Collaborative Sciences Center for ROAD SAFETY

FINAL REPORT

Examining the Traffic Safety Effects of Urban Rail Transit:

A Review of the National Transit Database and a Before-After Analysis of the Orlando SunRail and Charlotte Lynx Systems

April 15, 2020

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16. Abstract			
Studies of rail transit safety typically focus on collisions involving rail vehicles and other road users. Nonetheless, the introduction of new rail transit into a metropolitan area may result in changes to the design and use of streets and intersections that influence the safety of other road users. This study conducts a before-after analysis of the Orlando SunRail commuter rail system and the Charlotte Lynx light rail system to understand how the introduction of service influences the incidence of total and KAB crashes near stations and along affected intersections. It finds that for SunRail, total and KAB collisions increased near stations and intersections following the introduction of service, with angle collisions, rear-end collisions, and pedestrian collisions experiencing notable increases. Before, data for the Lynx system were somewhat unreliable, though this study found that the total number of crashes occurring near stations and along intersections were even higher for Lynx than for SunRail, with angle, rear-end, and pedestrian collisions occurring at particularly high numbers. This study uses satellite imagery to identify patterns in the configurations where crashes are likely to occur, and suggests enhancement to signal control that may address these issues.			
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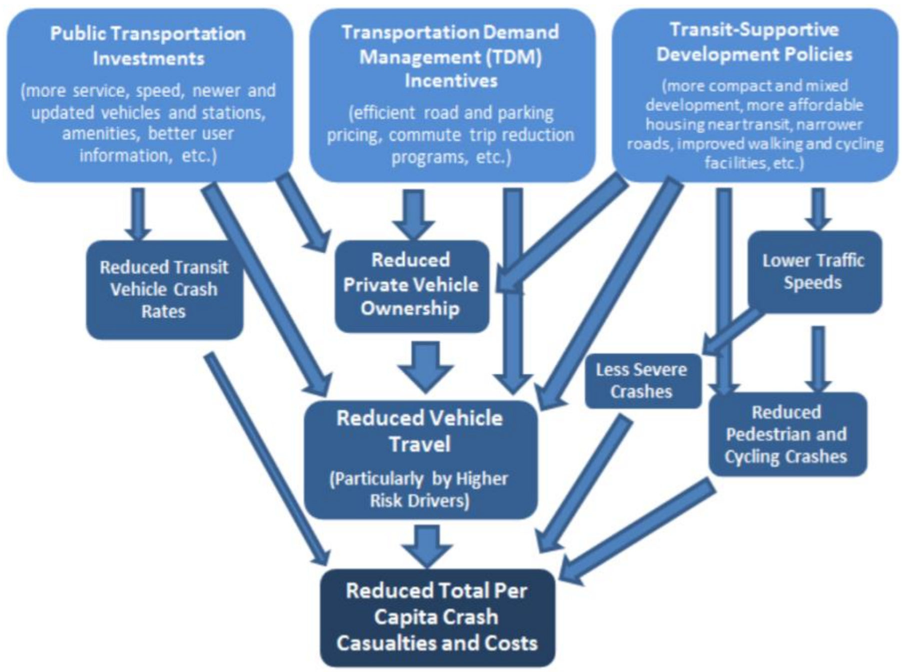
Introduction

Urban environments are spatially constrained. Additional growth into developed areas has created a growing need to enhance the mobility options of existing corridors, leading many cities to prioritize new transit investments. Proposals for new transit service, and particularly rail, are accompanied by the assertion that these systems will not only enhance mobility, but they will also enhance safety (e.g., Espinoza, 2018). Such assertions typically follow the logic that crashes are a function of vehicle miles traveled (VMT), and that investments in transit will decrease VMT and private automobile use, thereby reducing traffic-related deaths and injuries (see Figure 1).



Source: Litman, 2014

Figure 1: The Presumed Causal Path Between Transit Ridership and Traffic Safety

The realization of these safety benefits hinges on a net reduction in regional VMT. While it is certainly the case that new transit users will generate less VMT than they would in the absence of this service, it is unclear that such investments will translate into net regional safety benefits; just as induced demand results in increases in travel as a result of highway capacity expansion (Cervero, 2010; Downs, 2005), one would further expect any congestion relief produced as a result of transit capacity expansion would be offset by increases in vehicular travel as the system returns to its equilibrium state.

Regardless of the presumed relationship between transit use, regional VMT, and safety, the safety benefits of transit service appears to be mixed. It has been well-established that bus service compares favorably to the automobile, reporting roughly half the number of traffic fatalities per billion miles of travel. Heavy rail systems, which typically operate above or below grade, report similarly low fatality rates. However,, the same cannot be said for other types of rail transit. As shown in Table 1 below, the fatality rate associated with the provision of light rail service is fully *twice* that of personal automobiles. The fatality rate of urban passenger rail service is largely unknown; these systems typically run on active freight corridors which are compiled by the Federal

Railroad Administration (FRA) which do not distinguish crashes involving commuter rail from freight service in a usable form.

Table 1: Fatality Rates per Billion Miles Traveled, 2017 (calculated by authors using BTS data)

Mode	Fatalities	Miles Traveled (Billions)*	Fatality Rate
Passenger Car	37,133	3,212.4	9.4
Bus	90	19.3	4.7
Light Rail	51	2.8	18.2
Heavy Rail	88	17.7	5.0

* Transit ridership measured in terms of passenger miles traveled

The National Transit Database (NTD) provides information on collisions involving rail vehicles from 2002-2019. Nonetheless, these data do not include information on collisions involving passenger rail vehicles, nor do they distinguish between collisions involving streetcars and light rail systems for the 2002-2011 period. To understand the safety effects of the 23 light rail systems in the United States (see Figure 2), the research team examined the types of collisions involving rail vehicles and other road users for the 2012-2019 period. A more comprehensive analysis of the NTD data is further presented in Appendix A.

