Collaborative Sciences Center for ROAD SAFETY

Safe Systems Summit

Redefining Transportation Safety

Enhancing Multi-modal Mobility in the Central Florida Region with a Complex Systems Approach

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UCF

Motivation

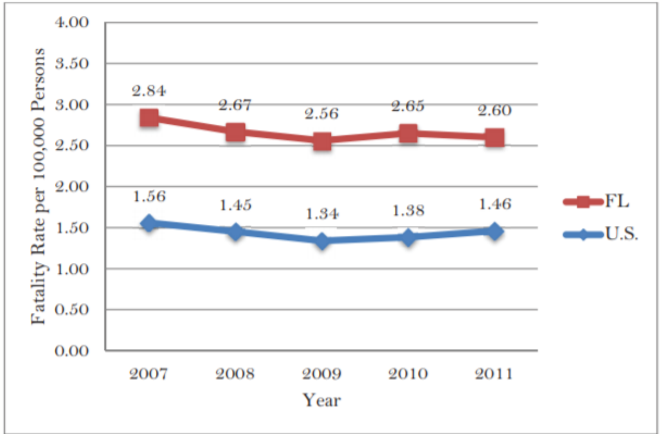
- Current paradigm of travel demand models in US are geared towards auto oriented mobility analysis
- In recent years, Florida is moving towards improving mobility by improving multimodal connectivity
- Several investments in non-auto alternatives have been made in recent years in the Central Florida region
  - SunRail
  - Juice bike system
  - Adding bicycle lanes to roadways
- With this growing emphasis in Florida's urban regions on non-auto mobility, we need methods that accommodate the potential adoption of non-auto modes within the planning process

Motivation

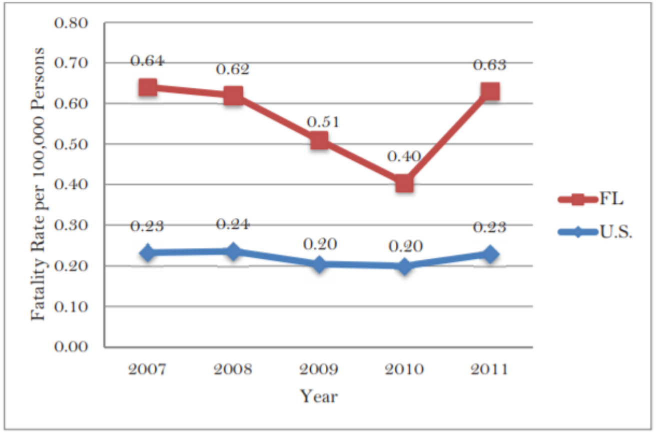
- We examined mobility factors influencing the non-auto modes
  - Pedestrian
  - Bicyclist
  - Transit
- For pedestrian and bicyclist modes, we developed framework to evaluate mobility and safety outcomes
- For transit, we developed ridership models for Lynx and SunRail systems
- In this presentation, we focus on the non-motorized trnasprotation component.

Motivation

- Safety risk posed to active transportation users in Florida is significantly higher compared to rest of the US
- Average pedestrian (bicyclist) fatalities per 1000 population is 2.56 (0.68) for Florida whereas for US it is 1.50 (0.24)



Pedestrian fatality rate per 100,000 population



Bicycle fatality rate per 100,000 population

Motivation

- Improving safety for non-motorists needs to be pro-actively addressed at the planning level
- The planning analysis is typically based on developing Crash frequency models and Crash severity models
- Crash frequency models focus on identifying attributes that result in traffic crashes and propose effective countermeasures to improve the roadway design and operational attributes
- Crash severity models focused on examining crash events, identifying factors that impact the crash outcome and providing recommendations to reduce the consequences in the unfortunate event (injuries and fatalities) of a traffic crash

