Collaborative Sciences Center for ROAD SAFETY

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Urban Freight and Road Safety: Trends and Innovative Strategies

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December 20, 2021

Research Background

- A boom in e-commerce activities
- Increasing freight demand
- More freight vehicles on local arterials and streets
- Growing road safety threats in urban neighborhoods

Research Objectives

- Using data from NC and TN surveillance systems to evaluate the impacts of urban freight on road safety through detailed spatial and longitudinal analyses.

- Reviewing novel last-mile delivery options and identifying the advantages and disadvantages of these options in improving road safety.

Exploring the Determinants of Crash Severity for Incidents Involving Vulnerable Road Users and Commercial Vehicles in North Carolina and Tennessee

Research Questions

- What are the spatial and temporal trends in VRU/freight vehicle crashes?

- What are the crash-level characteristics associated with VRU/freight crashes?

Data and Methods: Key Terms

- **Study Area**: non-interstate crashes involving vulnerable road users and commercial vehicles that occur within census-defined urbanized areas in North Carolina and Tennessee.

- **Vulnerable Road Users**: bicyclists and pedestrians.

- **Commercial Vehicles**: light trucks (mini-van/panel), single unit trucks (2-axel, 6-tire), single unit trucks (3 or more axels), tractor/doubles, tractor/semi-trailers, truck/tractors, truck/trailers, unknown heavy trucks, and common cargo vans.

Data and Methods: Data

- **NC data:**
  - 2007 to 2018.
  - Data Source:
    - Institute for Transportation Research and Education at North Carolina State University
    - NCDOT

- **TN data**
  - 2009 to 2019.
  - Data Source:
    - Tennessee's Integrated Traffic Analysis Network

Data and Methods: Variables

- **Key dependent variables:**
  - Non-commercial (=0) vs. commercial VRU crashes(=1)
  - injury outcomes of commercial VRU crashes
    - Severe (fatal or serious injuries) vs. Non severe

- **Crash-level correlates:**
  - Driver' and VRU's characteristics
  - Time of the day, weekends, weather
  - Crash environment

Data and Methods: Methods

- **Descriptive analysis (Chi-Squared test) to examine the disparities crash-level factors**
  - Between non-commercial and commercial VRU crashes;
  - Between injury outcomes of commercial VRU crashes (Severe vs. Non severe)

- **Logit Models**

Results in North Carolina

NC Data Description

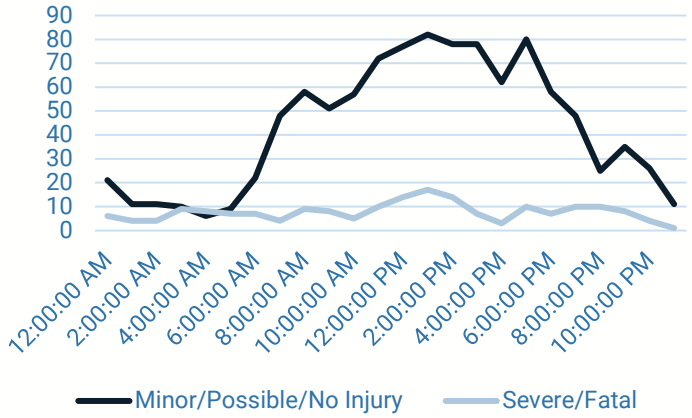


Figure 1: Crash Frequencies by Crash Hour

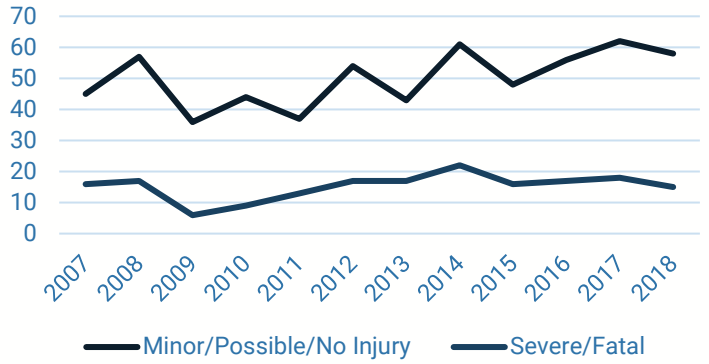


Figure 2: Crash Frequencies by Severity and Year

NC Data Description

Charlotte

Raleigh Durham

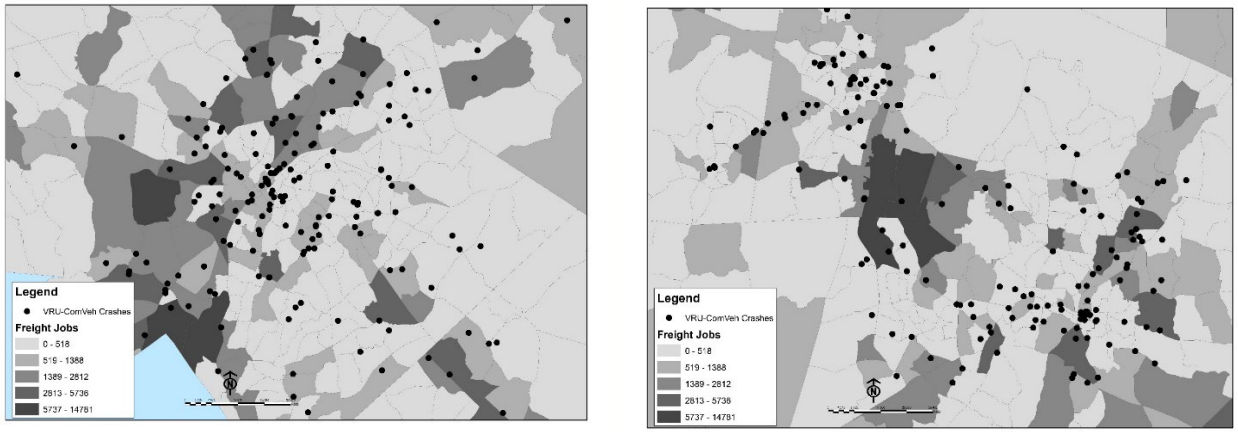


Figure 3: VRU-Commercial Crashes and Freight Jobs in Charlotte and Raleigh-Durham

