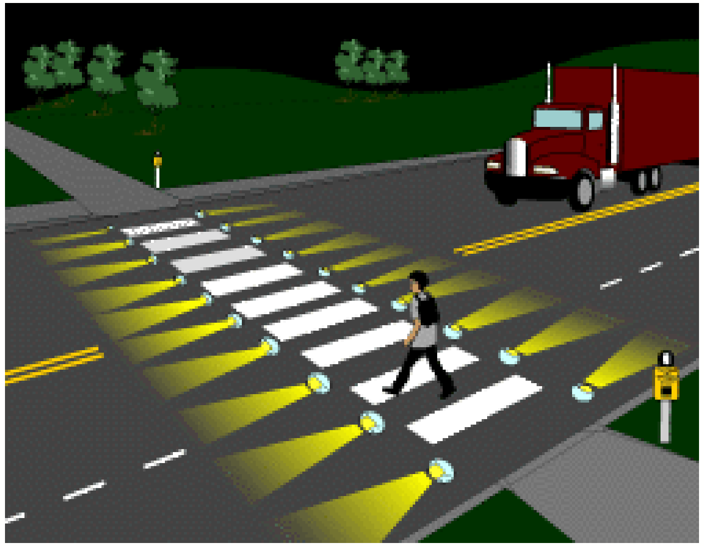
CMF	CRF(%)	Quality	Crash Type	Crash Severity	Area Type	Reference	Comments
0.6	40	★★☆☆☆	Vehicle/pedestrian	All	Urban	Li Chen, Cynthia Chen, and Reid Ewing, 2012	The treatment group included both ... [read more]
0.81	19	★★☆☆☆	Angle,Head on,Left turn,Rear end,Rear to rear,Right turn,Sideswipe	All	Urban	Li Chen, Cynthia Chen, and Reid Ewing, 2012	The treatment intersections included both ... [read more]

▸ Countermeasure: Install raised pedestrian crosswalks

▾ Countermeasure: Installation of a High intensity Activated crossWalK (HAWK) pedestrian-activated beacon at an intersection

CMF	CRF(%)	Quality	Crash Type	Crash Severity	Area Type	Reference	Comments
0.712	29	★★★★☆	All	All	Urban and suburban	Fitzpatrick, K., and Park, E.S., 2010	The authors of this study ... [read more]
0.849	15	★★★☆☆	All	Fatal,Serious injury	Urban and suburban	Fitzpatrick, K., and Park, E.S., 2010	The authors of this study ... [read more]

Pedestrians—only lightly covered in Highway Safety Manual



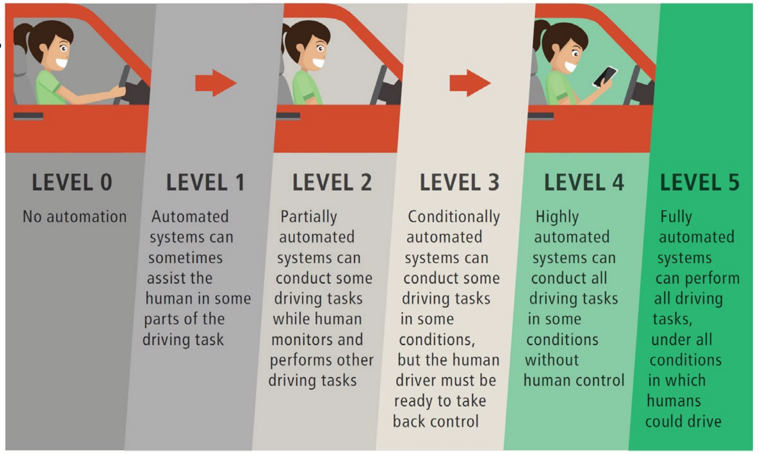
Pedestrians—lightly covered in ITS Architecture

- *Two new services for peds added in the ITS architecture*
- VS1 (veh safety) 2: Pedestrian and Cyclist Safety
  - Sensing and warning systems-interact with peds, cyclists, etc.
    - Warnings to VRU of possible infringement of crossing by approaching vehicles
    - SPaT-priority for people with **disabilities** needing additional crossing time
  - Integrates traffic, ped, and cyclist data from detectors & wireless devices (mobile phones) to request right-of-way or provide crossing info
- PT11: Transit Pedestrian Indication
  - "Vehicle to device" communications
  - Alerts peds of a transit vehicle & vice-versa, i.e., peds waiting for bus
  - Prevents transit-ped collisions

CAVs—Sandt & Owens, 2017

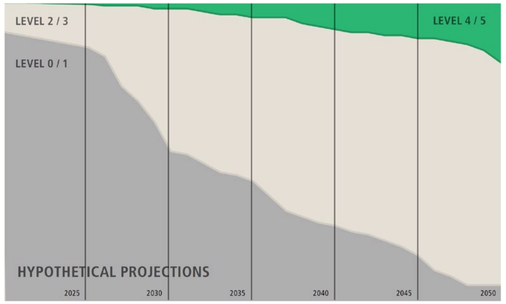
Issues

- Tech: Detection, V2P, Communication problems
- Infra: Right-of-Way, passing, speed problems
- Travelers: Pickup/drop off, mode shift, driver handoff problem
- Data problems-pre and post crash

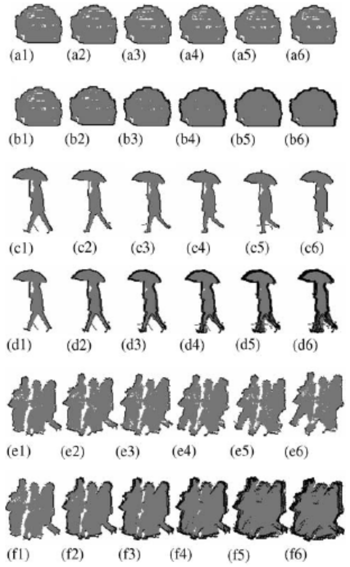


Stakeholders active in CAV R&D-

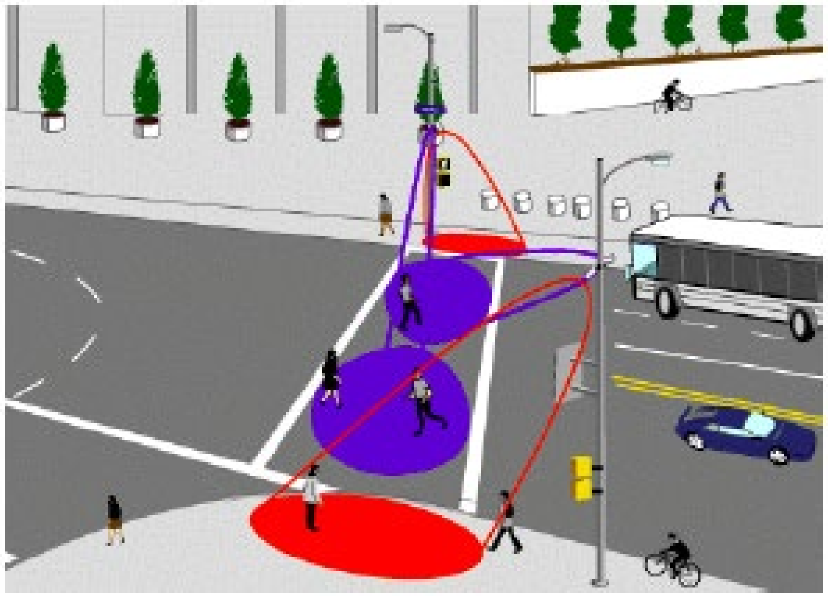
Collaborative & Open process



Detection problems & solutions—ML



Difficult—Cluttered situations



Sources: Journal papers & report

Transportation Research Record 1982

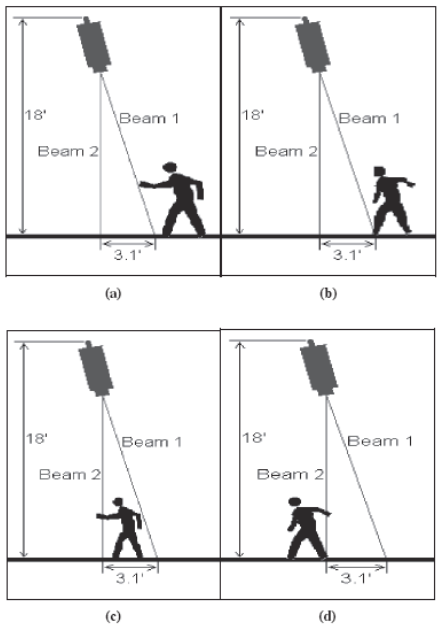


FIGURE 7 Pedestrian movement under the sensor.