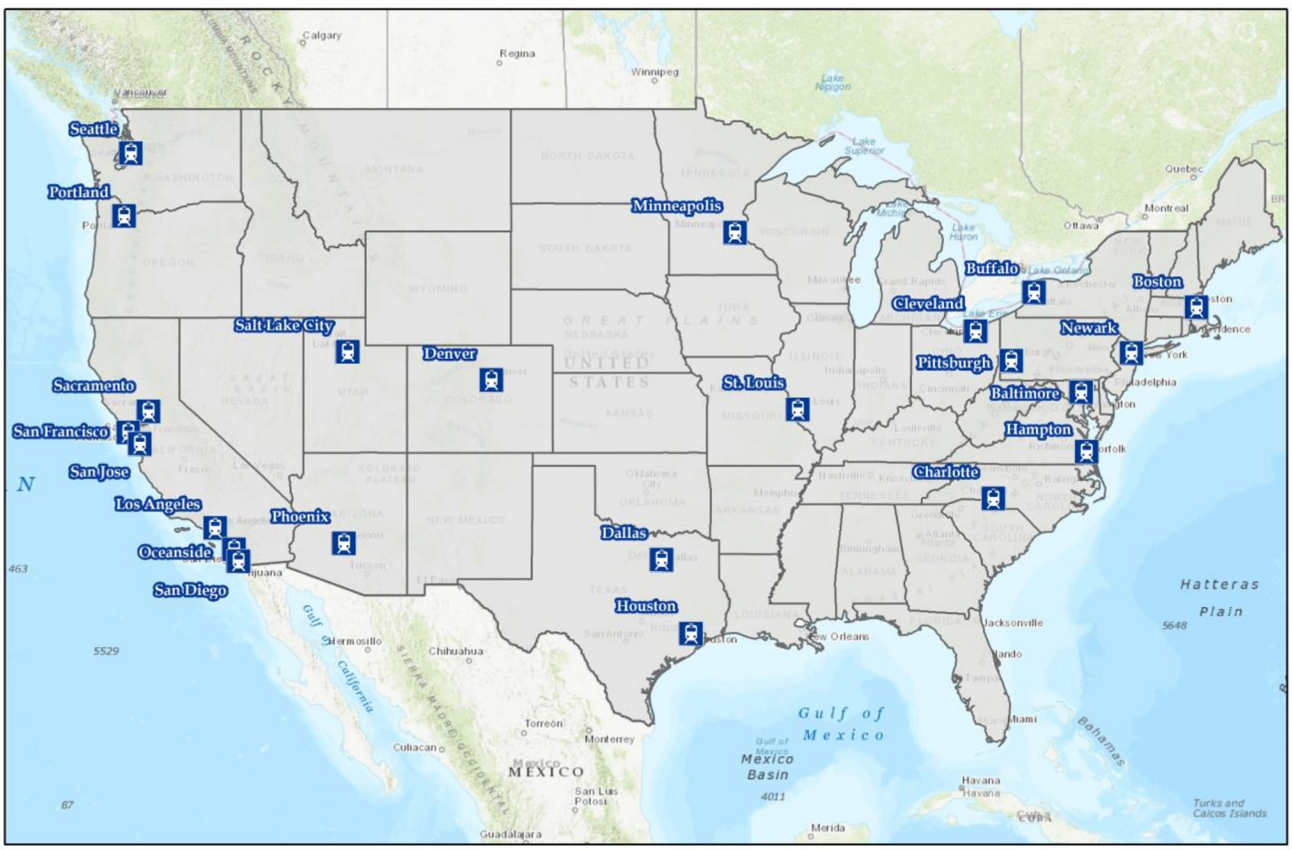


Figure 2: Light Rail Systems in the United States

There were more than 1,300 collisions involving light rail vehicles and other users between 2012 and 2019 (see Table 2). More than half (705) involved a collision with a motor vehicle, while the majority of the remainder (600) involved a collision with a "person," which included pedestrians and cyclists. As shown in Tables 3 and 4, these resulted in 1,532 injuries and 243 fatalities. It should be noted that the categories used for collisions and injuries and fatalities are different, with the latter two categories failing to distinguish injuries involving rail vehicle passengers and motorists. For injuries and fatalities, NTD data further disaggregate "persons" into bicyclists and pedestrians struck at a variety of locations. It is not clear from the data whether there is a one-to-one correspondence between the number of collisions and the number of persons injured or killed. As such, the reader should be cautious about drawing direct comparisons between these tables.

Table 2: Collisions involving Light Rail Vehicles in the United States, 2012-2018

Collisions	**2012**	**2013**	**2014**	**2015**	**2106**	**2017**	**2018**	**Total**
Motor Vehicle	99	69	106	113	130	115	73	705
Person	74	72	81	99	95	74	105	600
Fixed Object	0	2	2	6	3	3	0	16
Rail Vehicle	2	1	1	4	1	1	1	11
Bus Vehicle	2	0	0	0	0	1	0	3
Other	8	2	5	0	2	0	1	18
Total	185	146	195	222	231	194	180	1,353

Table 3: Injuries Associated with Collisions Involving Light Rail Vehicles in the United States, 2012-2019

Injuries	**2012**	**2013**	**2014**	**2015**	**2106**	**2017**	**2018**	**Total**
Bicyclist	5	11	16	14	9	6	9	70
Ped in Crossing	7	7	6	9	28	8	20	85
Ped Not in Crossing	6	3	7	8	14	6	10	54
Ped Crossing Tracks	15	13	14	17	0	0	0	59
Ped Walking Along Tracks	6	4	8	5	4	5	4	36
Other Vehicle Occupant	89	43	86	87	66	93	51	515
Other	37	70	80	117	96	104	83	587
Suicide	8	9	17	26	15	30	21	126
Total	173	160	234	283	232	252	198	1,532

Nonetheless, some general patterns may be established. While the largest share (38.5%) of injuries are categorized as "other," which is defined in the NTD as "a member of the public not specified," the second largest category is "other vehicle occupant," which includes persons injured or killed in non-rail vehicles, such as personal automobiles (33.6%). Pedestrians and cyclists account for less than a third of the total injuries. Of these, the highest number is pedestrians "in crossing," which is a pedestrian attempting to cross an intersection with a rail line. Of the total fatalities, 114 (42%) involve pedestrians and cyclists being struck by a light rail vehicle, while an additional 83 (34%) involve a crash categorized as a suicide.

Table 4: Fatalities Associated with Collisions Involving Light Rail Vehicles in the United States, 2012-2019

Fatalities	2012	2013	2014	2015	2106	2017	2018	Total
Bicyclist	0	6	3	2	2	4	2	19
Ped in Crossing	2	1	3	5	4	6	6	27
Ped Not in Crossing	1	2	0	2	1	2	5	13
Ped Crossing Tracks	6	3	6	9	0	0	0	24
Ped Walking along Tracks	5	2	5	3	0	0	3	18
Other Vehicle Occupant	9	1	2	5	5	7	2	31
Other	1	5	2	4	5	3	8	28
Suicide	11	11	7	11	16	16	11	83
Total	35	31	28	41	33	38	37	243

Why Urban Rail Safety May Be a Larger Problem than Collisions Involving Rail Vehicles

Data from the NTD only provide information pertaining to collisions, injuries, and deaths involving rail vehicles. Such a definition of rail safety almost certainly underestimates the potential hazards associated with urban rail service. Two factors are likely involved. The first is metropolitan areas, in efforts to reduce the capital costs of new rail transit service, have increasingly sought opportunities for adding such service along existing freight routes, routes which may not be well-adapted to the safe conversion from lower-speed freight operations to higher-speed transit service. Given that active freight lines often have a negative effect on residential and commercial activities, it is highly likely that these environments have not been designed with a concern for travelers boarding and alighting rail systems, particularly those accessing the system by walking and cycling. Second, many of these freight routes often run through urban areas at-grade, creating potential safety hazards not only at station areas, but along the intersections the service travels through. Safety hazards may occur not only through conflicts between rail vehicles and other road users, but through changes to the design, operation, and control of these intersections, which may lead to changes in patterns of multiple-vehicle and vehicle-pedestrian collisions.

This study seeks to fill this gap in our professional knowledge using before-after analyses of the Orlando SunRail passenger rail system and the Charlotte Lynx light rail system. To date, there has been little, if any, examination into how the addition of transit service may affect crash incidence. Specifically, this study examines changes in crash incidence before and after the introduction of service, focusing specifically on changes in crashes occurring within 0.1 mile and 0.25 miles of a station, as well as crashes occurring within 250 feet of an at-grade railroad crossing. Unlike much of the literature on rail safety, which focuses specifically on rail-vehicle and rail-pedestrian collisions, this study examines the impacts of these systems on all crash types, as changes to the design and configuration of intersections and station areas may not only result in increases in crashes involving rail vehicles, but may modify the road environment in a manner that results in crashes between other road users.

The sections below present a before-after analysis of the SunRail and Lynx systems, followed by a comprehensive summary of the findings and their implications. Appendix A of the report contains a detailed analysis of the information contained in the National Transit Database.