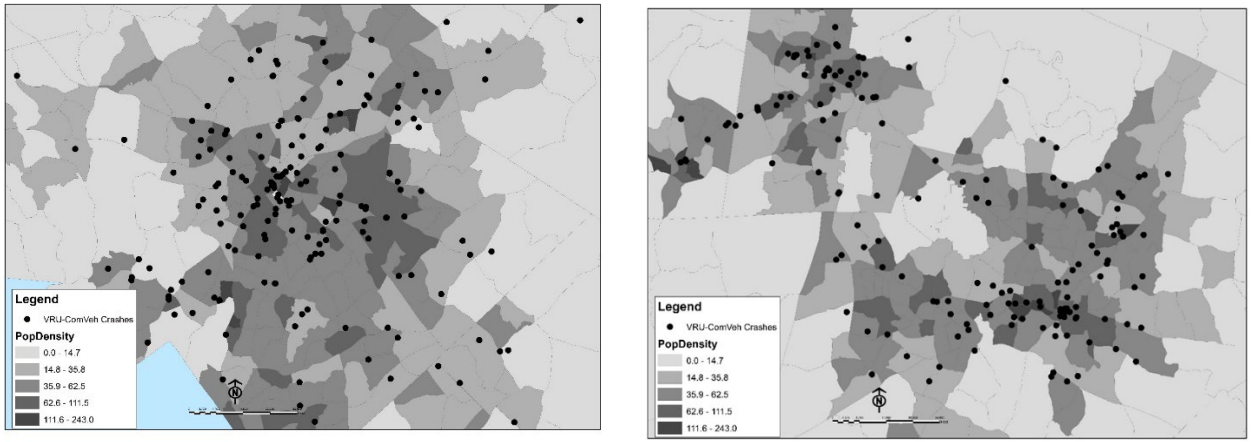


Figure 4: VRU-Commercial Crashes and Population Density in Charlotte and Raleigh-Durham

Descriptive Analysis Results

		Category Frequency	Frequency (Severe+Fatal)	Frequency (Fatal)
VRU Characteristics			Count (Percent)	Count (Percent)
Age	Chi Square		(c^2=10.44, p=0.06)	(c^2=4.58, p=0.47)
	0-15	123 (0.11)	22 (0.12)	7 (0.06)
	16-29	296 (0.27)	59 (0.20)	30 (0.10)
	30-49	348 (0.31)	88 (0.25)	29 (0.08)
	50-69	248 (0.22)	62 (0.25)	18 (0.07)
	70+	77 (0.07)	25 (0.32)	7 (0.09)
	Unknown	19 (0.02)	2 (0.11)	0 (0.00)
Race	Chi Square		(c^2=8.41, p=0.08)	(c^2=0.82, p=0.94)
	Black	366 (0.33)	74 (0.20)	29 (0.08)
	Hispanic	70 (0.06)	16 (0.23)	5 (0.07)
	Other/Mixed	120 (0.11)	34 (0.28)	10 (0.08)
	Unknown/Missing	39 (0.03)	4 (0.10)	2 (0.05)
	White	516 (0.46)	130 (0.25)	45 (0.09)
Sex	NS			
VRU Position	Chi Square		(c^2=22.74, p=0.00)	(c^2=9.93, p=0.08)
	Crosswalk	92 (0.08)	14 (0.14)	3 (0.03)
	Non-roadway	327 (0.29)	74 (0.23)	37 (0.11)
	Other/Unknown	54 (0.05)	9 (0.17)	3 (0.06)
	Road Side	38 (0.03)	8 (0.21)	4 (0.11)
	Sidewalk/Path	83 (0.07)	8 (0.10)	4 (0.05)
	Travel Lane	509 (0.46)	145 (0.28)	40 (0.08)

Note: NS-not significant for the Chi-Squared test

Descriptive Analysis Results

		Category Frequency	Frequency (Severe+Fatal)	Frequency (Fatal)
Crash Group	NS			
Vehicle Type	Chi Square		(c^2=16.68, p=0.00)	(c^2=39.93, p=0.00)
	Single Unit Truck	308 (0.28)	88 (0.29)	31 (0.10)
	Large Truck	204 (0.18)	59 (0.29)	37 (0.18)
	Light Truck	549 (0.49)	104 (0.19)	23 (0.04)
	Van	50 (0.05)	7 (0.14)	1 (0.02)
Speed Limit	Chi Square		(c^2=20.12, p=0.00)	(c^2=8.83, p=0.12)
	5-15	185 (0.17)	23 (0.12)	9 (0.05)
	20-25	183 (0.16)	49 (0.28)	20 (0.11)
	30-35	355 (0.32)	49 (0.14)	27 (0.08)
	40-45	193 (0.17)	28 (0.14)	22 (0.11)
	50+	71 (0.06)	6 (0.09)	3 (0.04)
	Unknown	124 (0.11)	30 (0.24)	10 (0.08)
Road Class	NS			
Development	Chi Square		(c^2=12.58, p=0.00)	(c^2=25.12, p=0.00)
	Commercial	624 (0.56)	136 (0.22)	56 (0.09)
	Industrial/Institutional	43 (0.04)	7 (0.16)	0 (0.00)
	Residential	389 (0.35)	92 (0.24)	22 (0.06)
	Rural	55 (0.05)	23 (0.42)	13 (0.24)

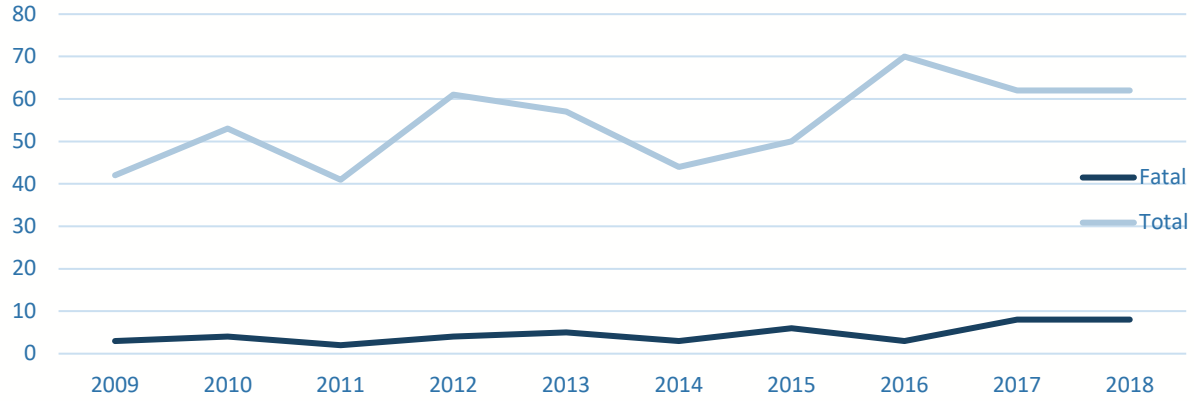
Note: NS-not significant for the Chi-Squared test