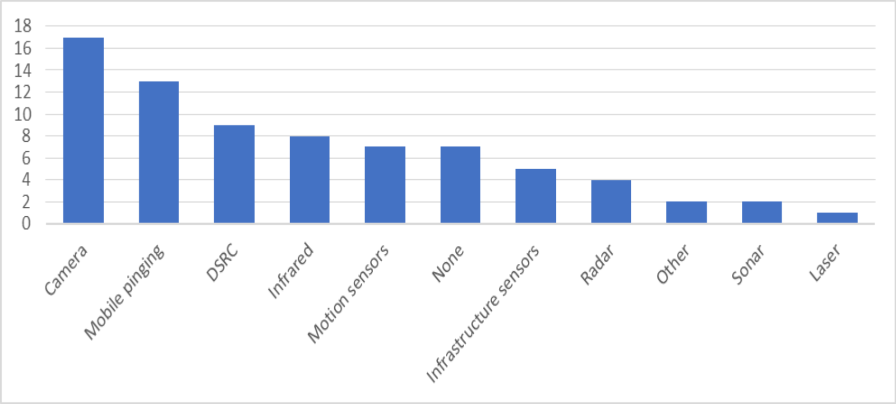
Sensing techs: Lidar-Radar, DSRC, LTE, Vision

V2P & P2V

- USDOT identified V2P techs→ Alert motorist by detecting ped with sensors
- Only some (~25%) techs alert peds

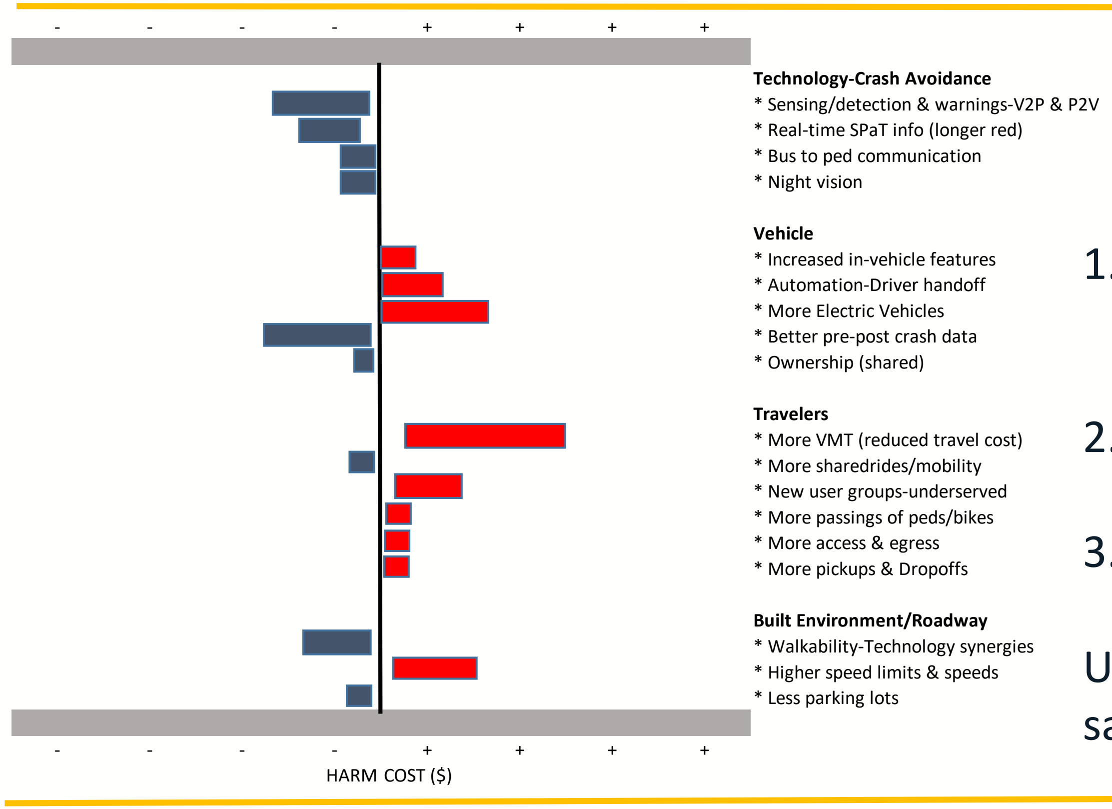
Research need: Framework to identify technologies for VRU crash reduction

Figure 3. Vehicle to pedestrian or bicyclist technologies (V2X) could aid in detection of and communication with pedestrians and bicyclists, but an array of technology and equity issues must still be addressed.



Sources: Sandt & Owens; Azad

What safety gains from CAVs may be expected for peds?



1. Mechanisms for automation→ Harm = Σ Crash Costs
2. Literature: Mechanism → Estimates of safety impacts
3. (Hypothesis—for illustration)

Uncertain—Will CAVs increase safety?

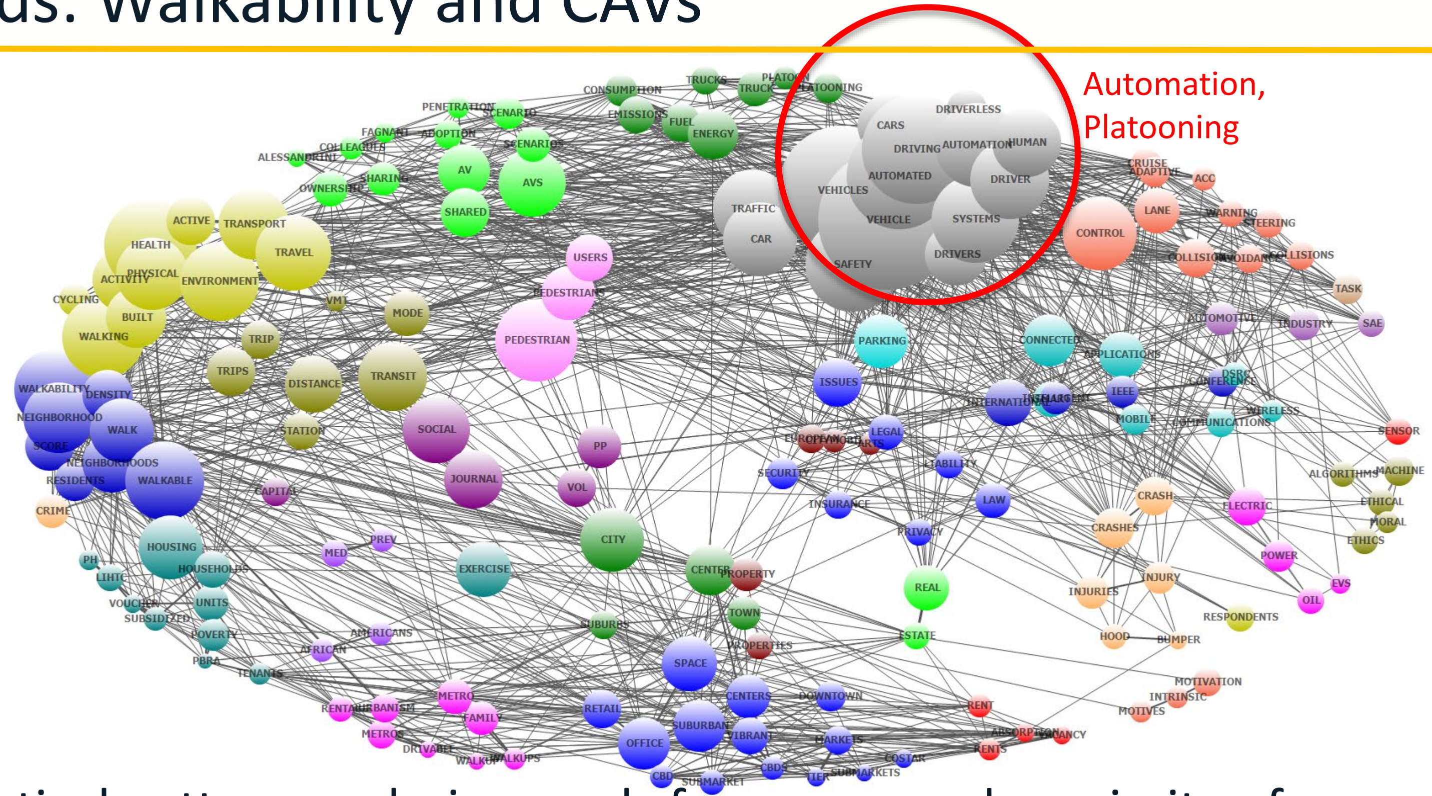
Walkability and CAVs—Literature review

Controlled keyword search
- 4 knowledge bases—TRID, ScienceDirect, Web of Science, Google Scholar
- 14 terms relating broadly to CAVs and safety
- generated >400 sources