Motivation

Literature in Non-motorized Safety

Crash Prediction Model

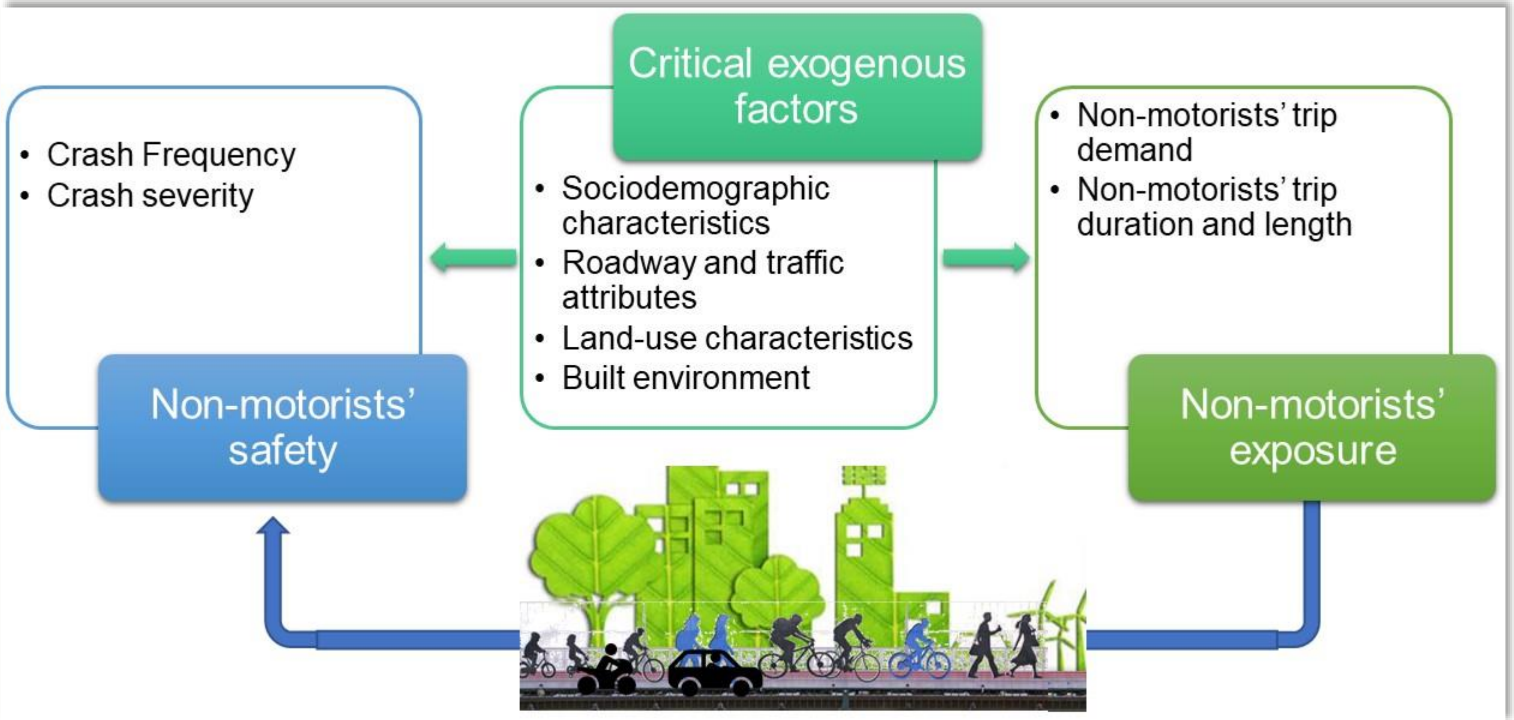
Crash frequency analysis → Quality Affected ← **Crash severity analysis**

Lack of true non-motorized exposure data

Motivation

- Non-motorized exposure is an important determinant in crash models
  - Pedestrian and bicycling volumes
- However, rarely do we have accurate non-motorized exposure for consideration in crash models
- With growing non-motorized modes investments – there is growing emphasis on studying the influence of these investments in increasing non-motorized activity and the corresponding safety outcomes
- To assess how recent investments in non-motorized transportation are influencing non-motorized mobility and safety, it is important to develop non-motorized demand prediction models
- High-resolution modeling frameworks such as activity-based or trip-based approaches could be pursued for evaluating planning level non-motorist demand.
  - Travel demand models focus on generating vehicular demand (for automobile and transit).
  - Non-motorized demand is rarely considered

Research Approach



Research Approach

- Integrated framework of non-motorized demand and safety
- 3-step approach proposed