Modeling Results: Severe vs non-Severe

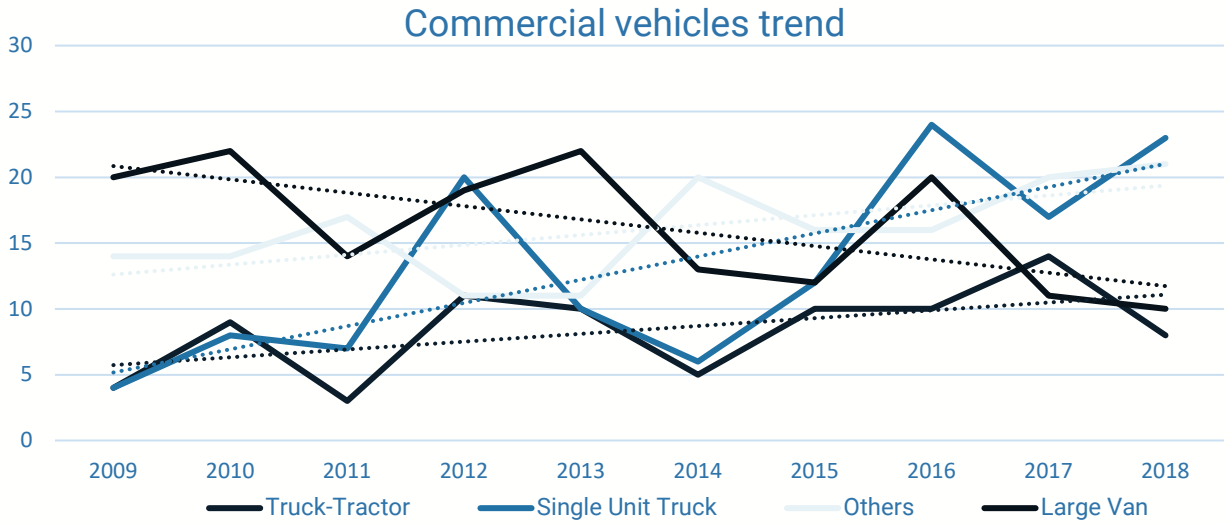
Variable	Estimate	S.E.	z value	p
Intercept	-2.130	0.495	-4.305	0.000
VRU Age Grp (ref.=30-49)				
VRU Race (ref.= African Americans)	NS			
VRU Position (ref.=Sidewalk/Path)	NS			
VRU Position Crosswalk	0.243	0.496	0.490	0.624
VRU Position Non-Roadway	0.816	0.414	1.970	0.049
VRU Position Other/Unknown	0.489	0.539	0.907	0.364
VRU Position Road Side	0.853	0.573	1.489	0.137
VRU Position Travel Lane	1.308	0.399	3.278	0.001
Development (ref.=Commercial)				
Development Industrial/Institutional	-0.552	0.446	-1.236	0.216
Development Residential	0.108	0.168	0.641	0.521
Development Rural	1.012	0.314	3.228	0.001
Crash Group (ref. =Ped in R to fWy)	NS			
Driver Vehicle Type (ref.=Single-unit truck)	NS			
Driver Vehicle Type Large Truck	-0.011	0.215	-0.051	0.960
Driver Vehicle Type Light Truck	-0.588	0.177	-3.322	0.001
Driver Vehicle Type Van	-0.880	0.443	-1.985	0.047
Speed Limit (ref.=30-35)				
Speed Limit 20-25	0.557	0.224	2.492	0.013
Speed Limit 40-45	0.195	0.234	0.831	0.406
Speed Limit 5-15	-0.449	0.261	-1.720	0.085
Speed Limit 50+	-0.446	0.383	-1.165	0.244
Speed Limit Unknown	0.436	0.258	1.695	0.090

Results in TN

TN Data Description



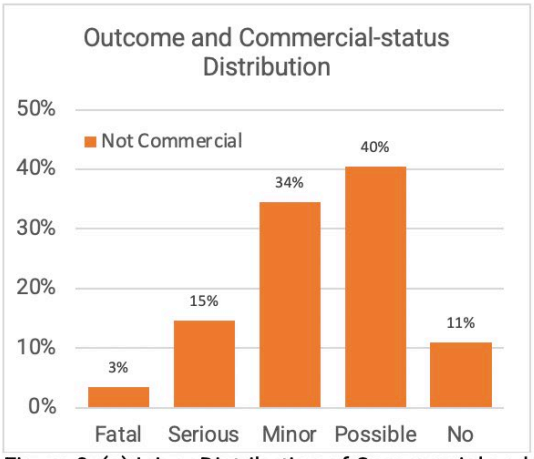
Yearly Trends for Fatal and All Commercial VRU Crashes in Tennessee



Yearly Crash Trends of Individual Commercial Vehicle Types in Tennessee

Figure 7: Yearly Crash Trends of Individual Commercial Vehicle Types in Tennessee

TN Data Description



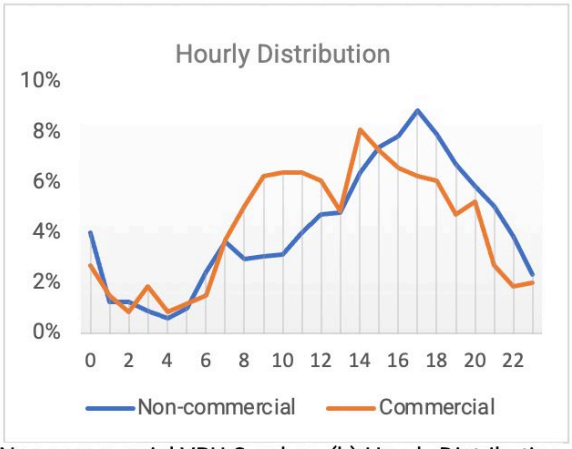
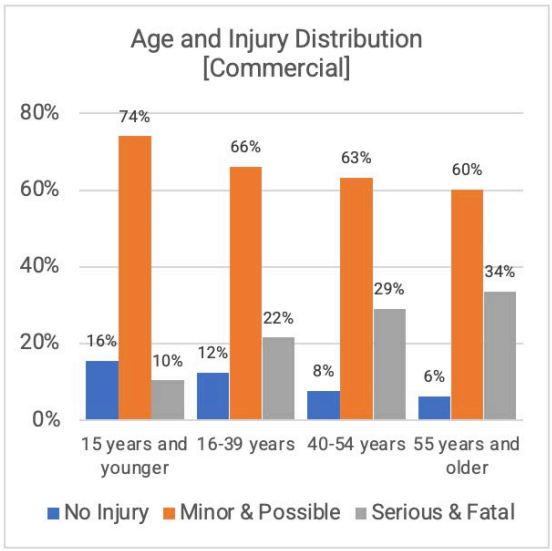


Figure 8: (a) Injury Distribution of Commercial and Non-commercial VRU Crashes, (b) Hourly Distribution of Commercial and Non-commercial VRU Crashes