Deeper look at subset of 82 sources relating explicitly to walkability

Text analytics performed on 70 peer-reviewed papers and technical reports

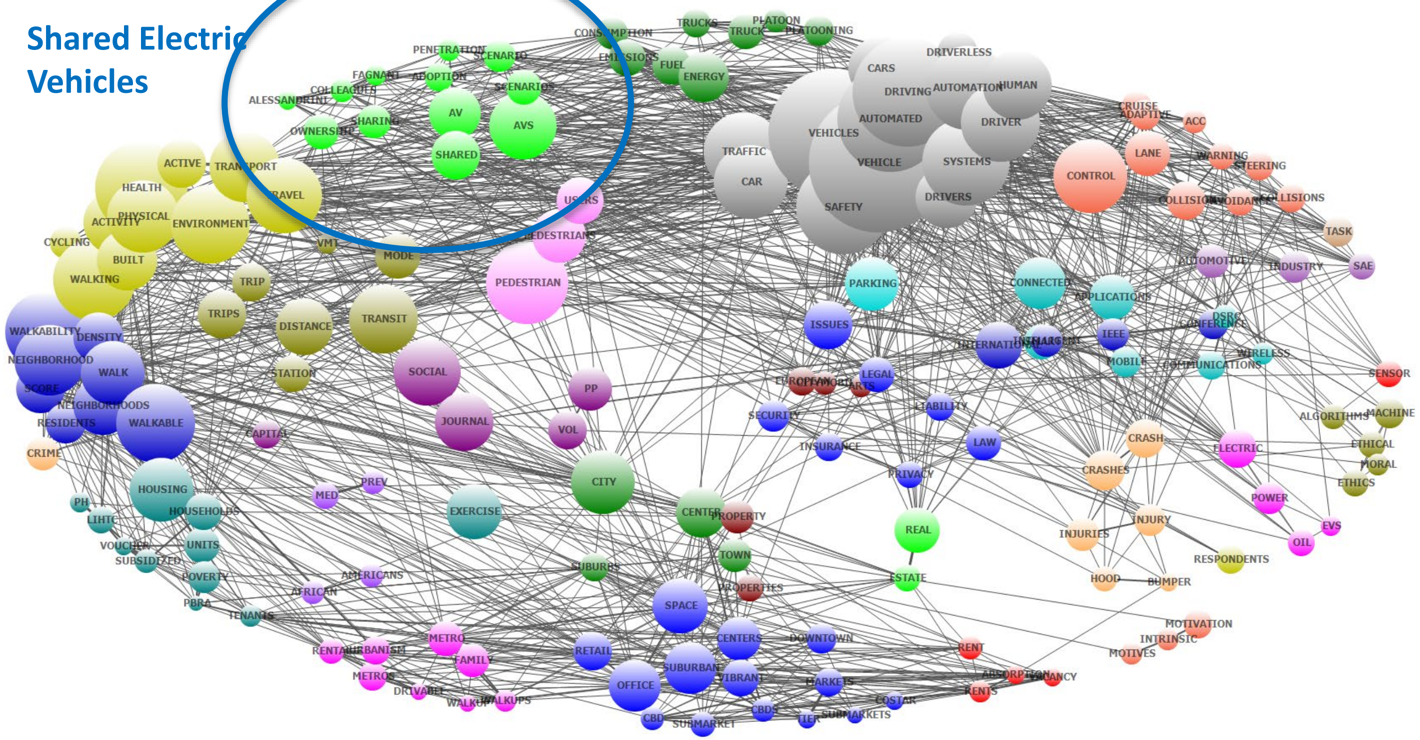
Trends: Walkability and CAVs



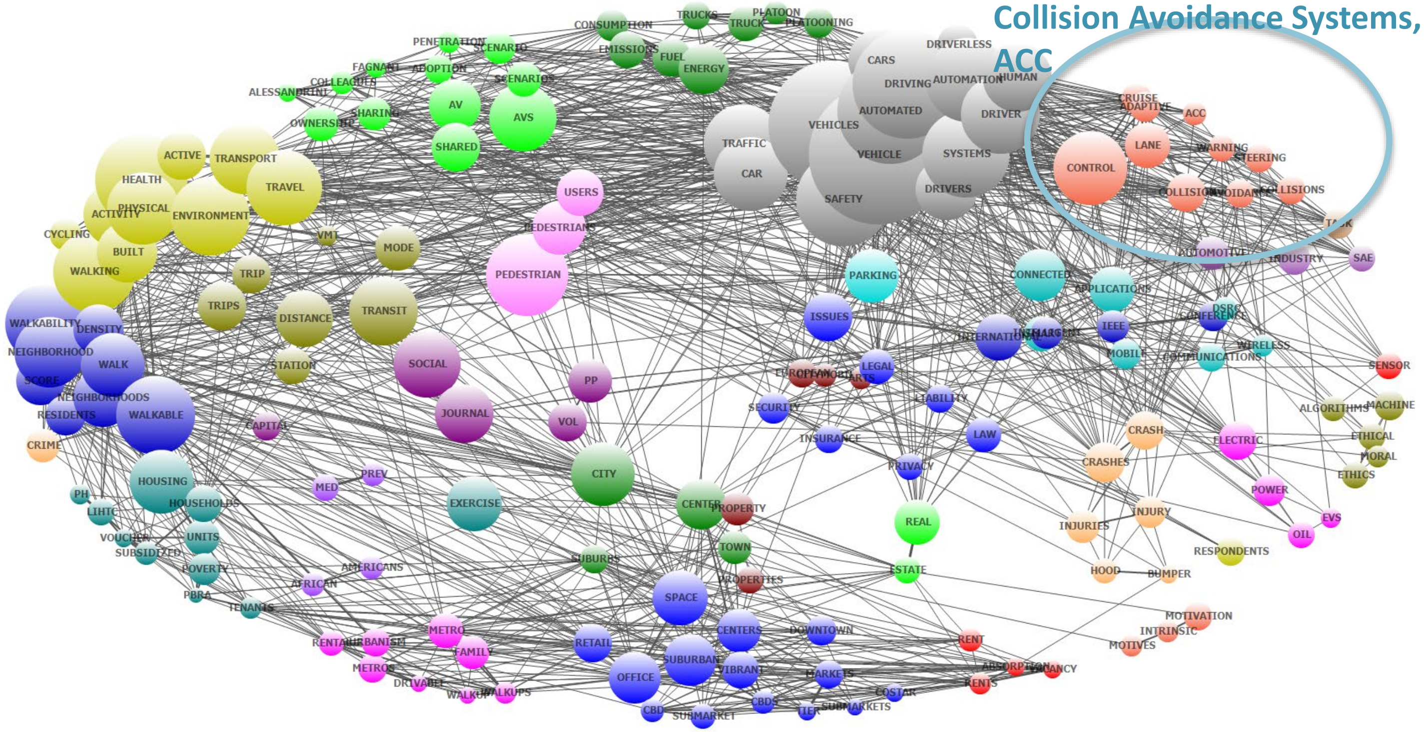
Statistical pattern analysis reveals frequency and proximity of concepts