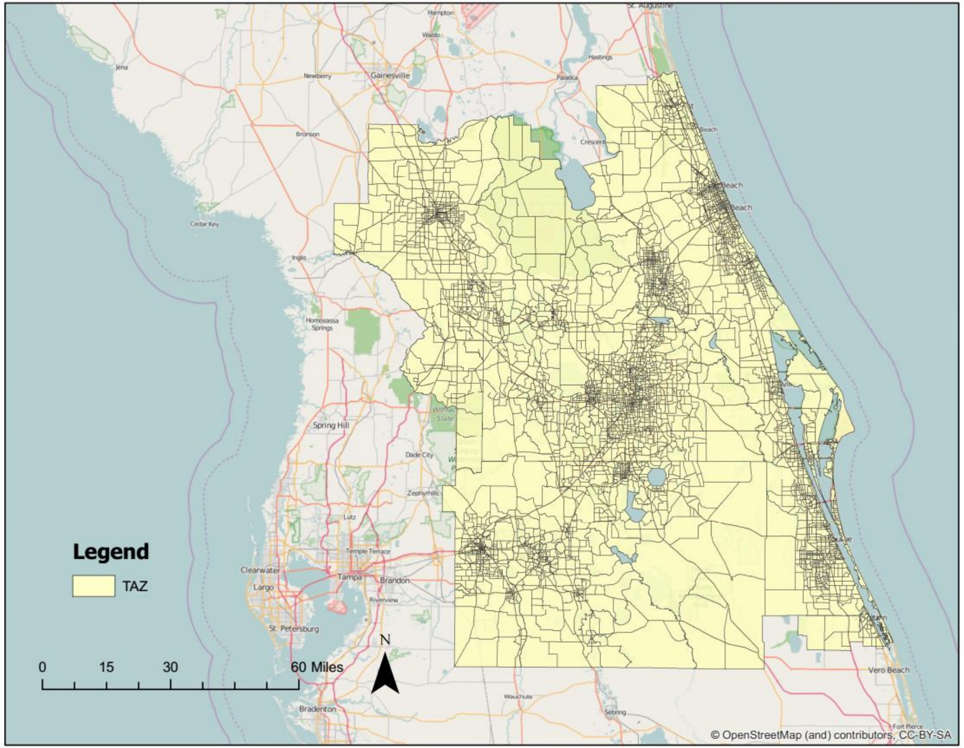
Research Approach

- Non-motorists demand is estimated at a zonal level by using aggregate trip information
- We develop four models:
  - Pedestrian generation model – based on zonal level pedestrian origin demand
  - Pedestrian attraction model – based on zonal level pedestrian destination demand
  - Bicycle generation model – based on zonal level bicycle origin demand
  - Bicycle attraction model – based on zonal level bicycle destination demand

Research Approach

- Predicted origin and destination trip counts are used from the exposure models to generate different zonal level trip exposure matrices for both pedestrian and bicycle modes to be considered as non-motorists exposure measures for safety evaluation.
- We estimate non-motorists safety models by employing predicted exposure matrices, generated from second step, along with other zonal attributes.
  - Zonal-level crash count model for examining pedestrian-motor vehicle crash occurrences
  - Zonal-level crash count model for examining bicycle-motor vehicle crash occurrences
  - Zonal-level crash severity model for examining pedestrian crash injury severity by proportions
  - Zonal-level crash severity model for examining bicycle crash injury severity by proportions

Study Area



- ❑ CFRPM v6.0
- ❑ 4,747 TAZs (Traffic analysis zones)
- ❑ 9 counties
- ❑ District 5, part of District 1 and 4
- ❑ Base year 2010

Data Preparation

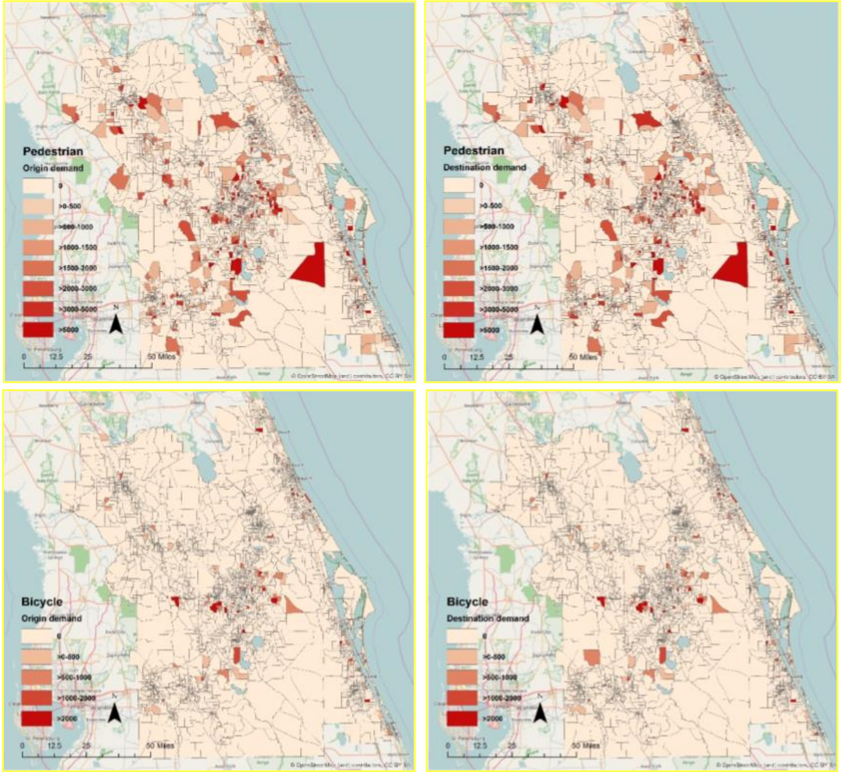
Data Source

- **Exposure Model**- 2009 NHTS (National Household Travel Survey)
  - 2,749 Household, 5,090 individuals
  - 22,359 trips, Walk trips (8.8%), Bike trips (1.3%),
  - **Person trip-weight considered**

- **Safety Model**- FDOT Crash Analysis Reporting System (CARS) and Signal Four Analytics (S4A)
  - Base year 2010
  - 1,474 Pedestrian Crash
  - 1,012 Bicycle Crash

STEP 1: EXPOSURE MODEL

Zones with non-motorized O-D demand



Data Preparation

EXPOSURE MODELS						
Models	Dependent variables	Definitions	Sample size	Zonal (weighted)		
				Minimum	Maximum	Mean
Pedestrian generation model	Pedestrian origin trip count	Total number of daily pedestrian trips originated in TAZs	4747	0.00	39232.01	265.45
Pedestrian attraction model	Pedestrian destination trip count	Total number of daily pedestrian trips destined in TAZs	4747	0.00	39232.01	261.70
Bicycle generation model	Bicycle origin trip count	Total number of bicycle trips originated in TAZs	4747	0.00	7012.43	35.02
Bicycle attraction model	Bicycle destination trip count	total number of bicycle trips destined in TAZs	4747	0.00	7012.43	34.94
SAFETY MODELS (Crash Frequency)						
Pedestrian crash count model	Pedestrian crash counts	Total number of pedestrian crashes in TAZs	4747	0.00	9.00	0.31
Bicycle crash count model	Bicycle crash counts	Total number of bicycle crashes in TAZs	4747	0.00	8.00	0.21