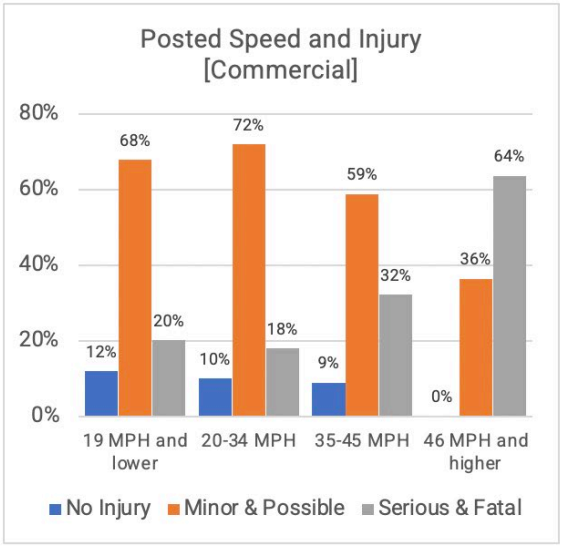


Figure 9: (a) Age and Injury Distribution of Commercial Crashes, (b) Posted Speed Limit and Injury Distribution of Commercial Crashes

Descriptive Analysis Results

Variables	Values	Commercial Indicator		Injury Severity				
		Non-Commercial	**Commercial**	**No**	**Possible**	**Minor**	**Serious**	**Fatal**
Age Category	15 years and younger	3213 (17)	77 (13)	12 (20)	28 (14)	29 (16)	7 (7)	1 (2)
	16-39 years	7900 (42)	218 (37)	27 (45)	83 (40)	61 (34)	33 (34)	14 (28)
	40-54 years	4027 (21)	155 (26)	12 (20)	44 (21)	54 (30)	29 (30)	16 (32)
	55 years and older	3654 (19)	143 (24)	9 (15)	52 (25)	34 (19)	29 (30)	19 (38)
	χ^2 - value/ p-value	**21.864**	**0**			**χ^2 - value/ p-value**	**28.659**	**0.004**
Alcohol or Drug Presence	No or Unknown	17842 (95)	561 (95)	57 (95)	204 (99)	173 (97)	88 (90)	39 (78)
	Yes	954 (5)	32 (5)	3 (5)	3 (1)	5 (3)	10 (10)	11 (22)
	χ^2 - value/ p-value	**0.123**	**0.726**			**χ^2 - value/ p-value**	**40.107**	**0**
Gender	Female	6797 (36)	195 (33)	16 (27)	84 (41)	51 (29)	23 (23)	21 (42)
	Male	11999 (64)	398 (67)	44 (73)	123 (59)	127 (71)	75 (77)	29 (58)
	χ^2 - value/ p-value	**2.68**	**0.102**			**χ^2 - value/ p-value**	**13.869**	**0.008**
Race	Black	6009 (32)	196 (33)	15 (25)	78 (38)	56 (31)	28 (29)	19 (38)
	White	7821 (42)	270 (46)	23 (38)	77 (37)	87 (49)	59 (60)	24 (48)
	Other	4966 (26)	127 (21)	22 (37)	52 (25)	35 (20)	11 (11)	7 (14)
	χ^2 - value/ p-value	**7.809**	**0.02**			**χ^2 - value/ p-value**	**26.734**	**0.001**
Driver Age Category	Others/Unknown	2364 (15)	50 (9)	6 (11)	19 (10)	16 (10)	8 (9)	3 (6)
	16-39 years	6603 (42)	165 (31)	14 (25)	64 (33)	55 (34)	23 (26)	17 (35)
	40-54 years	3221 (20)	186 (35)	24 (42)	71 (37)	53 (33)	28 (31)	15 (31)
	55 years and older	3589 (23)	128 (24)	13 (23)	39 (20)	38 (23)	31 (34)	14 (29)
	χ^2 - value/ p-value	**78.326**	**0**			**χ^2 - value/ p-value**	**10.715**	**0.554**
Driver Alcohol/ Drug	No or Unknown	17565 (98)	556 (98)	60 (100)	204 (99)	173 (97)	95 (97)	46 (92)
	Yes	385 (2)	13 (2)	0 (0)	3 (1)	5 (3)	3 (3)	4 (8)
	χ^2 - value/ p-value	**0.051**	**0.821**			**χ^2 - value/ p-value**	**8.775**	**0.067**
Driver Gender	Female	10060 (56)	122 (21)	11 (18)	45 (22)	45 (25)	20 (20)	6 (12)
	Male	7890 (44)	447 (79)	49 (82)	162 (78)	133 (75)	78 (80)	44 (88)
	χ^2 - value/ p-value	**266.803**	**0**			**χ^2 - value/ p-value**	**4.625**	**0.328**
Driver Race	Black	5386 (30)	164 (29)	14 (23)	68 (33)	58 (33)	15 (15)	15 (30)
	White	8158 (45)	312 (55)	32 (53)	106 (51)	89 (50)	69 (70)	30 (60)
	Other	4406 (25)	93 (16)	14 (23)	33 (16)	31 (17)	14 (14)	5 (10)
	χ^2 - value/ p-value	**26.148**	**0**			**χ^2 - value/ p-value**	**18.207**	**0.02**
Injury Class	No Injury	1879 (10)	60 (10)					
	Possible	7395 (39)	207 (35)					
	Minor	6274 (33)	178 (30)					
	Serious	2637 (14)	98 (17)					
	Fatal	611 (3)	50 (8)					
	χ^2 - value/ p-value	**52.651**	**0**					