Passenger Rail: Orlando's SunRail

SunRail is a commuter rail service in Central Florida spanning 35 miles along Orange, Seminole, and Volusia Counties. It began its operation in May 2014 with 12 stations. Figure 3 shows the alignment of the SunRail route and the locations of the SunRail stations. The station locations are listed and described:

- *Sand Lake Road Station:* The Sand Lake Road Station is the southern terminus of SunRail at the time of its opening in 2014. The station is located in Orange County and close to Orlando International Airport. The station has a park and ride lot with more than 400 parking spaces. The area within a quarter-mile of the station has barren land to the west and retail, offices, and industrial parcels to the east.
- *Orlando Health/Amtrak Station*: The Orlando Health station is located just west of Sligh Boulevard between West Underwood Street and West Copeland Drive in Orange County. The station also serves as a station for Amtrak trains. It does not provide park and ride facilities to SunRail users. The surrounding area within a quarter mile of the station has several medical facilities including hospitals, a cancer center, and a doctors' clinic, as well as industrial parcels.
- *Church Street Station*: The Church Street station is a gateway to the City of Orlando's downtown area. The Orlando City Hall, the Orange County government complex, the Orange County Tax Collector downtown office, the federal courthouse, the Wells' Built Museum of African American History and culture, and several churches are within a walking distance from the station. In addition, there are many restaurants, community retail, and government and other offices within a quarter mile of the station. The station also serves the Parramore residential and business area.
- *Lynx Central Station*: The Lynx Central station is located near the intersection of Garland Avenue and Amelia Street in downtown Orlando. The station also serves as a hub of the region's bus network. The following facilities are within easy walking distance from this station: county and federal courthouses, FAMU College of Law, downtown businesses, and entertainment and recreational venues.
- *Advent Health Station*: The station is located inside Advent Health Orlando's main campus. In addition, Loch Haven Park Neighborhood Center, Orlando Children's Theatre, Orlando Science Center, Orlando Museum of Art, and shopping, dining, and entertainment facilities are located within a walking distance of the station.
- *Winter Park Station*: The Winter Park Station is located on the southeast corner of the intersection of Morse Boulevard and Park Avenue in Orange County. The SunRail station is within an easy walking distance of the city's new Winter Park Welcome Center, the Farmer's Market, municipal complex, soccer and softball fields, and Rollins College, as well as an eclectic mix of residential housing.
- *Maitland Station*: The station is located just South of the Maitland Blvd near U.S. Highway 17-92 in Orange County. It is close to the City of Maitland's downtown area. One high-rise residential complex is just adjacent to the station. There is a pedestrian path connecting the station with the neighboring multi-houses. In addition, the surrounding area includes many commercial, retail, and office parcels within a walking distance to/from the station. The station has a park and ride lot with 125 parking spaces.
- *Altamonte Springs Station*: The station is located on the northeast corner of the intersection between Altamonte Drive and Ronald Reagan Boulevard in Seminole County. The station has a park and ride lot. The area within quarter mile surrounding the station includes the city of Altamonte Springs' municipal services complex, commercial and food retail, single-family and multi-family houses, and a park.

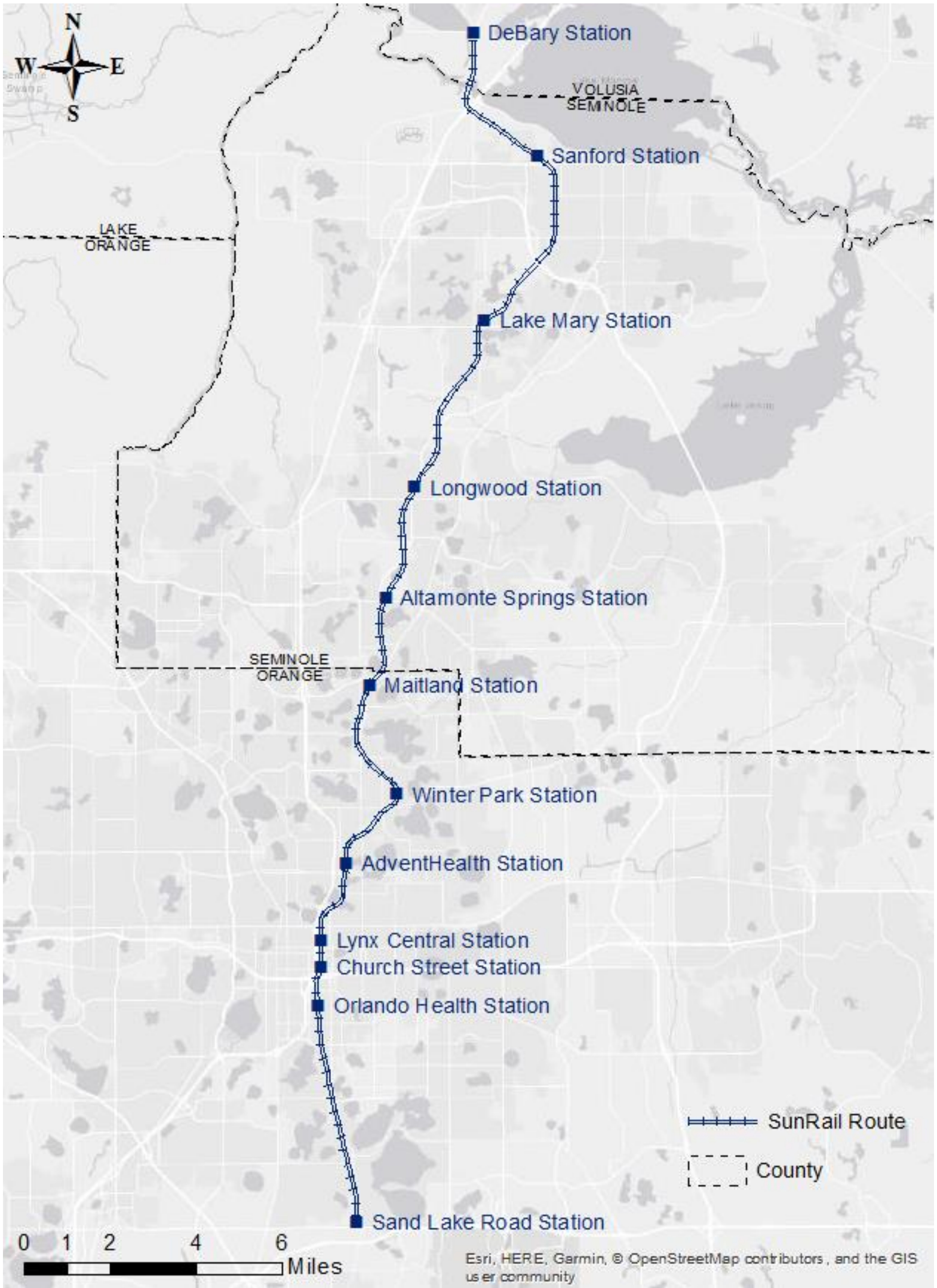


Figure 3: SunRail Alignment and Stations

- *Longwood Station*: The station is located near the intersection of Church Avenue and Ronald Reagan Boulevard in Seminole County. There is a park and ride lot for SunRail passengers within 200 ft of the station. In addition, the South Seminole hospital, the historic civic center, municipal services buildings, single-family houses, two parks, two churches, one farmer's market, and several restaurants and retail shops are within a walking distance of the station.
- *Lake Mary Station*: The Lake Mary station in Seminole County is located adjacent to the City of Lake Mary police department complex, near to the intersection of Crystal Lake Avenue/Old Lake Mary Boulevard and Palmetto Street. A multistoried residential apartment complex was built across the street from the station. There are also single-family houses, restaurants, retail stores, and parks within a quarter mile of the station. The station includes a park and ride lot with 315 spaces.
- *Sanford Station*: The Sanford station is located on the southeast corner of the intersection of State Road 46 and Airport Boulevard in Seminole County. It has a park and ride lot with more than 230 parking spaces. A new residential complex was built just on the east side of the tracks, with a direct connection with the station. In addition to several single-family houses, there is an industrial park within a quarter mile of the station.

Table 5 provides a summary of SunRail stations, including station milepost, presence/absence of park-and-ride facility, and the number of intersections in the neighborhoods of each SunRail station.