Trends: Walkability and CAVs

Shared Electric Vehicles



Trends: Walkability and CAVs



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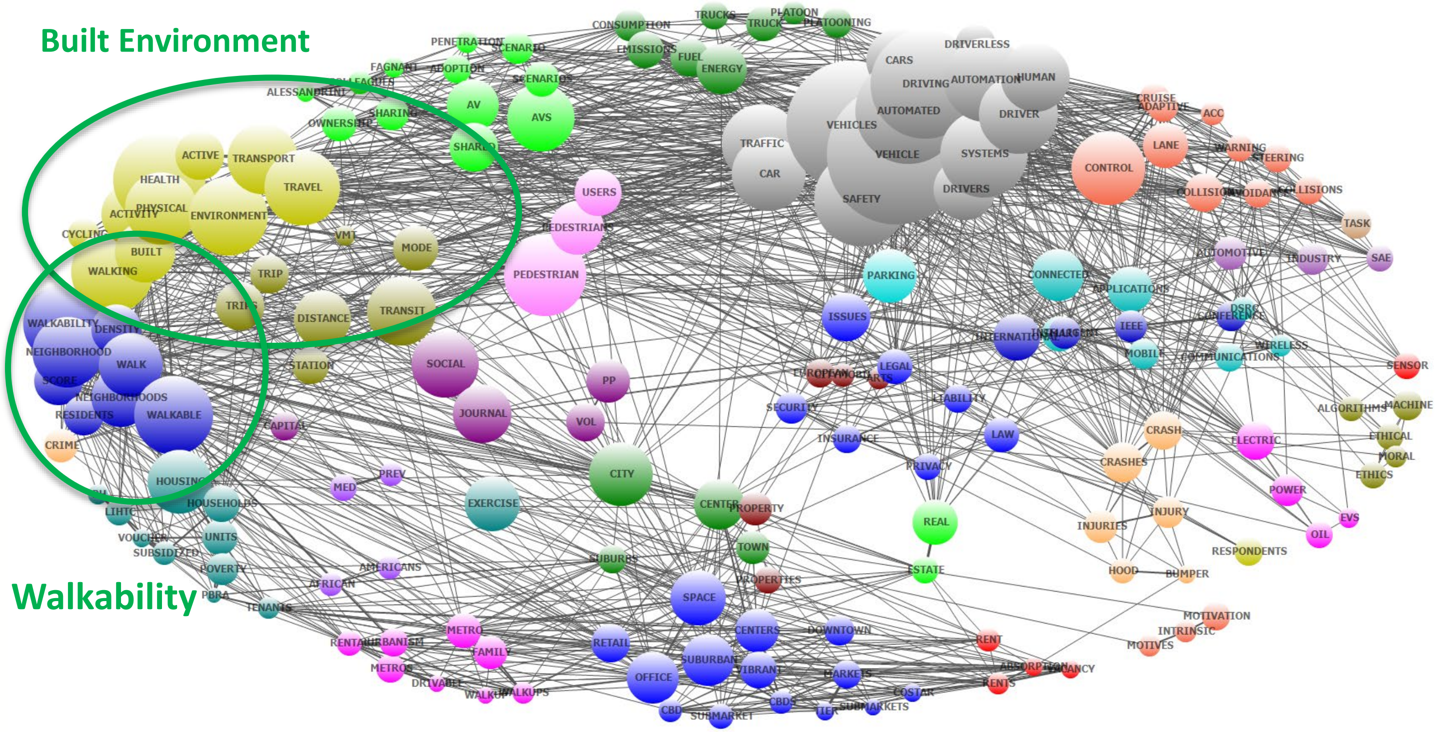
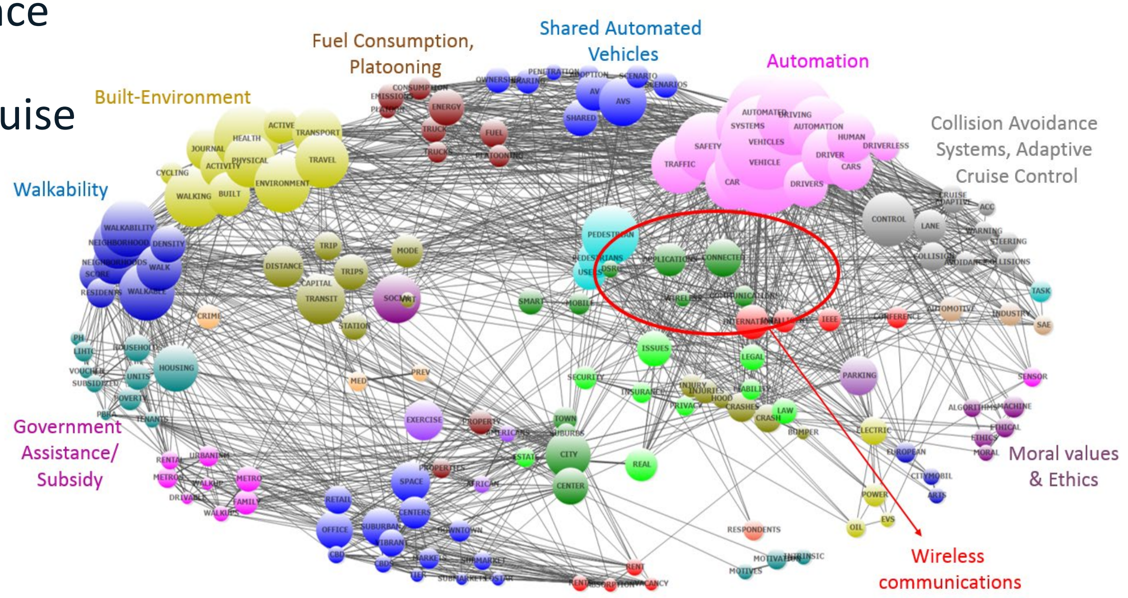
Trends: Walkability and CAVs



• Walkability and CAVs—Text analytics

Major themes to emerge:
- Automation-collision avoidance
- Communication/connectivity
    - Platooning & Adaptive Cruise Ctrl
- Shared & electric vehicles
- Walking/built environment
- Moral & ethical issues



Key Topics – Text Analytics

Broader Category	Topic	Keywords	Eigen-value	% Variance	Frequency	Cases	% Cases
Technology & Applications	Wireless Communications; Mobile Applications	Applications; Communications; Wireless; Mobile; Connected; Dedicated Short Range Communication; Smart	2.01	1.21	878	47	67.14%
	Adaptive Cruise Control; Controls	Cruise; Adaptive; Adaptive Cruise Control; Control; Lane	1.89	1.41	1627	59	84.29%
	Collision Avoidance Systems	Collision; Avoidance; Warning; Collisions	1.80	1.23	2868	63	90.00%
Safety	Pedestrian Injuries; Bumper	Bumper; Injuries; Hood; Injury; Crashes; Pedestrian; Crash	2.27	1.24	1363	57	81.43%
	Safety	Pedestrians; Users; Pedestrian; Traffic; Drivers; Safety	1.38	1.06	467	26	0.3714

- Walkability and CAVs—research directions

Three decades into paradigm shift toward walkable livable environments:

May CAVs threaten this progress by shifting walkers to other modes?

Might CAVs enhance gains in walkability?

What responsibility for safety should pedestrians have in CAV era?

Will space-efficient CAVs reduce traffic congestion and parking demand, and allow reallocation of liberated ROW?

- Walkability and CAVs—research directions

Parties to discussion about CAVs, walkability, walking—and larger concerns about safety and vulnerable road users

Academia

Public sector agencies

Private sector leaders

Manufacturers—vehicles, infrastructure, software/hardware

Forums needed for deliberation and debate…

Thank you!

Shay, Khattak & Wali, TRB 2018: 'Walkability in the connected and autonomous vehicle era: A US perspective on research needs'

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Limitations in Detection Technologies for Automated Driving Systems and Implications for Pedestrian Safety

Tabitha Combs, PhD[1]
Laura Sandt, PhD[2]
Michael Clamann, PhD[3]
Noreen McDonald, PhD[1]

Paper 18-03947
TRB 97th Annual Meeting
Jan 10, 2018
Washington, DC

[1]University of North Carolina Dept. of City & Regional Planning
[2]University of North Carolina Highway Safety Research Institute
[3]Duke University Pratt School of Engineering

Introduction

Motivation

Recent increases in US pedestrian fatalities

Rapid gains in autonomous-driving technology → rising expectations for near-term 'self-driving future'

Claim: replacing fallible human drivers with autonomous driving systems → substantial reductions in pedestrian deaths

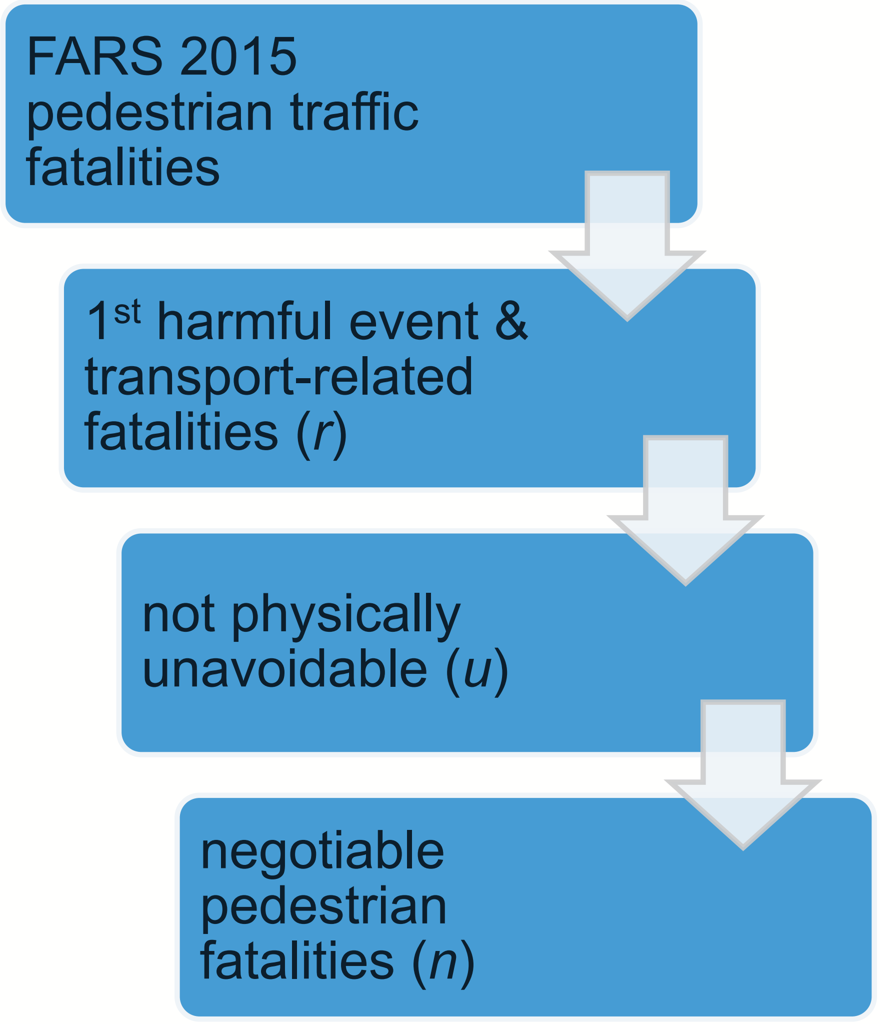
But technology to *detect* pedestrians pre-crash is far from perfect!