Methodology

- More than 84% and 96% TAZs have 0 pedestrian and bicycle trip counts
- Hurdle Negative Binomial Regression Approach

$$P_i(y_i|, \mu_{i,}\, \alpha) = \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(y_i + 1)\Gamma(\alpha^{-1})} \left(\frac{1}{1 + \alpha\mu_i}\right)^{\frac{1}{\alpha}} \left(1 - \frac{1}{1 + \alpha\mu_i}\right)^{y_i}$$

- ❑ $\mu_i = E(y_i|\boldsymbol{z}_i) = exp(\boldsymbol{\delta z}_i)$, function of explanatory variable $\boldsymbol{z}_i$
- ❑ where $\boldsymbol{\delta}$ is a vector of parameters to be estimated
- ❑ $\Gamma(\cdot)$ is the Gamma function and α is the NB dispersion parameter

Weighted Loglikelihood, $LL = w_i * \begin{cases} ln\,(\pi_i) & y_i = 0 \\ \ln\left(\frac{(1-\pi_i)}{(1-e^{-\mu_i})} P_i(y_i)\right) & y_i > 0 \end{cases}$

$w_i = \sum_{j=1}^{J} \frac{Yearly\ person\ trip\ weight}{365}$

where, j $(j = 1,2,3, \ldots J)$ represents the index for trip.

Estimation Results

Exposure Type	Component	Likelihood of Walk Trips	
		Increases	Decreases
Pedestrian Generator	Probabilistic	Land-use mix, Urban area and number of household	---
	Count	Proportion of 65+ aged population, proportion of arterial road, length of sidewalk, recreational, residential, office and institutional area	Average zonal speed, AADT, proportion of 3 or more lane roads, industrial area
Pedestrian Attractor	Probabilistic	Land-use mix, Urban area and number of household	---
	Count	Proportion of arterial road, length of sidewalk, number of business, entertainment, financial, shopping park and recreational center, recreational, residential, office and institutional area	AADT, proportion of 3 or more lane roads, number of restaurant, number of transit hub, industrial area

Estimation Results

Exposure Type	Component	Likelihood of Bicycle Trips	
		Increases	Decreases
Bicycle Generator	Probabilistic	Land-use mix, Urban area and number of household	---
	Count	Proportion of arterial roads, length of sidewalk, industrial, residential, recreational and institutional area	Proportion of 65+ aged population, AADT, proportion of 3 or more lane roads, retail/office area
Bicycle Attractor	Probabilistic	Land-use mix, Urban area and number of household	---
	Count	Proportion of arterial roads, length of sidewalk, number of educational, entertainment, restaurant, transit hub, park and recreational center, industrial, residential and institutional area	Proportion of 3 or more lane roads, number of commercial, financial and shopping center, recreational and office area

Validation

Models	Events	Observed	Predicted
Pedestrian generator model	Total Zones with zero trip count	4007.00	4006.80
	Total number of zonal trips	1260090.60	1255479.90
	Average zonal trips	265.45	264.48
Pedestrian attractor model	Total Zones with zero trip count	4010.00	4010.49
	Total number of zonal trips	1242270.50	1236690.70
	Average zonal trips	261.70	260.52
Bicycle generator model	Total Zones with zero trip count	4574.00	4573.82
	Total number of zonal trips	166248.45	165671.36
	Average zonal trips	35.02	34.90
Bicycle attractor model	Total Zones with zero trip count	4581.00	4581.18
	Total number of zonal trips	165845.77	171959.97
	Average zonal trips	34.94	36.22

STEP 2: EXPOSURE MATRICES

Destination Choice Model

- Examine the zonal attributes that influence the decision process of destination location
- Two different models: (1) Pedestrian destination choice model, and (2) Bicycle destination choice model
- A random utility maximization approach
- Offers the highest utility from the universal choice set of destination zone
- Generate the destination choice set by assuming that people will walk up to 2 miles and bike up to 6 miles in a trip
- **Objective:** forecast and/or evaluate policy implications for future year considering the real-world change
- Zonal level attributes only

Methodology

- Multinomial Logit Model (MNL)

$$R_{ij} = \frac{exp\left(\boldsymbol{\delta z}_{ij}\right)}{\sum_{j \in C_i} exp\left(\boldsymbol{\delta z}_{ij}\right)}$$