Descriptive Analysis Results

Variables	Values	Commercial Indicator		Injury Severity				
		Non-Commercial	**Commercial**	**No**	**Possible**	**Minor**	**Serious**	**Fatal**
Weekend	No	13691 (76)	464 (82)	51 (85)	170 (82)	137 (77)	77 (79)	42 (84)
	Yes	4259 (24)	105 (18)	9 (15)	37 (18)	41 (23)	21 (21)	8 (16)
	χ^2 - value/ p-value	**8.516**	**0.004**	**χ^2 - value/ p-value**			**3.152**	**0.533**
Time of Day	00:00 - 06:00	1604 (9)	48 (8)	2 (3)	17 (8)	16 (9)	12 (12)	6 (12)
	06:00 - 12:00	3469 (19)	167 (29)	16 (27)	56 (27)	57 (32)	27 (28)	18 (36)
	12:00 - 18:00	7218 (40)	225 (40)	29 (48)	92 (44)	67 (38)	31 (32)	13 (26)
	18:00 - 24:00	5659 (32)	129 (23)	13 (22)	42 (20)	38 (21)	28 (29)	13 (26)
	χ^2 - value/ p-value	**42.277**	**0.000**	**χ^2 - value/ p-value**			**14.712**	**0.258**
Route Signing	County Route	763 (4)	18 (3)	3 (5)	6 (3)	5 (3)	5 (5)	0 (0)
	Municipal Route	9947 (55)	292 (51)	30 (50)	110 (53)	88 (49)	46 (47)	27 (54)
	Other	4718 (26)	177 (31)	21 (35)	68 (33)	65 (37)	31 (32)	3 (6)
	State Route	1312 (7)	36 (6)	2 (3)	14 (7)	9 (5)	4 (4)	8 (16)
	US Route	1210 (7)	46 (8)	4 (7)	9 (4)	11 (6)	12 (12)	12 (24)
	χ^2 - value/ p-value	**10.273**	**0.036**	**χ^2 - value/ p-value**			**48.079**	**0.000**
Trafficway Type	Private/Parking	3678 (20)	155 (27)	16 (27)	61 (29)	56 (31)	28 (29)	5 (10)
	Trafficway	14271 (80)	414 (73)	44 (73)	146 (71)	122 (69)	70 (71)	45 (90)
	χ^2 - value/ p-value	**15.306**	**0.000**	**χ^2 - value/ p-value**			**9.385**	**0.052**
Weather	Clear	14600 (81)	468 (82)	53 (88)	177 (86)	147 (83)	75 (77)	39 (78)
	Cloudy	1201 (7)	50 (9)	2 (3)	15 (7)	17 (10)	11 (11)	6 (12)
	Other	421 (2)	7 (1)	3 (5)	2 (1)	1 (1)	1 (1)	0 (0)
	Rain	1728 (10)	44 (8)	2 (3)	13 (6)	13 (7)	11 (11)	5 (10)
	χ^2 - value/ p-value	**8.68**	**0.034**	**χ^2 - value/ p-value**			**17.791**	**0.122**
First Impact	Front End	7456 (42)	186 (33)	21 (35)	57 (28)	58 (33)	44 (45)	18 (36)
	Left Side	2327 (13)	63 (11)	1 (2)	25 (12)	23 (13)	8 (8)	8 (16)
	Non-Collision	348 (2)	16 (3)	0 (0)	4 (2)	5 (3)	3 (3)	5 (10)
	Other	2683 (15)	87 (15)	3 (5)	30 (14)	31 (17)	17 (17)	8 (16)
	Rear End	1581 (9)	89 (16)	15 (25)	36 (17)	25 (14)	13 (13)	1 (2)
	Right Side	3555 (20)	128 (22)	20 (33)	55 (27)	36 (20)	13 (13)	10 (20)
	χ^2 - value/ p-value	**44.745**	**0.000**	**χ^2 - value/ p-value**			**49.465**	**0.000**
Posted Speed Limit	19 mph and lower	4163 (23)	172 (30)	22 (37)	65 (31)	60 (34)	33 (34)	4 (8)
	20-34 mph	5338 (30)	146 (26)	15 (25)	60 (29)	48 (27)	18 (18)	9 (18)
	35-45 mph	7843 (44)	228 (40)	21 (35)	73 (35)	66 (37)	44 (45)	32 (64)
	46 mph and higher	216 (1)	11 (2)	0 (0)	2 (1)	2 (1)	3 (3)	4 (8)
	Unknown	390 (2)	12 (2)	2 (3)	7 (3)	2 (1)	0 (0)	1 (2)
	χ^2 - value/ p-value	**18.832**	**0.001**	**χ^2 - value/ p-value**			**42.318**	**0.000**
Travel Lanes	Five or more Lanes	1361 (8)	44 (8)	6 (10)	15 (7)	10 (6)	8 (8)	6 (12)
	One/two Lanes	9943 (55)	298 (52)	35 (58)	112 (54)	87 (49)	53 (54)	20 (40)
	Other	2944 (16)	121 (21)	10 (17)	44 (21)	42 (24)	24 (24)	8 (16)
	Three/four Lanes	3702 (21)	106 (19)	9 (15)	36 (17)	39 (22)	13 (13)	16 (32)
	χ^2 - value/ p-value	**9.878**	**0.02**	**χ^2 - value/ p-value**			**14.994**	**0.242**

Modeling Results: Commercial vs Non-Commercial-VRU

Particulars	Odds Ratio	Std. Err.	z	P>z
Age category (Base: 16 – 39 years)				
Below 15 years	0.90	0.12	-0.78	.433
40 - 54 years	1.25	0.14	2.03	.043
55 years and older	1.15	0.13	1.24	.214
Weekend	0.77	0.08	-2.36	.018
Time of Day (Base: 12:00 to 18:00)				
00:00 - 06:00	1.01	0.16	0.08	.937
06:00 - 12:00	1.50	0.16	3.83	.000
18:00 - 24:00	0.71	0.08	-3.06	.002
Private areas or Parking lot	1.35	0.14	2.84	.004
Weather (Base: Clear)				
Cloudy	1.11	0.17	0.67	.502
Other	0.48	0.18	-1.92	.055
Rainy	0.76	0.12	-1.73	.084
First Impact (Base: Front end)				
Left Side	1.12	0.16	0.78	.435
Rear End	1.98	0.28	4.82	.000
Right Side	1.62	0.19	4.20	.000
Other	2.25	0.32	5.63	.000
Driver Age (Base: 16 - 39 years)				
40 - 54 years	2.00	0.21	6.64	.000
55 years and older	1.18	0.14	1.46	.145
Others or unknown	1.34	0.23	1.65	.098
Male driver vs otherwise	4.79	0.52	14.38	.000
Injury Outcome (Base: No injury)				
Minor	0.85	0.13	-1.05	.293
Possible	0.89	0.14	-0.74	.458
Serious	1.19	0.21	1.01	.312
Fatal	2.65	0.56	4.63	.000
Constant	0.01	0.00	-25.60	.000

Modeling Results: Severe vs. Non-Severe

Particulars	Odds Ratio	Std. Err.	z	P>z
Age category (Base: 16 - 39 years)				
Below 16 years	0.69	0.31	-0.84	.402
40 - 54 years	1.66	0.46	1.82	.069
55 years and older	2.08	0.58	2.63	.009
Alcohol or Drug Presence	5.84	2.72	3.79	.000
Time of Day (Base: 12:00 to 18:00)				
00:00 - 06:00	1.96	0.80	1.67	.096
06:00 - 12:00	1.72	0.46	2.01	.044
18:00 - 24:00	1.44	0.43	1.25	.213
Weather (Base: Clear)				
Cloudy	1.81	0.68	1.59	.111
Other	0.25	0.41	-0.86	.392
Rainy	2.06	0.77	1.93	.054
First Impact (Base: Front end)				
Left Side	0.62	0.23	-1.32	.186
Rear End	0.54	0.20	-1.67	.095
Right Side	0.45	0.14	-2.65	.008
Other	0.98	0.32	-0.07	.944
Posted Speed (Base: less than 35 mph)				
35 - 45 mph	2.05	0.47	3.14	.002
46 mph and above	3.28	2.36	1.65	.099
Intersection vs non-Intersection	0.38	0.08	-4.36	.000
White driver vs Otherwise	2.52	0.58	4.02	.000
Commercial Vehicle Type (Base: Minivan/Utility/pickups and other vehicles)				
Large Van	1.85	0.57	2.01	.045
Single Truck Unit	2.18	0.66	2.56	.010
Tractor-trailer	2.84	0.97	3.07	.002
Constant	0.07	0.03	-6.16	.000

Summary

- There has been a statistically significant increase in these crashes in both North Carolina and Tennessee.