Table 5: SunRail Station Attributes

SunRail Station	Milepost	Park and Ride Lot	Number of Intersections within 0.10 mile	Number of Intersections within 0.25 mile
Sand Lake Road Station	796.47	Y	1	2
Orlando Health Station	791.36	N	10	59
Church Street Station	790.42	N	7	87
Lynx Central Station	789.81	N	10	74
AdventHealth Station	787.77	N	9	37
Winter Park Station	785.63	N	16	57
Maitland Station	782.66	Y	3	16
Altamonte Springs Station	780.14	Y	2	20
Longwood Station	776.82	N	7	31
Lake Mary Station	771.55	Y	5	23
Sanford Station	765.97	Y	1	8
DeBary Station	761.72	Y	2	20

SunRail operates on CSXT-A line, procured by the Florida Department of Transportation from CSX Transportation in November 2011. Both passenger and freight rails are allowed to use the line where passenger rail traffic consists of SunRail and Amtrak trains; freight rail traffic consists of a combination of CSXT trains that include tri-level auto trains, merchandise train, coal and rock unit trains, and intermodal unit trains. The following times are allocated to use the CSXT-A line for SunRail (commuter) and other services:

- 5:00 a.m. to 10:00 a.m. – Commuter operation only
- 10:00 a.m. To 3:00 p.m. – Commuter and freight operation only
- 3:00 p.m. To 10:00 p.m. – Commuter operation only

- 10:00 p.m. To 12:01 a.m. – Commuter and freight operation only
- 12:01 a.m. To 5:00 p.m. – Exclusive freight operation only
- Amtrak use – six Amtrak trains between 5:30 a.m. And 4:00 p.m.

SunRail operates five days a week Monday through Friday and is closed on weekends and certain holidays. When opened in 2014, SunRail trains run every 30 minutes during peak hours and every 120 to 150 minutes during midday and evening hours. Table 6 provides a summary of the distance, train running time and speed of SunRail trains between the stations. It usually takes 63 minutes to travel between the southern terminus Sand Lake Road Station and the northern terminus DeBary Station. The average speed of SunRail trains is thus 30.5 mph.

Table 6: SunRail Train Running Times

Station	Distance between Stations (mile)	Train Running Time between Stations (hr:min)	Train Speed between Stations (mph)
Sand Lake Road Station	0.00	0:00	0.0
Orlando Health Station	5.11	0:09	34.1
Church Street Station	0.94	0:03	18.8
Lynx Central Station	0.61	0:03	12.2
AdventHealth Station	2.04	0:05	24.6
Winter Park Station	2.14	0:07	18.3
Maitland Station	2.97	0:07	25.5
Altamonte Springs Station	2.52	0:06	25.2
Longwood Station	3.32	0:04	49.8
Lake Mary Station	5.27	0:06	52.7
Sanford Station	5.58	0:07	47.8
DeBary Station	4.25	0:06	42.5

Table 7 gives the total number of boarding and alighting passengers at each SunRail station during the three years from 2015 through 2017. On average, the annual ridership from 2015 through 2017 was approximately 75,000 per station. The table also shows that Sand Lake Road, Church Street, Lynx Central, Winter Park, and DeBary were busier stations, as more than 90,000 passengers per year either boarded or alighted at these stations.

Data Collection and Processing

SunRail route, station, and crossing locations were obtained as geographic information systems (GIS) shapefiles from Florida Department of Transportation's (FDOT's) Open Data Hub. Note that the shapefiles featured the currently operated SunRail service including the recent extension of SunRail route and stations, and both at-grade and grade-separated crossings along the entire SunRail route. A manual operation was done to select the SunRail route, 12 stations, and at-grade crossings prior to the recent development.

In addition, data were collected for several variables related to SunRail grade crossings. Street Maps and historical imagery from Google Maps and Google Earth applications were reviewed to collect data for the following variables associated with each SunRail grade crossing:

- Number of tracks
- Proximity to nearby intersection
- Land use
- Presence of lighting
- Number of crossing lanes
- Presence and type of median
- Presence of on-street parking
- Number of gates

Table 7: SunRail Annual Ridership

Station	2015		2016		2017		Average	
	Boarding	Alighting	Boarding	Alighting	Boarding	Alighting	Boarding	Alighting
DeBary	117,394	103,484	103,748	87,293	96,179	84,934	105,774	91,904
Sanford	67,825	61,525	64,844	60,181	60,099	55,282	64,256	58,996
Lake Mary	88,514	80,921	83,171	73,479	78,942	74,040	83,542	76,147
Longwood	63,541	59,061	59,590	56,489	57,133	53,849	60,088	56,466
Altamonte Springs	63,389	64,901	59,668	62,365	58,046	58,004	60,368	61,757
Maitland	46,240	46,965	40,603	43,300	40,396	41,766	42,413	44,010
Winter Park	115,798	127,444	91,327	100,163	86,689	93,060	97,938	106,889
FL Hosp. Health V.	51,339	56,915	49,615	55,993	49,620	54,020	50,191	55,643
Lynx Central	103,584	96,832	99,035	96,200	93,866	90,195	98,828	94,409
Church Street	103,848	107,396	96,529	102,971	95,985	103,470	98,787	104,612
Orlando Health	32,252	34,935	31,718	35,291	31,817	33,603	31,929	34,610
Sand Lake Road	118,822	132,167	107,376	113,499	103,109	109,838	109,769	118,501

Crash data were analysed for two different time periods: 2009-2011 and 2015-2017, reflecting three years of data before the beginning of SunRail construction in January 2012 and after the opening of SunRail in May 2014. We excluded data from May through January of 2014, immediately following the opening of the service, to account for adjustments in road user behavior as a result of the new service.

We obtained crash data from the FDOT-managed Unified Basemap Repository (UBR) and the web-based Traffic Safety Portal (TSP) —both managed by FDOT Safety Office. During data processing for this study, crash data from 2003 through 2014 were available in the UBR and data from 2012 through 2017 were available in the TSP. Crash data for the before period were extracted from the UBR and the after period were extracted from the TSP.

These provide counts of total crashes and further categorizes them by severity, including fatalities, incapacitating injuries, non-incapacitating injuries, possibly-injury crashes, and property damage only (PDO) crashes. This analysis examines total crashes, as well as KAB crashes, defined as crash leading to a fatality (K), an incapacitating injury (A), or a non-incapacitating injury (B). To examine the changes in crashes associated with SunRail service, the following crashes for both before- and after-period were extracted using ArcGIS tools:

- Crashes within 0.10 mile of each SunRail station
- Crashes within 0.25 mile of each SunRail station
- Crashes within 250 ft of each SunRail grade crossing

After assigning crashes to corresponding stations and grade crossings, a query was used to count the number of crashes by severity and type within the aforementioned buffer area for each SunRail station and grade crossing.

Before-After Results: Station-area Crashes

To gauge the relative influence of SunRail stations on crash incidence, this study used GIS to capture crashes within 0.1 miles and 0.25 miles of the stations. As shown in Table 8 below, total crashes within 0.1 miles of a station increased by 133% following the introduction of SunRail service, and KAB crashes increased by 67%. There was a good deal of variation around individual stations, with the areas around the Altamonte Springs and Advent Health stations experiencing particularly notable increases in total and KAB crashes. Wilcoxon ranked-signs tests were employed to determine to evaluate these systemwide effects. Changes in total crashes proved significant at the 0.001 level of confidence, while KAB crashes were significant only at the 0.185 level of statistical confidence. Nonetheless, the low number of crashes (15 before, 25 after) likely influences these estimates; we would expect that the inclusion of several additional years of data would result in the differences being statistically-significant at conventional levels.