Introduction

Research Question	Would **perfectly automated vehicles equipped with state-of-the-art pedestrian detection technology** have been capable of pre-crash detection of pedestrians in real-life, fatal crashes?
Findings	**Wide** range in virtual performance of hypothetical pedestrian sensors In theory, AVs have potential to dramatically reduce pedestrian fatalities, but **not** in the near future and **not** without critical caveats

Methods

1. Identify ‘negotiable’ fatalities



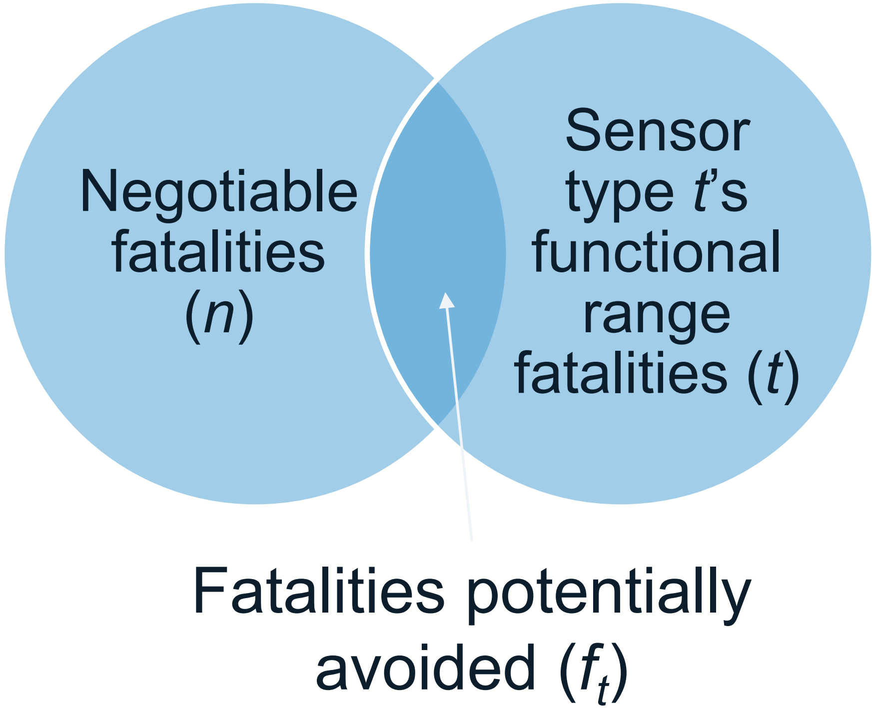
Methods

1. Identify ‘negotiable’ fatalities
2. **Determine functional ranges of available sensor types**

	Sensor Type			
Crash condition	Optical camera	LiDAR	Camera + LiDAR	Camera + LiDAR + Radar
Dark/low-light	✗	✓	✓	✓
Fog/ precip.	✗	✗	✗	✓
Reflective surfaces	✗	✗	✗	✓
Close-range pedestrian	✓	✗	✓	✓
Stationary pedestrian	✓	✓	✓	✓

Methods

1. Identify 'negotiable' fatalities
2. Determine functional ranges of available sensor types
3. **Calculate overlap**



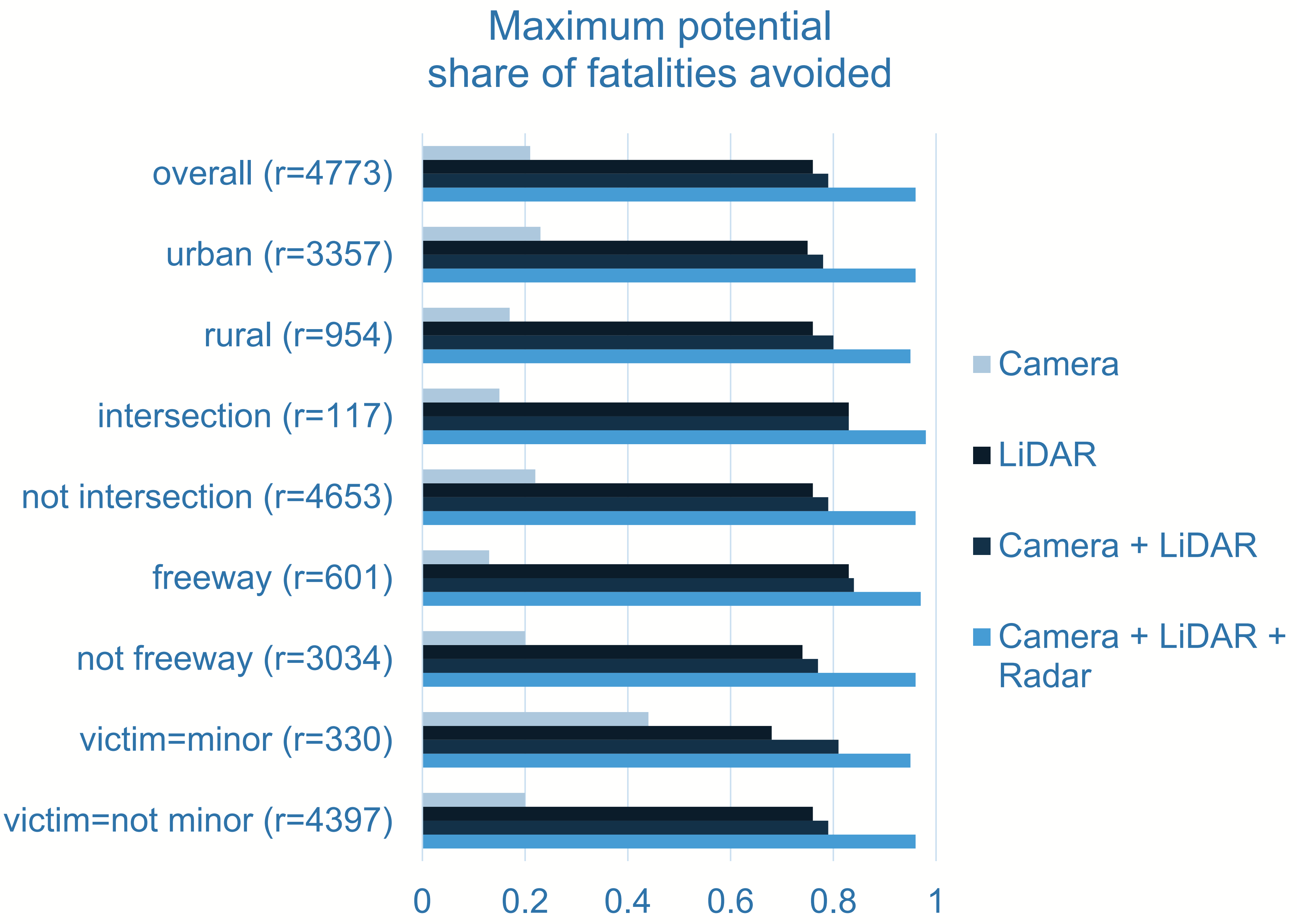
f_t / r = Maximum Potential Share of Fatalities Avoided

Findings

- **Fatalities**
  - 4,773 transport-related fatalities (*r*)
  - 130 unavoidable (*u*); 4,643 negotiable (*n*)

Conditions of negotiable fatalities	No good for…
76% dark/low-light	cameras
10% fog/precipitation	cameras, LiDAR
14% reflective surfaces	cameras, LiDAR
10% close-range pedestrians	LiDAR
6% stationary pedestrians	radar

Findings


Maximum potential
share of fatalities avoided
overall (r=4773)
urban (r=3357)
rural (r=954)
intersection (r=117)
not intersection (r=4653)
freeway (r=601)
not freeway (r=3034)
victim=minor (r=330)
victim=not minor (r=4397)
0
0.2
0.4
0.6
0.8
1
Camera
LiDAR
Camera + LiDAR
Camera + LiDAR + Radar

Conclusions

- **Choice of technology matters**

Cameras: narrow functional range captures few fatalities

LiDAR: decent performance with most likely potential for improvement

Radar: appears to perform best, but has crucial weaknesses

Conclusions

- Choice of technology matters
- Assumptions also matter

- Vehicles fitted with best available sensor tech—regardless of cost
- Perfect signal interpretation, perfect automation, perfect vehicle performance
- Fatality-avoiding evasive action exists
- Use of tech does not pose other challenges or health risks
- Pedestrian-vehicle interaction behavior does not evolve
- No discrepancies in deployment

Conclusions

- Choice of technology matters
- Assumptions also matter
- Takeaways

- Assuming improvements in affordability of sensor tech…AVs hold promise for reducing pedestrian fatalities over the long term, however:
- sensor fusion is necessary
- AVs never likely to be silver bullet
- In the near term: complementary approaches to improve pedestrian safety and mobility are still critical!