- ❑ R_{ij} is the probability of trip i representing the destination choice of trip makers $\boldsymbol{z}_{ij}$ is a vector of destination zonal attributes corresponding to destination zone j
- ❑ $\boldsymbol{\delta}$ is a vector of parameters to be estimated
- ❑ j $(j = 1,2,3, \ldots, J)$ be the index to represent a destination zone among a set of C_i alternatives of trip i
- ❑ trip i will have possibility of destined in zone j if $u_{ij}^* > \max\limits_{\substack{d=1,2,3,\ldots,J \\ d \neq j}} u_{iJ}^*$

Weighted Loglikelihood, $LL = \omega_i * \left(\sum_i Ln(R_{ij})\right)$

$$w_i = \sum_{j=1}^{J} \frac{Yearly\ person\ trip\ weight}{365}$$

Estimation Results

DESTINATION CHOICE	Likelihood of Destination Choice	
	Increases	Decreases
Pedestrian	Population density, proportion of people aged 65+, traffic signal, number of commercial, educational, financial, restaurant and transit hub, urban, residential and institutional area.	Proportion of people aged 18 to 21, average zonal speed, AADT, truck AADT, number of shopping center, industrial and recreational area
Bicycle	Proportion of 22-29 aged population, length of bike lane, average zonal speed, number of transit hubs ,commercial, educational, financial and shopping center, urban, residential, recreational, institutional and office area	Population density, number of restaurant, industrial area

Trip O-D Matrices

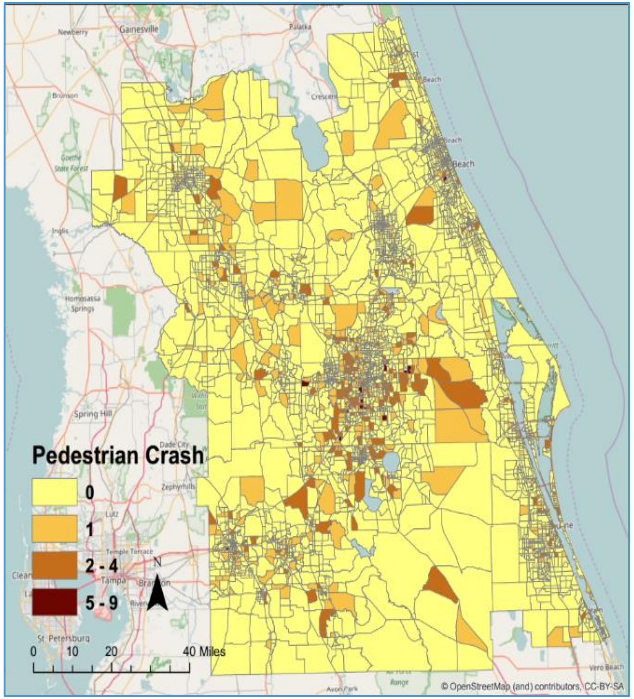
- Generate zonal level trip origin demand matrices using predictions from non-motorists generator model
- Generate zonal level trip destination demand matrices using predictions from non-motorists attractor model
- Combine trip origin and destination matrices to compute total trip demand matrices
- Dimension of total trip demand matrices are [4747x1] with total trips counts across different rows.
- The total zonal level trip demand matrices are generated for pedestrian and bicycle modes separately

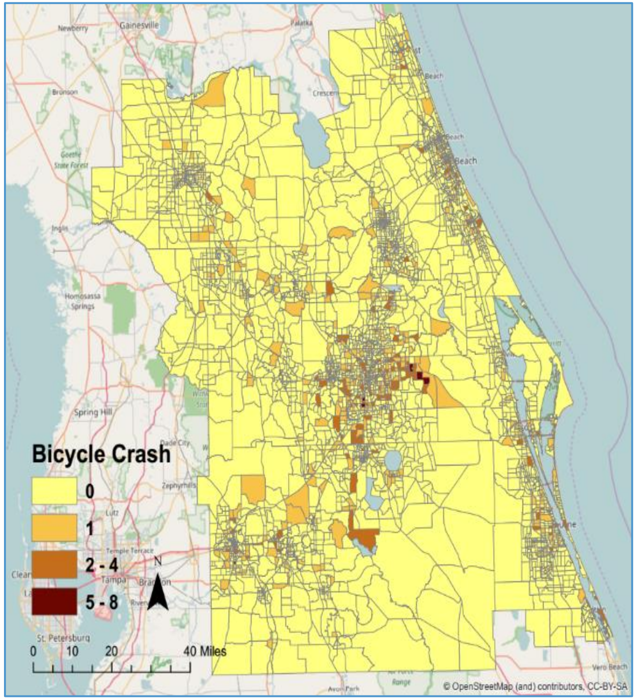
Trip O-D Matrices

County	Number of TAZs	Pedestrian			Bicycle		
		Trip origin demand	Trip destination demand	Total trip demand	Trip origin demand	Trip destination demand	Total trip demand
Brevard	692	154936.5	149804.8	304741.3	21663.59	23172.9	44836.49
Flagler	141	26241.46	23153.66	49395.12	2940.338	2634.027	5574.365
Indian River	37	12066.78	11826.16	23892.94	1735.289	999.454	2734.743
Lake	350	67309.28	66545.88	133855.2	10784.29	9977.642	20761.94
Marion	422	95199.85	89602.94	184802.8	5238.246	4226.254	9464.501
Orange	781	348163.9	355169.8	703333.7	57661.94	64084.73	121746.7
Osceola	250	67651.62	65181.71	132833.3	4026.134	3875.623	7901.758
Polk	621	185959.9	195543.4	381503.4	10931.12	10687.68	21618.8
Seminole	230	75690.14	79212.17	154902.3	12179.38	11558.89	23738.27
Sumter	147	32272.77	26598.91	58871.68	553.048	817.907	1370.955
Volusia	1076	189987.7	174051.2	364038.8	37957.98	39924.86	77882.84
Total	4747	1255480	1236691	2492171	165671.4	171960	337631.3