Table 8: Crashes within 0.1 Mile of a SunRail Station

	KAB*			Total*		
Station Area (0.1 Mile)	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**
Altamonte Springs	0	6	600.00%	9	32	255.56%
Church Street	5	5	0.00%	25	57	128.00%
DeBary	0	3	300.00%	0	4	400.00%
Advent Health	1	4	300.00%	2	14	600.00%
Lake Mary	1	0	-100.00%	2	4	100.00%
Longwood	2	5	150.00%	7	22	214.29%
Lynx Central	6	0	-100.00%	28	38	35.71%
Maitland	0	0	0.00%	1	0	-100.00%
Orlando Health	0	0	0.00%	3	1	-66.67%
Sand Lake Road	0	1	100.00%	1	4	300.00%
Sanford	0	0	0.00%	0	0	0.00%
Winter Park	0	1	100.00%	6	20	233.33%
Total	15	25	66.67%	84	196	133.33%
	Wilcoxon z=1.330; p(z)=0.1848			Wilcoxon z=2.592; p(z)=0.0095		

*Where there are 0 values, the percent change is reported as 100% of absolute crash count.

Table 9 further shows how specific crash types changed following SunRail operations. For total crashes, the greatest increases were observed in pedestrian, sideswipe, and rear-end collisions. For KAB crashes, the greatest increases were observed in pedestrian and rear-end collisions.

Table 9: Crash Types within 0.1 Miles of a SunRail Station

Station Area (0.1 Mile)	KAB*			Total*		
	Before	After	% Change	Before	After	% Change
Pedestrian	1	3	200.00%	1	4	300.00%
Bicyclist	1	0	-100.00%	1	0	-100.00%
Rail-Vehicle	0	0	0.00%	0	1	100.00%
Parked Car	0	0	0.00%	6	7	16.67%
Multiple Vehicle						
Rear-End	2	8	300.00%	25	76	204.00%
Head-on	0	2	200.00%	3	3	0.00%
Angle	9	6	-33.33%	21	37	76.19%
Sideswipe	1	1	0.00%	6	31	416.67%
Other Multiple Vehicle	0	4	400.00%	11	16	45.45%
Fixed Object	0	0	0.00%	6	17	183.33%
Other/Unknown	1	1	0.00%	4	4	0.00%
Total	15	25	66.67%	84	196	133.33%

*Where there are 0 values, the percent change is reported as 100% of absolute crash count.

The analysis of the 0.25-mile buffer reports similar results, although the overall effect is lessened, with total crashes increasing by 79%, and KAB crashes increasing by 9%. The results of the Wilcoxon ranked-signs tests was similar to that of the 0.1 mile buffer, with total crashes being significant at conventional levels and KAB crashes not entering at these levels, though the statistical confidence of both was less than the results of the 0.1 mile buffer. This makes intuitive sense; the influence of the station would be most directly experienced in the immediate area surrounding the station, and tape off as one gets further away from the station.

Table 10: Total and KAB Crashes within 0.25 Miles of a SunRail Station

Station Area (0.25 Mile)	KAB*			Total*		
	Before	After	% Change	Before	After	% Change
Altamonte Springs	15	13	-13.33%	52	75	44.23%
Church Street	58	62	6.90%	252	436	73.02%
DeBary	0	6	600.00%	1	11	1000.00%
Advent Health	14	20	42.86%	67	126	88.06%
Lake Mary	7	9	28.57%	24	79	229.17%
Longwood	4	5	25.00%	15	64	326.67%
Lynx Central	44	35	-20.45%	171	261	52.63%
Maitland	13	7	-46.15%	37	85	129.73%
Orlando Health	2	5	150.00%	21	30	42.86%
Sand Lake Road	21	25	19.05%	97	127	30.93%
Sanford	4	3	-25.00%	9	14	55.56%
Winter Park	1	10	900.00%	33	88	166.67%
Total	183	200	9.29%	779	1396	79.20%
	Wilcoxon z=1.062; p(z)=0.2881			Wilcoxon z=3.061; p(z)=0.0022		

*Where there are 0 values, the percent change is reported as 100% of absolute crash count.

Considering crashes by type (see Table 11), there is a notable increase in injuries involving pedestrians, which nearly doubled to 29 following the operation of SunRail service. As with the 0.1 mile area, rear-end and sideswipe collisions are the crash types with the largest overall percentage increases.

Table 11: Crash Types within 0.25 Miles of a SunRail Station

	KAB*			Total*		
Station Area (0.25 Mile)	**Before**	**After**	**% Change**	**Before**	**After**	**% Change**
Pedestrian	16	29	81.25%	32	36	12.50%
Bicyclist	11	8	-27.27%	20	12	-40.00%
Rail-Vehicle	0	0	0.00%	0	4	400.00%
Parked Car	0	1	100.00%	30	46	53.33%
Multiple Vehicle						
Rear-End	30	59	96.67%	234	478	104.27%
Head-on	4	9	125.00%	19	38	100.00%
Angle	79	56	-29.11%	219	348	58.90%
Sideswipe	7	10	42.86%	80	231	188.75%
Other Multiple Vehicle	16	13	-18.75%	68	89	30.88%
Fixed Object	12	10	-16.67%	48	89	85.42%
Other/Unknown	8	5	-37.50%	29	25	-13.79%
Total	183	200	9.29%	779	1396	79.20%

*Where there are 0 values, the percent change is reported as 100% of absolute crash count.

Before-After Results: Intersection-related Crashes

The safety hazards associated with the introduction of rail transit are presumed to involve collisions involving rail vehicles and other road users or, in the areas immediately surrounding a transit station, vehicle-pedestrian collisions as a result of increased pedestrian activity. Yet the provision of surface rail leads to a change in the operation of affected intersections, which may not only lead to crashes involving trains and other road users, but between road users attempting to navigate the intersection. To date, there has not been a single study that has sought to understand how surface rail might influence intersection safety. To understand the potential safety effects of SunRail on intersection safety, the research team used GIS to draw a 250 foot buffer around the 93 intersections that include a SunRail crossing, which corresponds with the intersection area of influence, and captures all of the crashes that occurred within before and after the introduction of service.

As shown in Table 12 below, all crash types increased along these at-grade intersections following the introduction of SunRail service. T-tests of the differences found that all of these crashes, except for head-on and "other," increased at confidence levels of 0.1 or greater. In many of these cases, the percentage increase is quite dramatic; vehicle-pedestrian collisions increased by 250%, vehicle-bicyclist collisions increased by 450%, and rail-vehicle collisions increased by 750%. Yet of greater note is not simply the percentages of the increase, but the change in absolute numbers, particularly for multiple vehicle collisions; angle collisions increased from 34 to 135, and rear-end collisions increased from 81 to 220.

Table 12: Total Crashes within 250 feet of SunRail Grade Crossing

	Before	After	% Change	t-statistic	p-value
Pedestrian	2	7	250.00%	1.518	0.066
Bicyclist	2	11	450.00%	2.229	0.014
Rail-Vehicle	2	17	750.00%	2.698	0.004
Parked Car	6	16	166.67%	2.575	0.006
Multiple Vehicle					
- Rear-End	81	220	171.60%	4.580	0.000
- Head-on	9	8	-11.11%	-0.257	0.399
- Angle	34	135	297.06%	5.329	0.000
- Sideswipe	14	64	357.14%	4.676	0.000
- Other Multiple Vehicle	18	47	161.11%	2.702	0.004
Fixed Object	17	73	329.41%	3.624	0.000
Other/Unknown	13	21	61.54%	1.238	0.109
Total	198	619	212.63%	6.762	0.000

Table 13 below shows the counts and test statistics for KAB crashes. Overall, the introduction of SunRail service resulted in KAB crashes to nearly double, going from 37 in the before period to 67 afterwards. T-Test results show that these differences are significant at the 0.006 level of statistical confidence. Because of the low absolute numbers of crashes, the test results were less conclusive regarding the distribution of individual crash types, though pedestrian, bicyclist and angle crashes all entered at the 0.1 level of statistical confidence or greater, reporting crash increases of 500%, 600%, and 81%, respectively.