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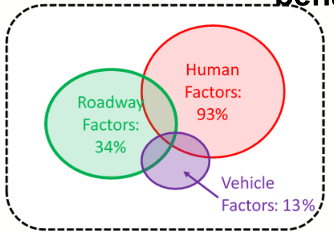
Analysis of Crashes Involving Pedestrians across the United States: Implications for Connected and Automated Vehicles

Meng Zhang [*1], *Asad Khattak* [*1], *& Elizabeth Shay* [*2]

**1 University of Tennessee, & *2 Appalachian State University*

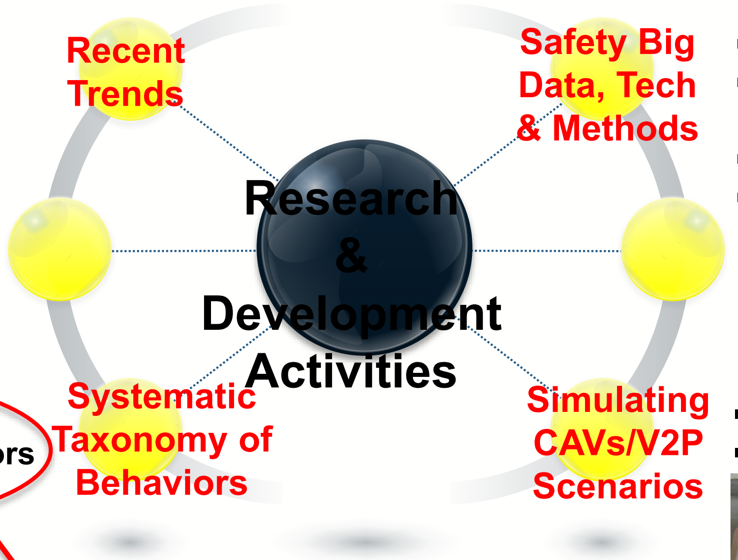
Introduction - CAVs and vulnerable road users

- CAVs & Walkability
- Ped safety & behavior



- National perspective
- Pre-crash behavior & errors
- Human-error typologies

	Fatal	Non-fatal
Pedestrian	12,203	14
Driver	33	12,184



- Knowledge base
- Ped-bike pre-incident maneuvers
- Crash/Near-crash/Baseline-NDS
- Crash distributions across US

- Virtual reality data
- Scenarios

Research Issues

- ~5,000 pedestrian deaths/year
- Assessment of future pedestrian-vehicle conflicts
- Current single vehicle-pedestrian fatal crashes across the U.S.
- Focus: Pedestrian & driver pre-crash actions

Source: Google image

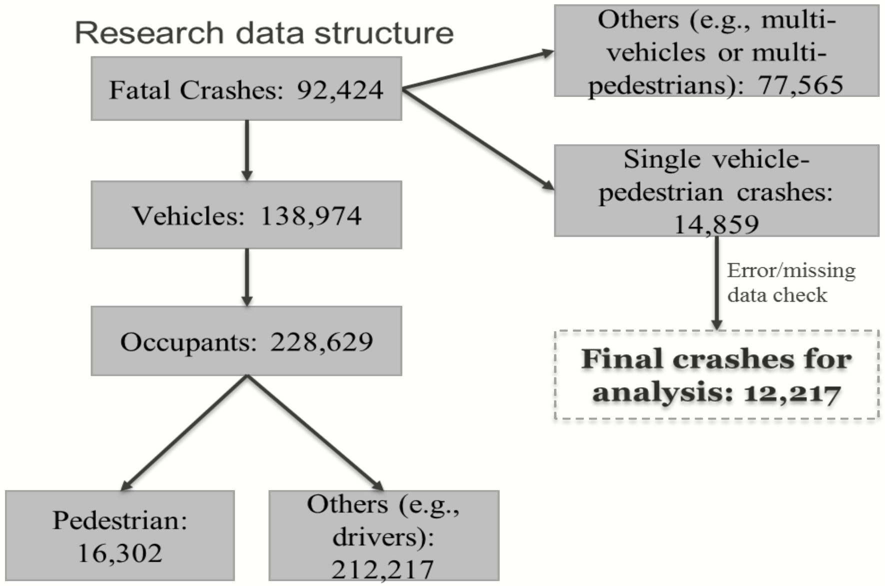
Data Sources

Fatality Analysis Reporting System (FARS)

- **2013 - 2015**
- **Crash type = Single vehicle-pedestrian fatal crashes**

Integrated with county level census data

→Unique database



Data structure in FARS (2013-2015)

Conceptual framework

Single vehicle-ped fatal crashes:
N=12,217

Clustered at County level (N=3,143)

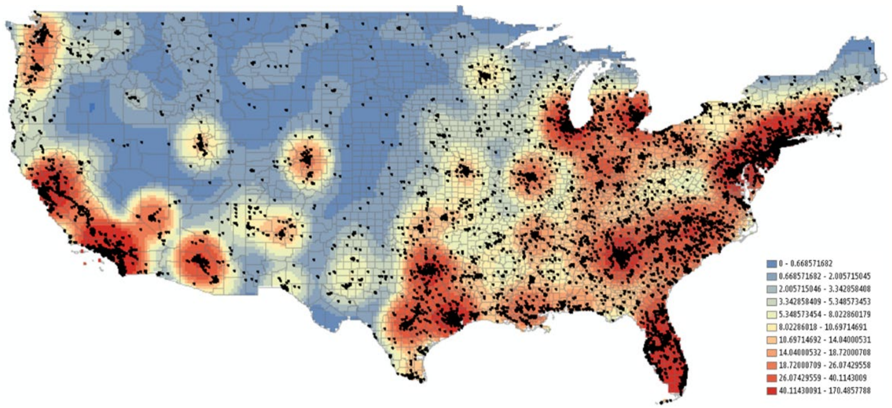
Key correlates:
- Pedestrian behavior
  - Dart out
  - Improper X-ing
  - Inattention…
- Driver behavior
  - Reckless…

County census data:
N=3,143

Control Variables:
- Education level
- Household income
- Poverty level
- Population density

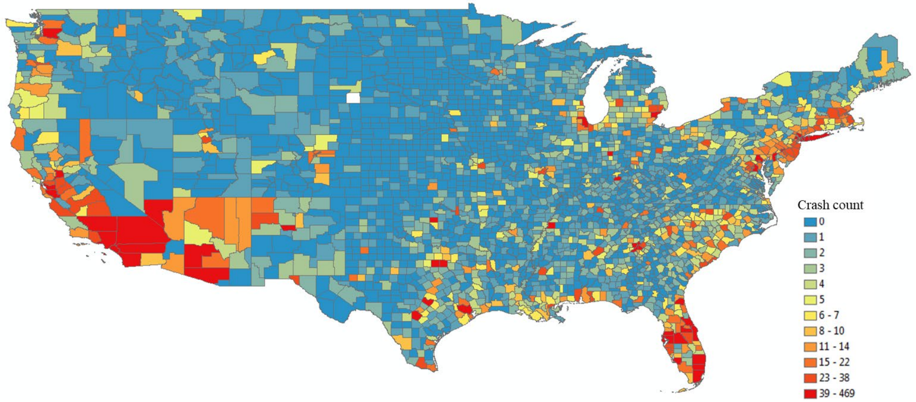
Crash outcomes:
- Fatal crash frequency at county level

Distribution of ped-driver fatal crashes



a) Kernel density distribution (N=12,217)

Geographically Weighted Poisson Regression (GWPR)



b) Distribution of crash frequency at county level (N=3,143)