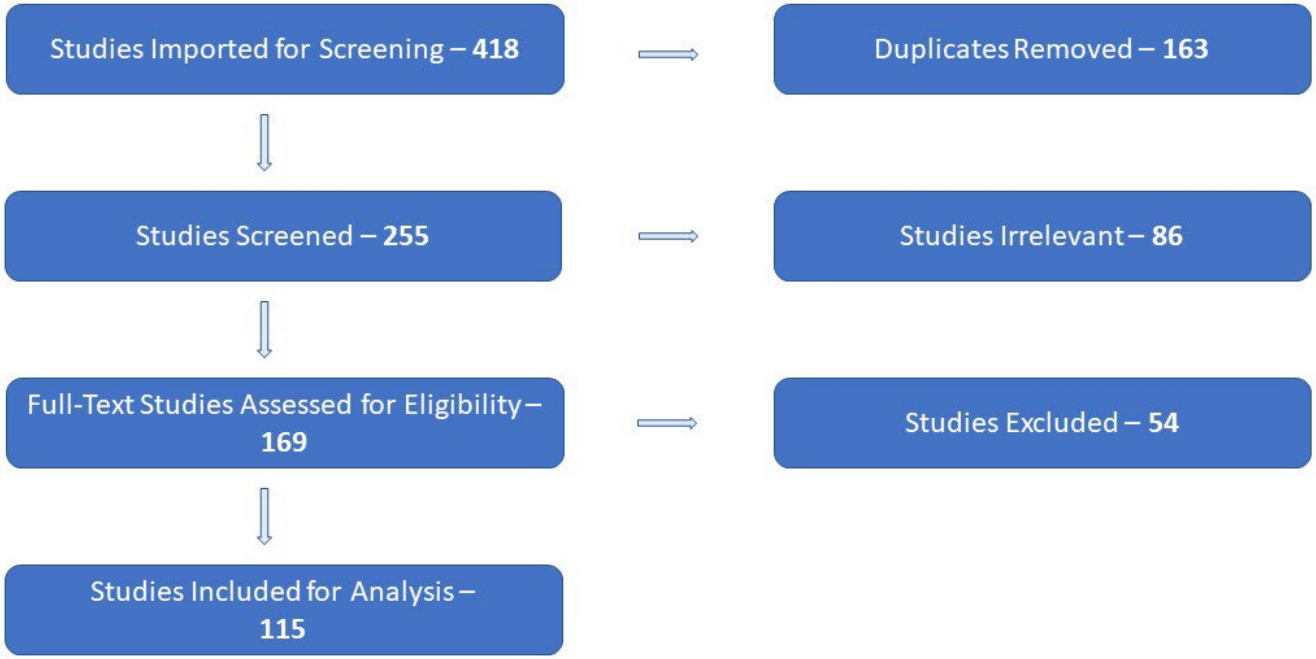
- The position of the VRU with respect to the street cross-section is an important determinant of the likelihood that the VRU will be severely injured or killed.
  - Compared to the base case of “sidewalk/path,” a crash in which the VRU was located within the travel lane is nearly five times more likely to produce a severe injury or death.

- When compared to large commercial variables, light trucks and vans are less likely to produce severe and fatal crashes.

Last Mile Strategies for Urban Freight Delivery

A Systematic Review

Methods: Systematic Reviews and Meta Analyses



Last Miles Strategies-Innovative Vehicles

Strategy	Includes	Authors	# of Articles
Freight Cycles	Tricycles, quadracycles, cycle logistics, cargo bikes, electric cycles	Bandiera et al., 2019; Choubassi et al., 2016; Clausen et al., 2016; Conway et al., 2012; Conway et al., 2017; de Oliveira et al., 2017; Fikar, Hirsch, & Gronalt, 2017; Fiori & Marzano, 2018; Guerrero & Díaz-Ramírez, 2017; He & Haasis, 2019; Heinrich, Shulz, & Geis, 2016; Martins-Turner & Nagel, 2019; Marujo et al., 2018; Navarro et al., 2016; Niels, Hof, & Bogenberger, 2018; Perboli & Rosano, 2019; Perboli et al., 2018; Perboli & Rosano, 2016; Saenz, Figliozzi, & Faulin, 2016; Schier et al., 2016; Slabinac, 2015; Staricco & Brovarone, 2016; Tipagornwong & Figliozzi, 2014; Weiss & Onnen-Weber, 2019	24
Alternative Fuel Freight Vehicles	Electric freight vehicles, hybrid-powered freight vehicles, electromobility	Amodeo et al., 2015; Bandiera et al., 2019; de Oliveira et al., 2017; Guerrero & Díaz-Ramírez, 2017; He & Haasis, 2019; Lebeau et al., 2013; Lebeau et al., 2015; Morganti & Browne, 2018; Morganti & Dablanc, 2014; Napoli et al., 2013; Perboli & Rosano, 2019; Ranieri et al., 2018; Shau et al., 2015; Taefi et al., 2015; Teoh, Kunze, & Teo, 2016	16
Autonomous Freight Vehicles	Robotic freight vehicles, shared autonomous vehicles, automated ground vehicles, self-driving parcels	Beirigo, Schulte, & Negenborn, 2018; Boysen, Schwerdfeger, & Weidinger, 2018; Digiesi et al., 2017; He & Haasis, 2019; Marsden et al., 2018; Mitrea & Kyamakya, 2017; Perboli & Rosano, 2019; Silvestri, Zoppi, & Molfino, 2019; Slabinac, 2015	9
Modular Freight Vehicles	Modular electric vehicles, transferable containers	Andaloro et al., 2015; Dell'Amico & Hadjidimitriou, 2012; He & Haasis, 2019; Rezgui et al., 2019; Slabinac, 2015	5
Delivery Drones	Drones	Guerrero & Díaz-Ramírez, 2017; He & Haasis, 2019; Perboli & Rosano, 2019; Slabinac, 2015	4
Light Commercial Vehicles	Delivery vans	Morganti & Dablanc, 2014	1
Underground Freight Pipline	Freight conveyors	Slabinac, 2015	1
Freight Trams	Gondolas	Staricco & Brovarone, 2016	1