STEP 3: SAFETY MODELS (CRASH FREQUENCY)

Crash Frequency Analysis





Total number of pedestrian and bicycle crashes for the year 2010

Data Preparation

SAFETY MODEL (Severity)	Zonal					
	Pedestrian			Bicycle		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Zone with no crashes	3798			4028		
Zones with crashes	949			719		
Proportion of property damage only crashes	0.00	1.00	0.11	0.00	1.00	0.12
Proportion of minor injury crashes	0.00	1.00	0.24	0.00	1.00	0.32
Proportion of non-incapacitating injury crashes	0.00	1.00	0.38	0.00	1.00	0.41
Proportion of incapacitating injury crashes	0.00	1.00	0.18	0.00	1.00	0.14
Proportion of fatal crashes	0.00	1.00	0.09	0.00	1.00	0.02

Methodology

- Zonal level (TAZ level) pedestrian and bicycle crashes
- Count model for examining pedestrian and bicycle crash risks
- Negative Binomial (NB) model
- NB probability expression for random variable y_i

$$P_i(y_i|\mu_i\,,\alpha) = \frac{\Gamma\left(y_i+\frac{1}{\alpha}\right)}{\Gamma(y_i+1)\Gamma\left(\frac{1}{\alpha}\right)}\left(\frac{1}{1+\frac{\mu_i}{\alpha}}\right)^{\frac{1}{\alpha}}\left(1-\frac{1}{1+\frac{\mu_i}{\alpha}}\right)^{y_i}$$

where, $\Gamma(\cdot)$ is the Gamma function, α is the NB dispersion parameter and μ_i is the expected number of crashes occurring in TAZ i over a given period of time.

- The log-likelihood function for the NB model

$$LL = \sum_{i=1}^{N} log(P_i)$$

Estimation Results

CRASH FREQUENCY	Likelihood of Crash Counts	
	Increases	Decreases
Pedestrian	Population density, traffic signal density, proportion of arterial road, length of sidewalk, AADT, number of educational, transit hubs, restaurant, park and recreational center, urban, residential and land use mix	Proportion of people aged 65+, pedestrian trip demand
Bicycle	Population density, traffic signal density, proportion of arterial road, length of bike and bus lane, AADT, number of commercial, financial, restaurant, hospital, urban, residential and land use mix, bicycle trip demand	Proportion of people aged 65+,proportion of local road, truck AADT, recreational area

Validation

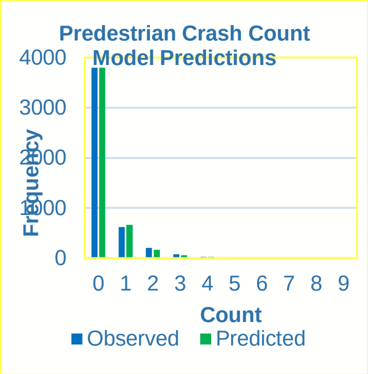
- To evaluate the in-sample predictive measures
- Compute Mean Prediction Bias (MPB) and Mean Absolute Deviation (MAD)

$$MPB = \frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)}{n} \text{ and } MAD = \frac{\sum_{i=1}^{n}|\hat{y}_i - y_i|}{n}$$

where, $\hat{y}_i$ and y_i are the predicted and observed values for event i (i be the index for event ($i = 1,2,3,\ldots,N$)) and n is the number of events.

In-sample predictive fit measures for count models				
Models	Mean crash		MPB	MAD
	Observed	Predicted		
Pedestrian	0.31	0.33	-0.81	11.44
Bicycle	0.21	0.22	-0.28	6.41

Table: Predictive performance evaluation



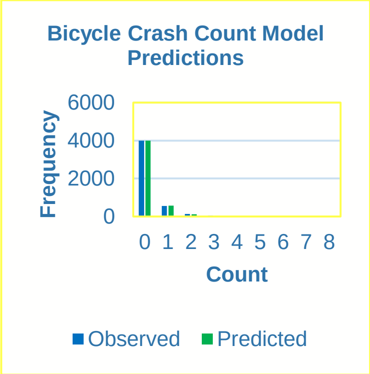


Figure - Crash count model predictions

STEP 3: SAFETY MODELS (CRASH SEVERITY)