Poisson vs. GWPR model

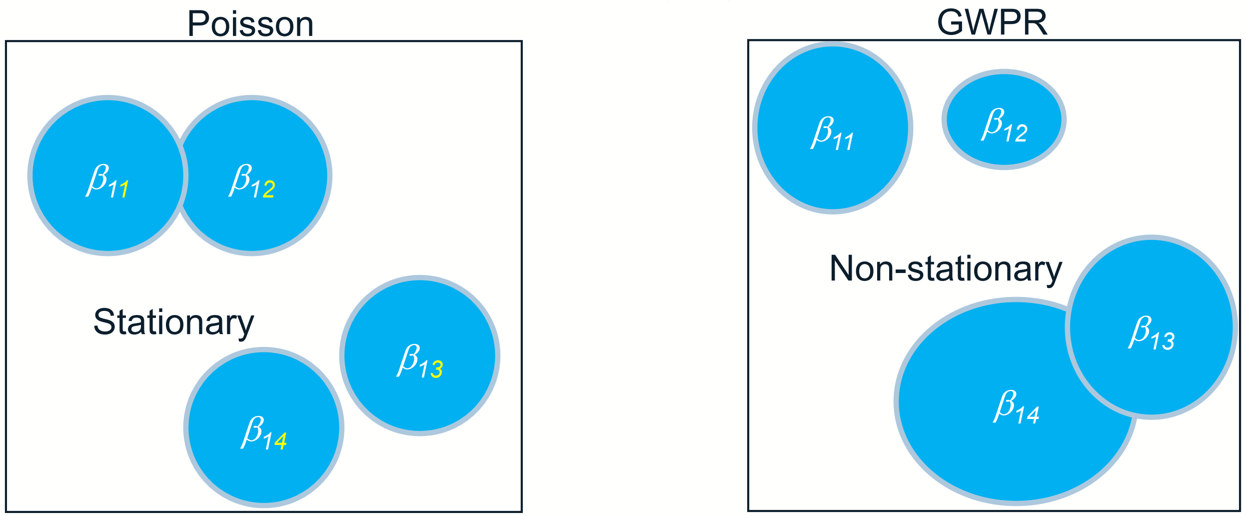
Poisson: $ln(Y) \sim \sum \beta_j \cdot X_j$

GWPR: $ln(Y) \sim \sum \beta_{ji} \cdot X_j$

Location 1,2,3,4

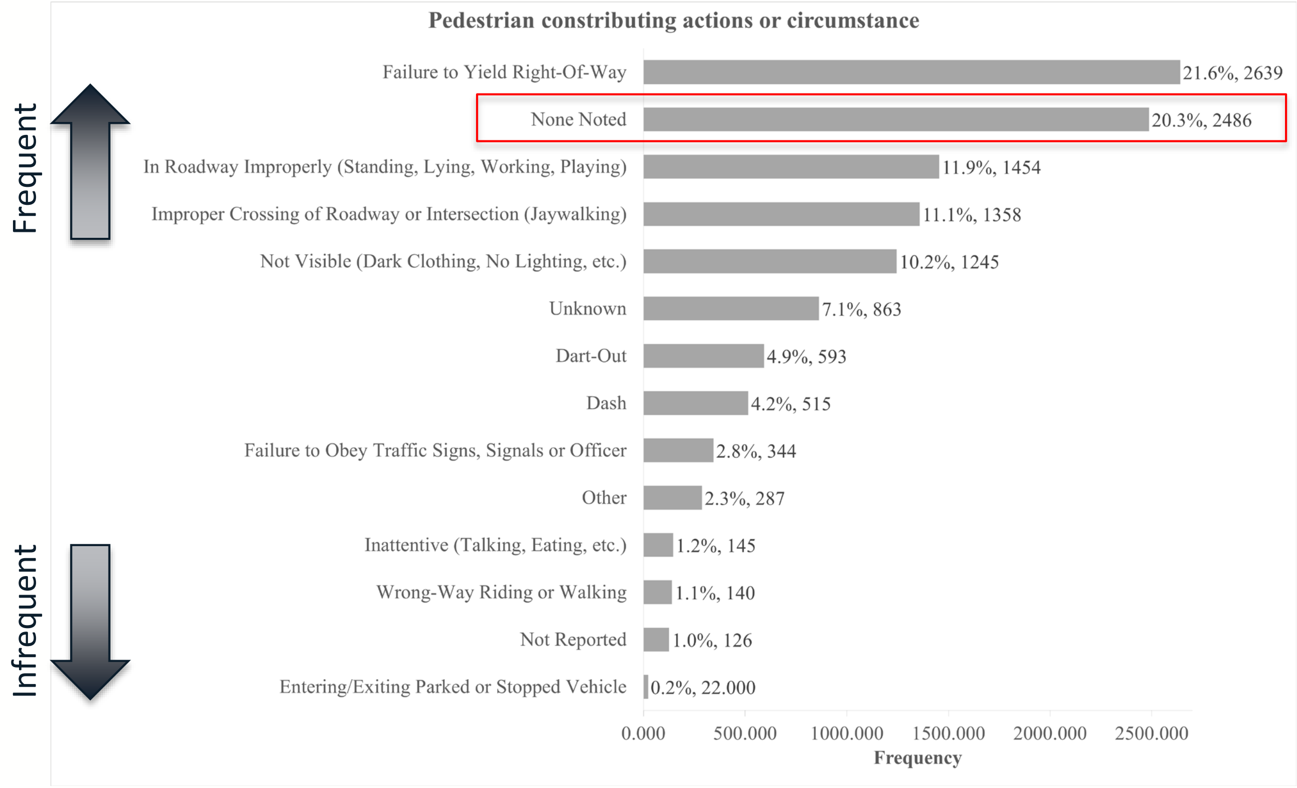
β = Coefficients for variables

X = Independent variables, e.g., pre-crash behavior



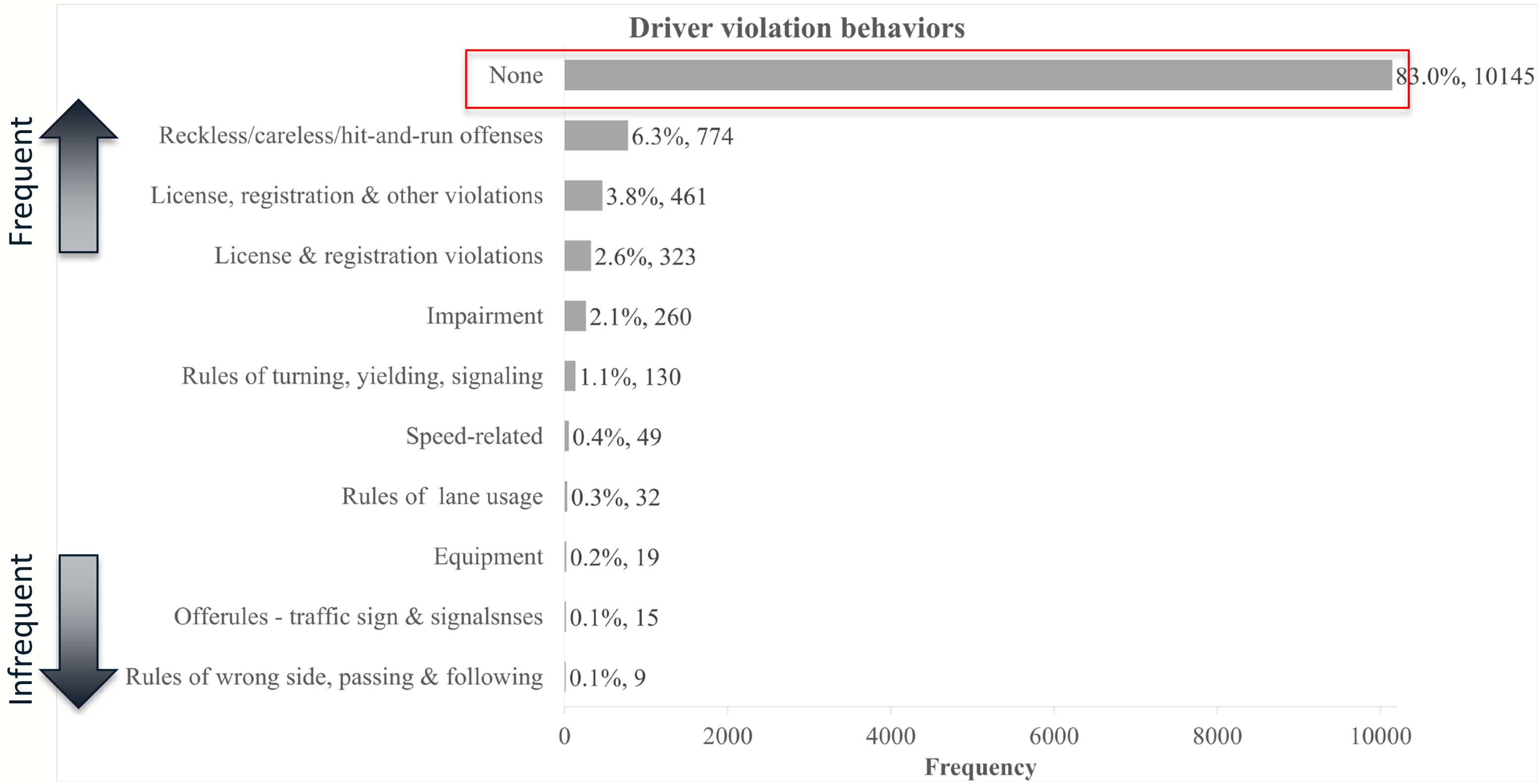
Spatial Heterogeneity

Results - Distribution of ped behaviors



Note: The percentages are added to 100% (N=12,217).