Table 13: KAB Crashes within 250 feet of SunRail Grade Crossing

	Before	After	% Change	t-statistic	p-value
Pedestrian	1	6	500.00%	1.683	0.048
Bicyclist	1	7	600.00%	1.751	0.042
Rail-Vehicle	2	2	0.00%	0.000	0.500
Parked Car	1	1	0.00%	0.000	0.500
Multiple Vehicle					
- Rear-End	11	14	27.27%	0.538	0.296
- Head-on	1	2	100.00%	0.575	0.283
- Angle	11	20	66.67%	1.579	0.059
- Sideswipe	4	2	-50.00%	-0.815	0.209
- Other Multiple Vehicle	2	4	100.00%	0.815	0.209
Fixed Object	2	6	200.00%	1.269	0.104
Other/Unknown	1	3	300.00%	1.000	0.160
Total	37	67	81.08%	2.537	0.006

Discussion: Factors Influencing Crashes along SunRail At-Grade Intersections

Considered as a whole, rear-end collisions had the greatest overall increase following the provision of service, more than doubling in the after period, jumping from 81 such collisions, to 220. An examination of the locations reporting the highest number of rear-end collisions reveals a consistent configuration; these locations occur on multi-lane arterial thoroughfares, with a rail crossing located roughly 250' downstream from a signalized, multi-lane intersection (see Figure 4). In this case, the safety issue appears to be associated with confusion resulting from the secondary railroad crossing located in proximity to the signalized intersection. While all of the intersections have Manual on Uniform Traffic Control Devices (MUTCD)-compliant crossbuck signs and advance warning pavement markings, these do not appear to be sufficient to prepare platooned vehicles to adequately brake in response to a lead vehicle stopping for railway closure.

This is an issue that can be addressed by coordinating the control of the signalized intersection with the railroad flashing-light system. The MUTCD indicates that if the flashing light system "is located within 200 feet of an intersection or midblock location controlled by a traffic control signal, the traffic control signal should be provided with preemption in accordance with Section 4D.27" (FHWA, 2009 p. 776). In all of the cases considered here, the railway crossings are located roughly 250 feet from the intersection, thus outside of the area where an advancing train would trigger preemption at the signalized intersection. Our findings suggest it may be desirable to expand the area for signal preemption to at least 250'.

Nevertheless, we should note that despite the dramatic increase in rear-end collisions following the introduction of SunRail Service, these were not associated with a corresponding increase in KAB collisions, which increased only from 11 to 14. Again, this is unsurprising; rear end collisions, when compared against other crash types, tend to be less severe due to a reduction in impact force attributable to both vehicle traveling in the same direction, as well as because contemporary automobiles are generally designed to absorb the force of such collisions.

Figure 4: Locations with Post-SunRail Increases in Rear-end Collisions

Of greater concern is the dramatic increase in angle collisions, which jumped form 34 in the before period to 135 in the after period, and which saw KAB collisions nearly doubled from 11 to 20. Several of these intersections appear to report high numbers of crashes as a result of localized factors that emerged concurrent with the introduction of SunRail service, such as the construction of a highway on- and off-ramps along an arterial adjacent to the rail crossing. Nonetheless, locations where angle crashes concentrate tend to be those where the rail crossing runs parallel to an adjacent cross street (See Figure 5). The issue here, which involves two vehicles colliding at the intersection, appears to be attributable not to the rail service, but instead to intersection design and control. We do not have information on how the signal configurations may have changed before and after the start of service, though angle crashes are attributable to intersection control features such permitted left turns, inadequate sight distance, and an inadequate change interval between opposing streams of traffic.[1] Localized factors may be further contributing to these increases. A review of satellite imagery reveals that Horatio Ave (below, left) allows permitted left-turns, a known contributing factor to angle collisions, and Airport boulevard (below, right) was double-tracked to accommodate SunRail service, which may expand the intersection area of influence to levels that affect decision sight distances. In either case, there is a consistency in the overall design of environments with concentrations of angle collisions; specifically, which is the location of the rail line parallel to an intersecting street.

Figure 5: Locations of Post-SunRail Increases in Angle Collisions

Finally, crashes involving a rail car crashing into a vehicle rose from 2 in the before period, to 17 in the after period, though the number of KAB crashes involving rail-vehicle collisions remained constant at 2. Most rail-vehicle crashes at intersections were isolated events, with two exceptions (see Figure 6): 4 rail-vehicle crashes occurred at the rail line's intersection with Michigan Street, while 2 occurred at the intersection with N. Ronald Reagan Boulevard. Neither location employs four-quadrant gates, which almost certainly contributes to the safety issue, while the turn lanes associated with an upstream signal along Ronald Reagan

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[1] The change interval is the combination of the yellow interval and the all-red clearance interval.

Boulevard extend back into the rail crossing, suggesting that intersection control may result in vehicles queuing on the tracks. Further, both locations received additional track in support of SunRail service, with Ronald Reagan going from a 1 to 2-track configuration and Michigan Street going from a 2- to 3-track configuration.

Figure 6: Locations of Multiple Rail-Vehicle Collisions

Safety Performance Functions (SPF) for Intersection-related Crashes

To further understand safety risks occurring along at-grade crossings, a safety performance function (SPF) for SunRail grade crossings was developed using the after-period crash data. An SPS is a regression equation that correlates the predictor variables to the crash frequency. The predictor variables include traffic volume, traffic control, roadway and neighborhood characteristics. Table 14 gives a summary of the predictor variables used in this study to develop SPFs for SunRail grade crossings.

Table 14: Description of Model Variables

Variable	Type	Description
Annual Average Daily Traffic (AADT)	Continuous	Min: 0; Max: 48,500; Mean: 9,080
Land use	Categorical	3 categories: residential, institutional, and commercial/industrial
Roadway speed limit	Categorical	2 categories: ≤25 mph, >25 mph
Number of lanes	Continuous	Min: 2, Max: 6, Mean: 2.72
Number of gates	Continuous	Min: 1, Max: 4, Mean: 2.13
Road type	Categorical	3 categories: divided, undivided, one-way
Distance to nearest intersection	Categorical	4 categories: 75 ft, 200 ft, 500 ft, >500 ft
Crossing angle	Categorical	3 categories: 0° – 29°, 30° – 59°, 60° - 90°
Functional class	Categorical	3 categories: arterial, collector, local
Presence of lighting	Categorical	2 categories: yes, no
Presence of on-street parking	Categorical	2 categories: yes, no

SPFs were developed under the assumption that crashes were random, independent, and overdispersed. As such, a negative binomial (NB) distribution was used to account for overdispersion in the model. Table 15 gives the summary of the results, which include parameter estimates and associated statistics for the statistically significant variables. It shows that the dispersion parameter is positive and greater than zero, which indicates the suitability of the NB model. To detect statistically significant variables, a level of significance of 0.10 was considered for AADT and a level of significance of 0.20 was considered for all other variables (Harwood et al., 2010).

Table 15: Negative Binomial Model Results

Variable	Estimate	Std. Error	z-value	p-value
Intercept	-0.646	0.285	-2.268	0.023
AADT in thousands	0.041	0.012	3.367	0.001
Number of lanes	0.329	0.118	2.790	0.005
Speed limit[a]: >25 mph	0.324	0.254	1.277	0.202
Distance to nearest intersection[b]: 200 ft	-0.450	0.255	-1.765	0.078
Distance to nearest intersection[b]: 500 ft	-0.777	0.285	-2.731	0.006
Distance to nearest intersection[b]: >500 ft	-1.185	0.532	-2.229	0.026
Dispersion parameter	0.693			

[a] base category: ≤25 mph
[b] base category: 200 ft

Based on the aforementioned criterion, AADT, number of lanes of crossing roads, distance to nearest intersection, and roadway speed limit were found to have significant associations with crashes at SunRail grade crossings. In particular, AADT, number of lanes, and roads that have speed limit 25 mph or higher exhibit positive associations, indicating that the likelihood of crash frequency increases as the unit of each variable increases. On the other hand, the table shows that the frequency of crashes at SunRail grade crossings lessens as the distance to the nearest intersection increases. In other words, crashes are more likely to occur when there is an intersection close to the grade crossing.