Severity Modeling Methodology

Crash severity levels	**Fraction of crashes**
Fatal	Fatal count/Total crash count
Incapacitating injury	Incapacitating injury count/Total crash count
Non-incapacitating injury	Non-incapacitating injury count/Total crash count
Possible injury	Possible injury count/Total crash count
No injury	No injury/Total crash count

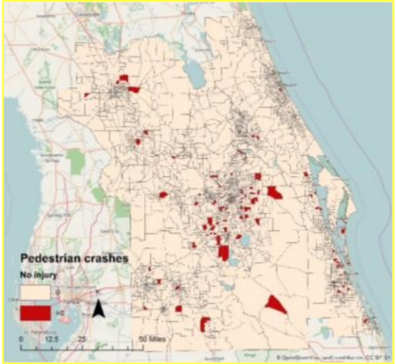
Severity Modeling Methodology

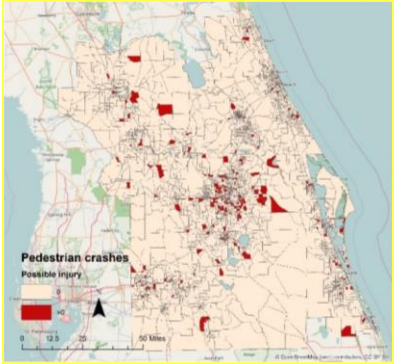
- We propose an alternative approach to examine crash frequency by severity
- We adopt a fractional split model
  - To examine the fraction of crashes by each severity level at zonal level
  - as opposed to modeling the number of crashes
  - by severity in a single probabilistic model system
  - while recognizing the inherent ordering in the severity outcome levels
- Specifically, we adopt an Ordered Probit Fractional Split (OPFS) model to study crash proportion by severity levels

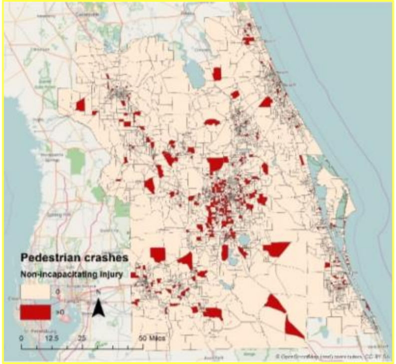
Data Preparation

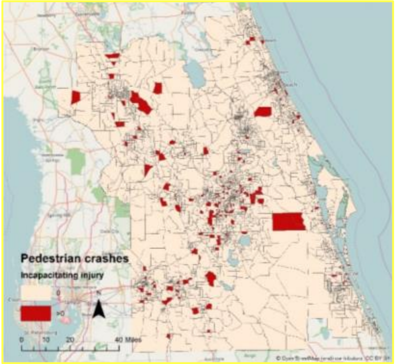
SAFETY MODEL (Severity)	Zonal					
	Pedestrian			Bicycle		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Zone with no crashes	3798			4028		
Zones with crashes	949			719		
Proportion of property damage only crashes	0.00	1.00	0.11	0.00	1.00	0.12
Proportion of minor injury crashes	0.00	1.00	0.24	0.00	1.00	0.32
Proportion of non-incapacitating injury crashes	0.00	1.00	0.38	0.00	1.00	0.41
Proportion of incapacitating injury crashes	0.00	1.00	0.18	0.00	1.00	0.14
Proportion of fatal crashes	0.00	1.00	0.09	0.00	1.00	0.02

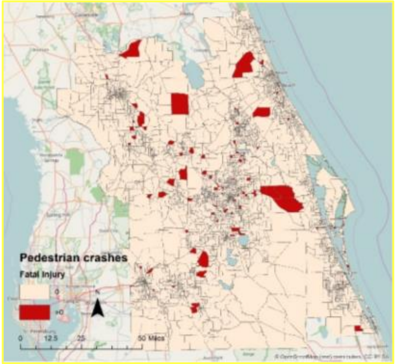
Zones with Severity Outcomes (Pedestrian Crashes)