Last Miles Strategies-Urban Goods Consolidation

Strategy	Includes	Authors	# of Articles
Urban Consolidation Centers	Urban distribution centers, micro consolidation centers, city logistics centers, logistics hotels, freight consolidation, consolidation centers	Aljohani & Thompson, 2018; Allen et al., 2018; Amodeo et al., 2015; Andaloro et al., 2015; Cherrett et al., 2012; Clausen et al., 2016; Conway et al., 2012; Dablanc et al., 2013; Digiesi et al., 2017; Finnegan et al., 2005; Gogas & Nathanail, 2016; Guerrero & Díaz-Ramírez, 2017; Handoko et al., 2016; Kin et al., 2018; Lagorio, Pinto, & Golini, 2016; Lebeau et al., 2013; Letnik et al., 2018; Lin, Chen, & Kawamura, 2016; Navarro et al., 2016; Ndhaief, Bistorin, & Rezg, 2017; Nguyen, Lau, & Kumar, 2015; Nsamzinshuti et al., 2016; Paddeu, 2017; Paddeu et al., 2018; Roca-Riu, Estrada, & Fernandez, 2016; Staricco & Brovarone, 2016; van Heeswijk, Mes, & Schutten, 2017; van Rooijen & Quak, 2010; Veličković et al., 2018	29
Parcel Lockers	Lockers, smart lockers, delivery lockers, dropboxes	Alves et al., 2019; Binetti et al., 2019; Carotenuto et al., 2018; Deutsch & Golany, 2018; Faugère & Montreuil, 2018; He & Haasis, 2019; Iwan, Kijeska, & Lemke, 2016; Lemke, Iwan, & Korczak, 2016; Moroz & Polkowski, 2016; Perboli & Rosano, 2019; Perboli et al., 2018; Pronello, Camusso, & Valentina, 2017; Zenezini et al., 2018	13
Pickup Points	Proximity stations, try-and-buy outlets, collection-and-delivery points	Allen et al., 2018; da Silva, de Magalhães, & Medrado, 2019; Digiesi et al., 2017; Guerrero & Díaz-Ramírez, 2017; Ranieri et al., 2018; Zenezini et al., 2018	6

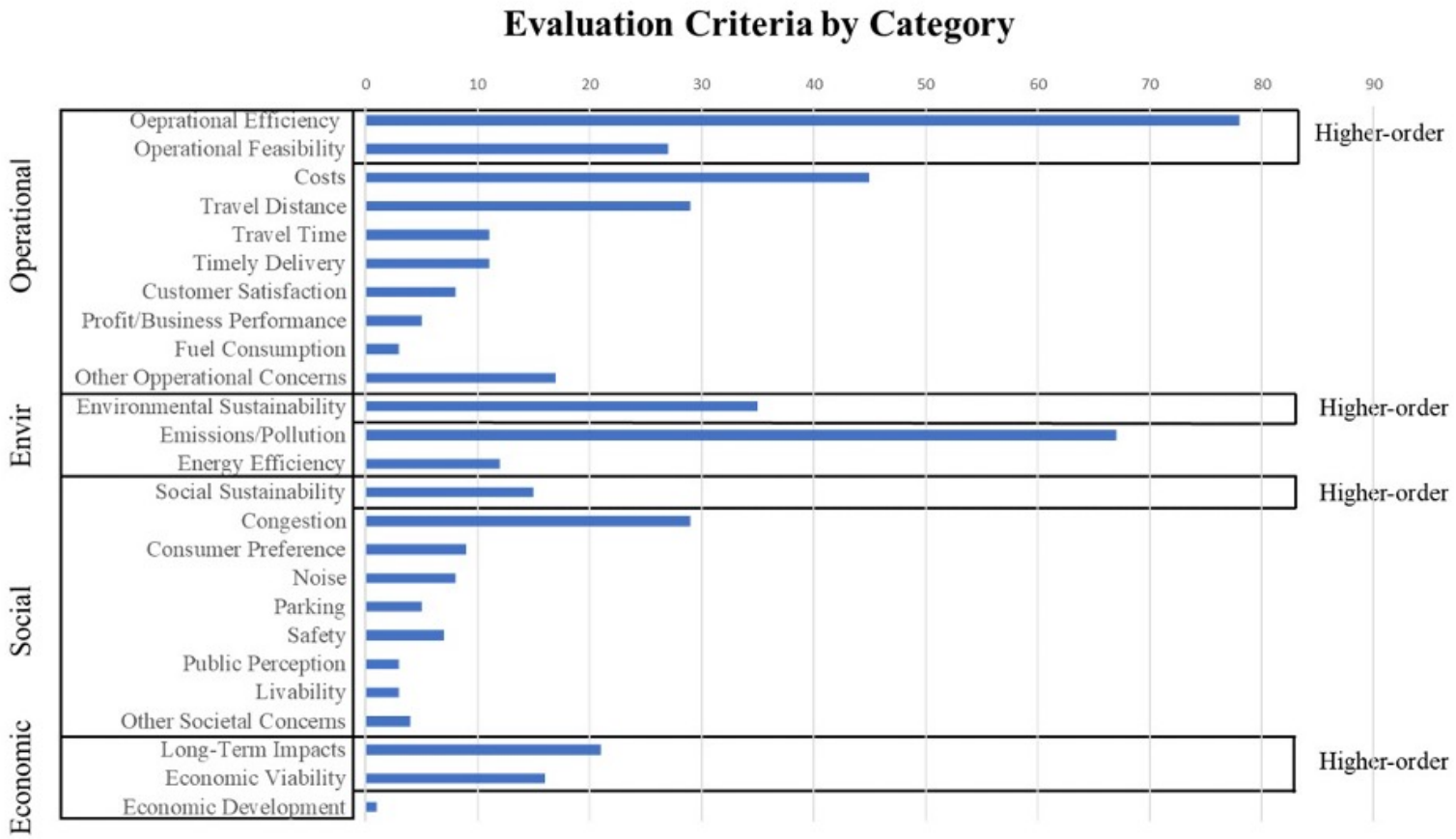
Last Miles Strategies-Technological and Routing Advancements in City Logistics