Light Rail: Charlotte's Lynx

The City of Charlotte's light rail system, commonly referred to as Lynx Blue Line (hereafter referred to simply as Lynx), started its operation in November 2007 with 14 stations between South Boulevard and 7th Street, spanning 9.6 miles. Figure 7 shows the alignment of the Lynx route and the locations of the Lynx stations. A brief description of the 14 stations is provided below.

- *South Boulevard*: The station platform is grade separated. There is an elementary school on one side of the station, and restaurants, bank, and stores on the other side.
- *Sharon Road West*: The station platform is grade separated. Land use around the station is of industrial type.
- *Arrowood*: The station does not have any direct connection with the adjacent road.
- *Archdale*: The station platform is elevated. There are residential and commercial units around the station
- *Woodlawn*: The station platform is not at the ground level but is accessible by ramps. Land use around the station is of commercial type.
- *Scaleybark*: The station platform is at the ground level. There are stores, auto services, and an office complex around the station.
- *New Bern*: The station platform is at the ground level. There is a residential complex at the corner of the station.
- *East/West Blvd*: The station platform is at the ground level. There are retail stores around the station.
- *Bland Street*: The station platform is at the ground level, and land sue around the station is of commercial type.
- *Carson*: The station platform is at the ground level. There are two apartment complexes at two corners of the stations. In addition, there are retail stores around the station.
- *Stonewall*: The station is elevated and located on top of the Westin Hotel parking deck. There are offices, hotels, and retail stores around the station.
- *Tyvola*: The station platform is elevated. Land use around the station is of commercial type.
- *3rd Street*: The station platform is grade-separated. There are offices, hotels, and retail stores around the station.
- *Charlotte Transportation Center*: The station platform is grade-separated. The station is located in the city of Charlotte's transportation hub, and as such pedestrian activity is very high at this station.
- *7th Street*: The station platform is at the ground level, and land use around the station is of commercial type.

Figure 7: Lynx Route Alignment and Stations

Table 16 gives the number of boarding and alighting passengers at each station of the Lynx Line in 2009, as obtained from the Charlotte Department of Transportation. It shows that a total of 4.7 million passengers used Lynx in 2009, which indicates a daily ridership of approximately 13,000. The maximum number of Lynx passengers was handled by the Charlotte Transportation Center station, as more than 22% of total Lynx passengers either boarded or departed from the Lynx trains at this station. This station is in downtown Charlotte and acts as a transportation hub by providing extensive connections to inter- and intra-state bus service. In addition, more than 810,000 passengers boarded the Lynx trains and approximately 790,000 passengers alighted form Lynx trains annually at the South Boulevard station, which is the southern terminus. Next, the 7th Street, Arrowood, and 3rd Street stations each served more than 300,000 passengers annually.

Of the other stations, the Sharon Road West, Archdale, Tyvola, Woodlawn, Scaleybark, and East/West Boulevard stations each served 200,000-300,000 Lynx passengers in 2009.

Table 16: Lynx Ridership in 2009

Station	Boarding	Alighting
South Boulevard	818,609	791,865
Sharon Road West	267,744	250,380
Arrowood	340,551	360,246
Archdale	215,381	205,412
Tyvola	254,715	242,606
Woodlawn	209,192	217,041
Scaleybark	254,335	227,281
New Bern	160,829	152,688
East/West Boulevard	209,666	187,717
Bland Street	95,114	95,959
Carson	79,118	73,361
Stonewall	87,161	98,252
3rd Street	316,563	399,303
Charlotte Transportation Center	1,079,557	1,145,841
7th Street	363,673	304,254
Total	**4,752,208**	**4,752,206**

Data Collection and Processing

Lynx alignment and station data were downloaded in the form of Geographic Information System (GIS) shapefiles from the City of Charlotte's open data portal. The Lynx alignment was overlaid on the Google Maps to identify the Lynx crossings. After locating the crossings, every crossing was manually inspected to record whether the crossing was at-grade. A total of 16 crossings were identified as at-grade Lynx crossings.

Crash data for Charlotte was obtained from Highway Safety Information Systems (HSIS) for all the available years, which is 2004-2017. The construction of Lynx began in February 2005 and the service was open in November 2007. At least three years of crash data before the beginning of the construction and after the opening of the Lynx service would be ideal to avoid the possible effect of the regression to the mean. Given that the crash data for Charlotte was not available for years prior to 2004, the before-period data was limited to single year (i.e., 2004). On the other hand, analysis of crash data for the after-period was based on crashes that occurred between 2009 and 2011, i.e., consisting of three years of data from the beginning of the next year after six months of opening. To enable a meaningful comparison between these two different time frames, we report only the one-year average for the after period.

To understand the safety risks associated with Lynx, the following crashes for both before- and after-period were extracted using ArcGIS tools:

- Crashes within 0.10 mile of each Lynx station
- Crashes within 0.25 mile of each Lynx station,
- Crashes within 250 ft of each at-grade Lynx crossing

Lynx Data Limitations and Comparison to SunRail

A few limitations with the data should be noted before presenting our findings. First, as noted above, we were unable to obtain three years of before data, suggesting that regression-to-the-mean may be in effect for the before-period results. Second, the manner in which crash data were recorded changed between the before and after periods, making us uncertain about the extent to which the findings for the before and after periods are directly comparable. Data from the before period do not provide information on crash type, preventing this study from analyzing changes in the types of crashes that occurred (e.g., whether the crashes involved pedestrians, cyclists, or motorists). Finally, the operation of Lynx service corresponded with the onset of the Great Recession, which led to a temporary 25% reduction in traffic fatalities nationally. To understand whether similar factors may be involved here, we examined how crash incidence in Charlotte-Mecklenberg County as a whole, in which Lynx is based, changed between the before and after periods. The country reported a 21% reduction in total crashes between the before and after periods, irrespective of Lynx service. It seems highly probable that these general crash reductions influence our after-period findings.

Because we are more confident with our findings for SunRail, we begin by presenting general results that compare Lynx to SunRail to provide a baseline for comparison. Considered as a whole, the Lynx system reported far more total crashes, per station and per intersection, than did SunRail. As shown in Table 17, below, there were 550% more crashes within 0.1 miles of a Lynx station than a SunRail Station, and 47% more crashes within 0.25 miles. This corresponded to 22% more KAB crashes within 0.1 miles of a Lynx station, though Lynx also showed 44% fewer crashes within 0.25 miles. This is consistent with the findings for SunRail, which showed that the greatest safety effect occurred in the immediate (0.1 mile) area surrounding the station. Lynx further reported a substantially-higher number of crashes for each at-grade intersection (86%), as well as higher numbers of KAB crashes per intersection (57%). Considered as a whole, this indicates that the area affected by the Lynx system is far more crash-prone than SunRail.