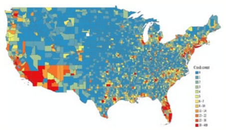
Results - Distribution of driver behaviors



Note: The percentages are added to 100% (N=12,217).

Results - Selected variables

	Variables	N	Mean	Std. Dev.	Min	Max
Crash frequency/rate	Crash frequency	3143	3.887	15.604	0	469
	Crash rate by county population (/1000)	3143	0.030	0.053	0	1.069
	Crash rate by county population density	3143	0.040	0.209	0	5
Pedestrian pre-crash behavior*	Dart out/ Dash	3143	0.353	1.415	0	30
	Failure to obey traffics signs	3143	0.109	0.807	0	23
	In roadway improperly (standing, lying, walking)	3143	0.463	1.494	0	23
	Inattention (talking, eating)	3143	0.046	0.291	0	8
	Improper crossing (jaywalking)	3143	0.432	2.809	0	104
	Invisibility (dark clothing, no light)	3143	0.396	1.192	0	16
Driver pre-crash behavior*	Reckless	3143	0.246	1.067	0	21
	Impairment	3143	0.083	0.483	0	11
	Rules of turning/yield	3143	0.041	0.361	0	14
	License/registration violation	3143	0.103	0.669	0	17



Note: These behaviors are shown at the aggregated county level.

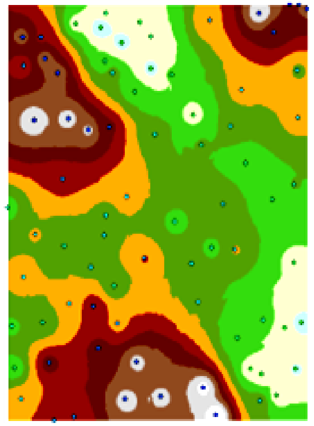
Results - GWPR vs. Poisson model

Variables		Poisson model β	Local GWPR model β Min	β Max	Lwr Quartile	Upr Quartile	Upr-Lwr > 2SE
Pedestrian pre-crash behavior	Dart out/ Dash	0.138	0.007	0.4	0.169	0.253	TRUE
	Failure to obey traffics signs	-0.166	-2.36	0.17	-0.953	-0.099	TRUE
	In roadway improperly (standing, lying, walking)	0.11	0.089	0.66	0.198	0.421	TRUE
	Inattention (talking, eating)	0.048	-	-	-	-	-
	Improper crossing (jaywalking)	-0.034	-	-	-	-	-
	Invisibility (dark clothing, no light)	0.159	-	-	-	-	-
Driver pre-crash behavior	Reckless	0.136	-	-	-	-	-
	Impairment	0.001	-	-	-	-	-
	Rules of turning/yield	-0.245	-	-	-	-	-
	License/registration violation	0.075	-	-	-	-	-
Statistic summary		N=3,143 Prob. > χ^2=0.00 R^2=0.619 AICc=24,503*	Best bandwidth = 166 R^2=N/A, percent deviance explained: 0.673 AICc=14,621				

: Negative correlation
: Positive correlation
: Non-significant at 95% level

Note: "TRUE" means the significance of spatial variance of the coefficient
*: The AICc is reported for Poisson model with the three selected variables

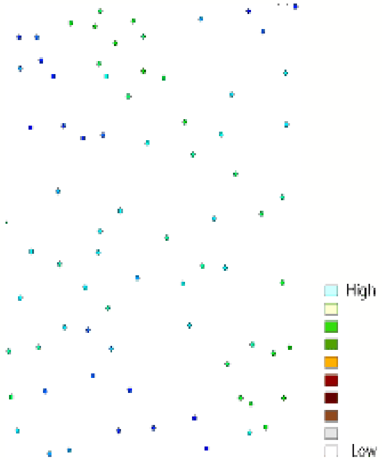
Spatial interpolation

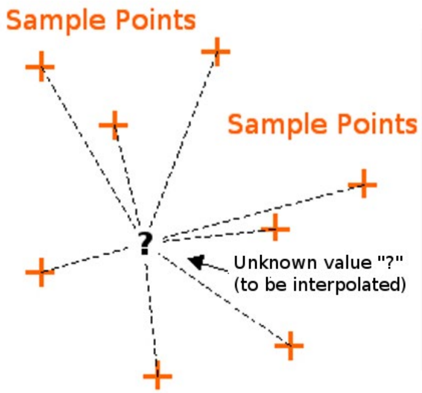


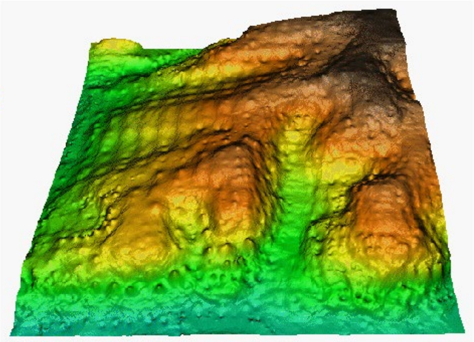
Contour parameter map

Interpolate coefficients to create coefficient surface

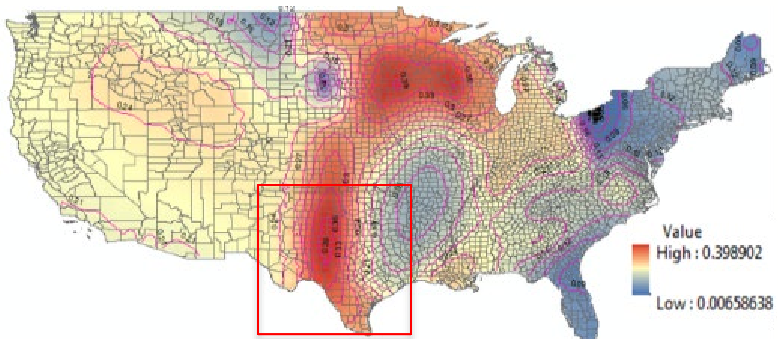
IDW- Inverse distance weighted (IDW) interpolation



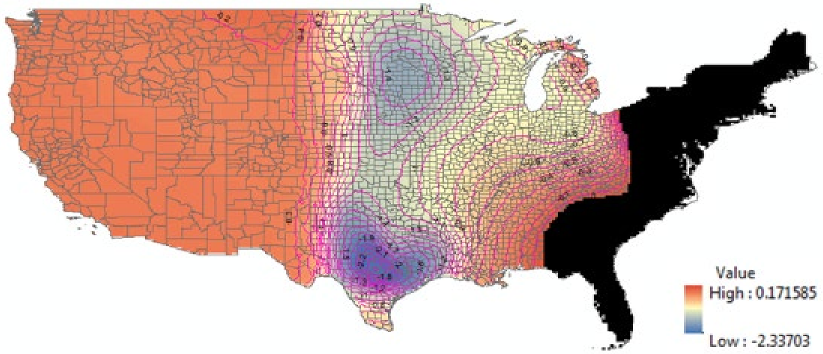




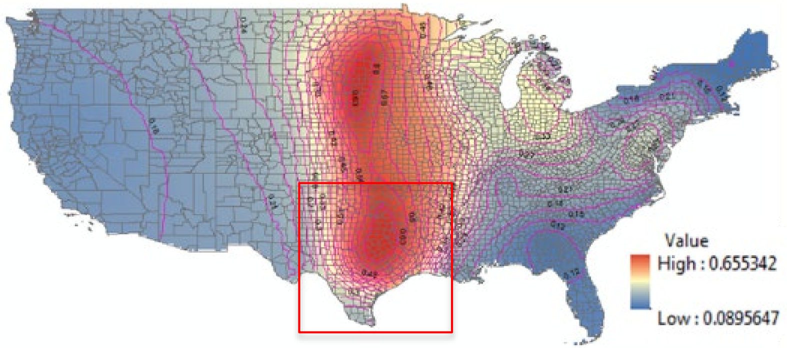
Local parameter estimates



a) Dash/Dart out



b) Failure to obey traffics signs



c) In roadway improperly (standing, lying, walking)

Local parameter estimates for single vehicle-pedestrian fatal crashes

Note: Black areas indicate that local parameter are not statistically significant at 95% level in that region

Closure

- Key contributors to pedestrian involved fatal crashes
  - Dart-out/Dash, Failure to yield right of way, Improperly present at roadway, Dark clothing/Not visible…
  - Method is scalable to other injury levels
- Substantial variations in pedestrian behavior across regions
  - Systematically accounting spatial heterogeneity
    - Better identification of hazardous areas & correlated behaviors
    - Develop context-sensitive countermeasures → Local policy
  - Results helpful in designing field tests for CAVs in specific areas
- Implications and research needs
  - V2P testing needed in diverse environments
  - Predicting ped-driver trajectories
  - Night vision
- Key Limitations
  - Accuracy
    - Location, police report

Future research - VR simulation-V2P coordination

- Decentralized algorithms
- VR testing platform
- Access to high quality data