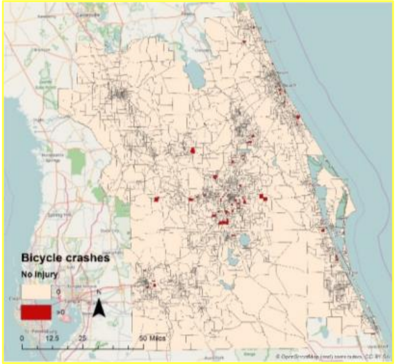


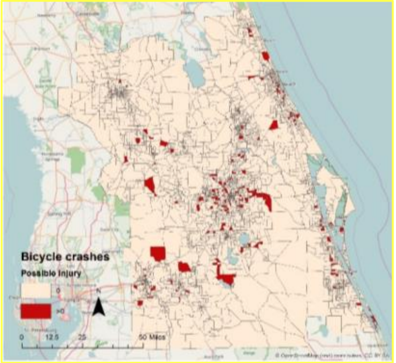


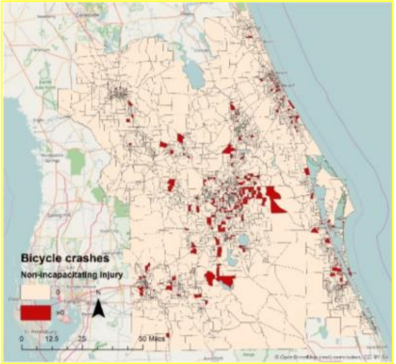


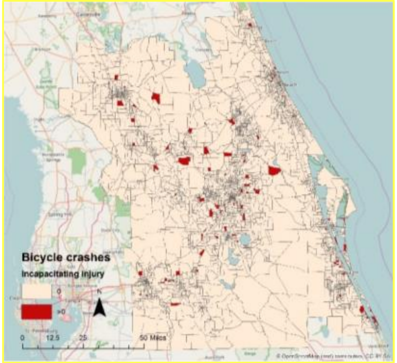


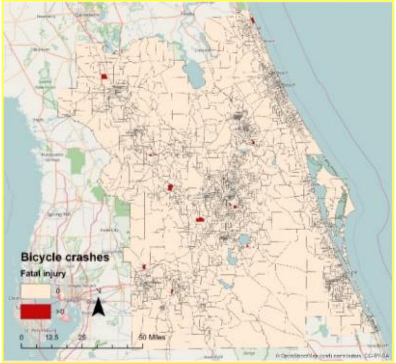
Zones with Severity Outcomes (Bike Crashes)











Estimation Results

CRASH SEVERITY	Likelihood of Crash Proportions	
	Increases	Decreases
Pedestrian	VMT	Population density, proportion of people aged 22 to 29, number of commercial center, urban area, pedestrian trip demand
Bicycle	Number of flashing beacon, school signal, park and recreational center, residential area	Population density, availability of bike lane, number of hospitals, urban area, total bicycle trip demand per household

POLICY SCENARIO ANALYSIS

Policy Scenarios

- Compute aggregate level exogenous variable impact in demand and safety models
- All zones, Pedestrian and Bicycle separately
- Multiple CBDs considered in Central Florida region
- Compute effect as percentage change

Policy Scenarios

Scenarios	Description of scenarios	Study region	Number of zones	Change in zonal demand		Change in crash count		Change in crash severity proportions	
								Fatal Crash	
				Walk	Bicycle	Walk	Bicycle	Walk	Bicycle
Scenario 1	50% reduction in traffic volume with 2 miles buffer area of different central business district (CBD)	All zones	4747	0.164	0.043	-0.63	3.144	-4.967	-0.066
		Zones within 2 miles buffer of CBD	703	1.804	0.389	-3.266	-2.889	-4.687	-0.045
Scenario 2	30% reduction in traffic volume with 2 miles buffer area of different central business district (CBD)	All zones	4747	0.096	0.026	-0.437	3.622	-4.963	-0.066
		Zones within 2 miles buffer of CBD	703	1.060	0.231	-2.120	-0.274	-4.664	-0.045
Scenario 3	15% reduction in traffic volume with 4 miles buffer area of different central business district (CBD)	All zones	4747	0.125	0.030	-0.482	3.554	-4.963	-0.066
		Zones within 4 miles buffer of CBD	1375	0.498	0.090	-1.280	1.680	-4.55	0.003
Scenario 4	5% reduction in traffic volume with 6 miles buffer area of different central business district (CBD)	All zones	4747	0.071	0.013	-0.34	3.935	-4.96	-0.066
		Zones within 6 miles buffer of CBD	1985	0.166	0.027	-0.589	3.281	-4.891	0.015

Policy Scenarios

	Description of scenarios	Study region	No. of zones	Change in zonal demand		Change in crash count		Change in crash severity proportions	
								Fatal Crash	
				Walk	Bicycle	Walk	Bicycle	Walk	Bicycle
Scenario 5	All zones have sidewalk and the new proposed sidewalk length = $\frac{(TAZ\ area)^{0.5}}{2}\ meter$	All zones	4747	-0.438	0.108	-1.360	4.367	-1.013	-0.063
Scenario 6	50% increase in existing sidewalk length	All zones	4747	0.705	0.289	0.985	4.436	-1.111	-0.071
Scenario 7	15% reduction in zonal average maximum speed	All zones	4747	1.407	0.000	-0.143	0.000	-1.107	0.000
Scenario 8	25% reduction in zonal average maximum speed	All zones	4747	2.389	0.000	-0.150	0.000	-1.135	0.000
Scenario 9	15% reduction in zonal proportion of 3+lane road	All zones	4747	0.287	0.576	-0.138	4.436	-1.077	-0.068
Scenario 10	25% reduction in zonal proportion of 3+lane road	All zones	4747	0.484	0.337	-0.143	4.415	-1.085	-0.066

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- My students
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Questions

- Project report - http://www.people.cecs.ucf.edu/neluru/Reports/FinalReport_BDV24-977-15.pdf

- http://www.people.cecs.ucf.edu/neluru/index.html

Completed Research Projects

1. "Evaluating the benefits of multi-modal investments on promoting travel mobility in Central Florida" Role: PI; Sponsor: Florida Department of Transportation; Project Duration September 2015 - August 2018. [Final Report] [Link to FDOT Report]