Strategy	Includes	Authors	# of Articles
Collaborative Logistics	Logistics marketplaces, shared resources, joint distribution, last-mile pooling	Allen et al., 2017; Allen et al., 2018; Bates, Knowles, & Friday, 2017; Cherrett et al., 2012; Dallasega et al., 2018; de Souza et al., 2014; Digiesi et al., 2017; Durand, Mahjoub, & Senkel, 2013; Eidhammer & Anderson, 2014; Giordani et al., 2018; Giret, Julian, & Botti, 2019; Guerlain, Cortina, & Renault, 2016; Handoko & Lau, 2016; He et al., 2019; Kin et al., 2018; Munoz-Villamizar & Montoya-Torres, 2015; Paddeu et al., 2018; Ranieri et al., 2018	18
Vehicle Routing Problem Improvements	Optimization, approximate dynamic programming, distance minimization	Amodeo et al., 2015; Breunig et al., 2019; Digiesi et al., 2017; Ducret, Lemarie, Roset, 2015; Ehmke & Mattfield, 2012; Lebeau et al., 2015; Martins-Turner & Nagel, 2019; Munoz-Villamizar & Montoya-Torres, 2015; Orjuela-Castro, Orejuela-Cabrera, & Adarme-Jaimes, 2019; Perboli et al., 2018; Peroboli & Rosano, 2016; Ranieri et al., 2018; Rezgui et al., 2019; van Heeswijk, Mes, & Schutten, 2017; Zhou et al., 2018	15
Crowdshipping	Crowd logistics, crowdsourced delivery, crowd-tasking, transit logistics, taxi crowdshipping, neighbor relay	Akeb, Monsaf, and Durand, 2018; Allen et al., 2019; Chen & Pan, 2018; Devari, Nikolaev, & He, 2018; Gatta et al., 2018; Gatta et al., 2019; Gdowska, Viana, & Pedroso, 2019; Guo et al., 2015; He & Haasis, 2017; Kulinska & Kulinska, 2016; Serafini et al., 2019; Simoni et al., 2016; Slabinac, 2019; Wang et al., 2019	14
Mobile Depots	Micro depots, mobile city hubs	Allen et al., 2018; Arvidsson & Pazirandeh, 2017; He & Haasis, 2019; Marujo et al., 2018; Niels, Hof, & Bogenberger, 2018; Staricco & Brovarone, 2016; Verlinde, Macharis, & Milan, 2014; Weiss & Onnen-Weber, 2019	8
Temporal Changes	Workplace deliveries, off-hour deliveries, roaming delivery	Allen et al., 2018; Dablanc et al., 2013; Digiesi et al., 2017; Nsamzinshuti et al., 2016; Reyes, Savelsbergh, & Toriello, 2017	5
Enhanced Use of Existing Infrastructure	Spare capacity maximization, taxi logistics, urban waterway logistics, freight buses, freight subway,	Staricco & Brovarone, 2016; Horl et al., 2016; He & Haasis, 2019; Kin et al., 2018	4

Last Miles Strategies-Emerging Planning Tools and Policies

Strategy	Includes	Authors	# of Articles
Urban Access Restrictions	Dynamic access, limited traffic zones, urban freight restrictions, intelligent transportation systems, congestion pricing	Allen et al., 2018; Chen, Wu, & Hsu, 2019; Dablanc et al., 2013; Finnegan et al., 2005; Navarro et al., 2016; Pronello, Camusso, & Valentina, 2017	6
Urban Loading Zones	Drop zones, shared drop zones, loading bays, shared loading zones	Allen et al., 2018; Cherrett et al., 2012; Letnik et al., 2018; Lopez et al., 2019; Pronello, Camusso, & Valentina, 2017; Ranieri et al., 2018	6
Parking Regulations	Freight parking management	Kolbay, Mrazovic, & Larriba-Pey, 2017; Dablanc et al., 2013	2
Certification Requirements	Consultation processes	Dablanc et al., 2013	1

Evaluation of Strategies: Operational, Environmental, Social and Economic



Summary

- Four categories of last-mile delivery strategies that help in synthesizing the large number of solutions.
  - Innovative vehicles,
  - Urban goods consolidation,
  - Technological and routing advancements in city logistics
  - Emerging planning tools and policies.

- The most common evaluation criteria by far are those that fall within the operational category. Considering the prominence of safety in other transportation arenas, we suggest that future research on the topic of last-mile delivery and urban freight should pay more attention to the effects of proposed strategies on safety outcomes.

E-cargo Bikes to Address Urban Freight Problems

Characteristics of E-cargo Bikes

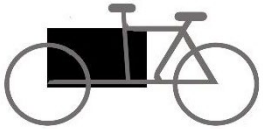
- Being relatively small,
- Requiring less parking space and saving time by finding parking spaces faster than delivery vans,
- Producing less noise and emission relative to delivery vans,
- Being able to use bike infrastructure and maneuver through the city without being significantly affected by heavy traffic, especially in urban areas, and
- Having shorter distances from customers compared to delivery vans.

Types of E-cargo Bikes

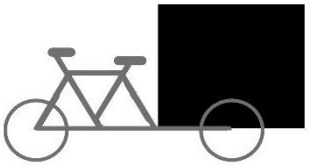
Standard bicycle with panniers or shoulder bag

Standard bicycle with a trailer

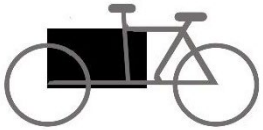
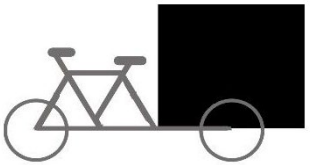
Cargo bike



Cargo trike



Characteristics of Different Types of E-Cargo Bikes

Category	Payload	Advantages	Disadvantages
Standard bicycle with panniers or shoulder bag 	Up to 40 kg	• Fast in traffic • Ease of use • Ease of storage • Ease of parking • Use on and off-road paths • Lower costs (purchase and maintenance)	• Limited capacity • Lack of visibility • Security concerns
Standard bicycle with a trailer 	Up to 80 kg	• Ability to carry larger loads • Potential advertising revenue • Lower costs (purchase and maintenance) • Use on and off-road paths	• Limited security • Weather concerns • Stability concerns • Push/pull effects while riding
Cargo bike 	Up to 80 kg	• Ability to carry larger loads • Ease of use • Potential advertising revenue • Use on and off-road paths • Secure and weather protected	• Higher costs (purchase and maintenance) • Additional security required • Greater riding ability required
Cargo trike 	Up to 250 kg	• Ability to carry larger loads • Ease of use • Potential advertising revenue • Secure and weather protected • Comparable with a small van	• Slower in traffic • Higher costs (purchase and maintenance) • May have road restrictions • Greater riding ability and strength required

Efficiency of E-Cargo Bikes to Address the Last-mile Delivery

- European cycle logistics projects have been economically successful, achieve high profits, and favorable to start-ups, while the bike model (e.g., trailer bike, cargo bike, tricycle, traditional bike) affects economic performance.

- Studies agree on the importance of the location of distributing centers in a cost-saving that could result from implementing e-cargo cycles for delivery activities in dense urban cores

- The fuel costs effects were small on e-trikes competitiveness with vans while the carbon emission reduction is considerable and could range from 51% to 72%

Conclusion

- A statistically significant increase in commercial-VRU crashes in North Carolina and Tennessee, highlighting the importance of looking at VRU-commercial vehicle crashes to improve traffic safety.

- The small vehicles for last-mile delivery are less likely to produce crashes causing severe injuries or fatalities. If carriers continue their trend of using smaller vehicles for last-mile delivery, there is evidence to suggest that crashes between VRUs and this type of delivery vehicle are less likely to cause severe injuries or fatalities.

Conclusion

- Four types of last-mile delivery strategies: innovative vehicles, urban goods consolidation, technological and routing advancements in city logistics, and emerging planning tools and policies.

- Limited studies have examined the effects of those proposed strategies on safety outcomes, highlighting research needs on assessing safety impacts of these last-mile delivery strategies.

- E-cargo bikes have lower vehicle and maintenance costs, lower parking costs, the potential of higher speed in traffic congestion, fewer driver training requirements, and lower negative environmental impacts, but still have limitations in terms of security issues