Table 17: Comparison of SunRail vs. Lynx

	SunRail	Lynx	Difference
Stations	12	15	
Avg Crashes 0.1 Mile from Station	7.0	45.7	552.4%
Avg. KAB Crashes 0.1 Mile from Station	2.1	2.5	21.6%
Avg. Crashes 0.25 Mile from Station	116.3	171.1	47.0%
Avg. KAB Crashes 0.25 Mile from Station	16.7	9.4	-43.6%
Grade Crossings	93	16	
Avg. Crashes per Grade Crossing	6.7	12.3	84.0%
Avg. KAB Crashes per Grade Crossing	0.7	1.1	57.3%

Before and After Results: Station-area Crashes

As shown in Table 18, total crashes occurring within 0.1 mile of a Lynx station decreased by 31% following the introduction of service, while KAB crashes decreased by 21%. The results of the Wilcoxon ranked-signs test show that the results for total crashes is significant at the 0.003 level of confidence, while the results for KAB crashes were not significant. Nonetheless, it should again be noted that Charlotte-Mecklenburg County, as a whole, experienced a 21% reduction in total crashes during this time period, suggesting that at least some portion of the observed reduction may not be attributable to safety benefits associated with the service, but instead a product of area-wide declines in crash incidence. While the before-period crash data did not provide information on crash type, this data was available for the after period and is nonetheless instructive and is presented in Table 19. Angle crashes provide to by the type of crash that occurs most frequently near Lynx stations, and also reported the highest numbers of KAB collisions.

Table 18: Total and KAB Crashes within 0.1 Miles of a Lynx Station

Station Area (0.1 Mile)	KAB Crashes (one year)*			Total Crashes (one year)		
	Before	After	Pct. Change	Before	After	Pct. Change
3rd St/Convention Center	3	1	-66.67%	29	14	-51.72%
7th St	3	0.67	-77.78%	35	29.33	-16.19%
Archdale	1	2	100.00%	43	32	-25.58%
Arrowood	0	0	0.00%	11	7	-36.36%
Bland St	1	0.67	-33.33%	19	9.33	-50.88%
Carson	1	0.33	-66.67%	10	6	-40.00%
Charlotte Transportation Center	1	2	100.00%	40	27	-32.50%
East/West	0	1	100.00%	35	35.67	1.90%
I-485/South Blvd	0	0.33	33.00%	7	4.33	-38.10%
New Bern	1	0	-100.00%	18	8.33	-53.70%
Scaleybark	3	1.67	-44.44%	11	9.33	-15.15%
Sharon Road West	1	0.67	-33.33%	25	10.67	-57.33%
Stonewall	1	0.33	-66.67%	31	14.67	-52.69%
Tyvola	0	2	200.00%	16	20	25.00%
Woodlawn	0	0	0.00%	1	0.67	-33.33%
Total	16	12.67	-20.83%	331	228.33	-31.02%
	Wilcoxon z=-0.770; p(z)=0.4411			Wilcoxon z=-2.956; p(z)=0.0031		

*Where there are 0 values, the percent change is reported as 100% of absolute crash count.

As shown in Table 20, the same general percentages are observable within 0.25 miles of a Lynx station, which reported 35% fewer crashes in the after period, and 20% fewer KAB crashes. The results of the Wilcoxon ranked-signs test did not find either difference to be significant at conventional levels of statistical confidence. Table 21 shows the distribution of crash types for the after period, with angle crashes being the crash type occurring most frequently and resulting in the largest number of KAB collisions.

Table 19: Crash Types within 0.1 Mile of a Lynx Station

Station Area (0.1 Mile)	KAB (one-year avg.)		Total (one-year avg.)	
	Before	After	Before	After
Pedestrian	n/a	2	n/a	7
Bicyclist	n/a	0.33	n/a	1.33
Rail-Vehicle	n/a	0	n/a	0.33
Parked Car	n/a	0	n/a	2
Multiple Vehicle				
Rear-End	n/a	3.33	n/a	71.67
Head-on	n/a	0	n/a	2.33
Angle	n/a	4.67	n/a	84.67
Sideswipe	n/a	0.67	n/a	38
Other Multiple Vehicle	n/a	0	n/a	5.67
Fixed Object	n/a	0	n/a	3.67
Other/Unknown	n/a	1.67	n/a	11.67
Total	n/a	12.67	n/a	228.33

Table 20: Total and KAB Crashes within 0.25 Miles of a Lynx Station

Station Area (0.25 Mile)	KAB Crashes (one year)*			Total Crashes (one year)		
	Before	After	Pct. Change	Before	After	Pct. Change
3rd St/Convention Center	6	5.67	-5.56%	128	82.67	-35.42%
7th St	14	4.33	-69.05%	183	92.67	-49.36%
Archdale	3	4	33.33%	71	52.67	-25.82%
Arrowood	1	1.33	33.33%	57	41	-28.07%
Bland St	3	3	0.00%	57	49.33	-13.45%
Carson	1	2.33	133.33%	49	47	-4.08%
Charlotte Transportation Center	4	6.67	66.67%	130	97	-25.38%
East/West	7	2	-71.43%	117	85.33	-27.07%
I-485/South Blvd	0	1.67	1.67%	26	20.33	-21.79%
New Bern	3	0.67	-77.78%	37	25	-32.43%
Scaleybark	3	3.67	22.22%	57	32.33	-43.27%
Sharon Road West	3	0.67	-77.78%	61	18.33	-69.95%
Stonewall	3	2.67	-11.11%	78	53.33	-31.62%
Tyvola	7	5	-28.57%	139	93.33	-32.85%
Woodlawn	1	3.33	233.33%	117	65	-44.44%
Total	59	47	-20.34%	1307	855.33	-34.56%
	Wilcoxon z=-0.370; p(z)=0.7117			Wilcoxon z=-0.540; p(z)=0.5894		

*Where there are 0 values, the percent change is reported as 100% of absolute crash count.

Table 21 Crash Types within 0.25 Miles of a Lynx Station

Station Area (0.25 Mile)	KAB (one-year avg.)		Total (one-year avg.)	
	Before	After	Before	After
Pedestrian	n/a	6.67	n/a	18
Bicyclist	n/a	2.33	n/a	6
Rail-Vehicle	n/a	0	n/a	0.67
Parked Car	n/a	0.33	n/a	10.33
Multiple Vehicle				
Rear-End	n/a	8	n/a	253.33
Head-on	n/a	1.67	n/a	7
Angle	n/a	20.33	n/a	345.67
Sideswipe	n/a	1.33	n/a	135
Other Multiple Vehicle	n/a	0	n/a	24.67
Fixed Object	n/a	0.33	n/a	13.67
Other/Unknown	n/a	6	n/a	41
Total	n/a	47	n/a	855.33

Before-After Results: Intersection-related Crashes

To examine the effects of Lynx service on the crashes that occurred at these intersections, this study used GIS to create a 250' buffer around each at-grade intersection and identified all of the crashes occurring within. Unfortunately, information from North Carolina's Highway Safety Information System (HSIS) did not provide information on specific crash type for the 2004 period, thus limiting our comparison of crashes before and after the introduction of Lynx service to crash totals only. As shown in table 22, below, the number of crashes occurring near at-grade intersections decreased from 78 to 65, a decrease of roughly 16%. Nonetheless, the Charlotte region as a whole reported a 21% decrease in crashes during this time period, suggesting that these intersections did not experience the safety reductions one would have expected based on the county's overall safety record during this period. KAB crashes remained constant at roughly 6 per year both before and after the operation of Lynx service.

Of these crashes, and similar to the crashes occurring near Lynx stations, angle crashes are the crash type most likely to occur, as well as the crash type resulting in the greatest number of injuries and deaths. Because of our concerns with Lynx's data for the before period (see the discussion above), it is worth comparing the number of distributions of Lynx's intersections against those for SunRail. As shown in Table 23, each at-grade Lynx crossing experiences, on average, substantially more crashes than do comparable intersections for the SunRail system. Of particular note is the higher incidence of total and KAB crashes involving rear-end and angle collisions. Most of the other crash categories for Lynx show reductions when compared to SunRail, though the substantially higher share of total and KAB crashes categorized as "other/unknown" (668% and 1140%, respectively) suggests is likely not attributable to any reduced incidence of these crashes, but instead because the crash type was not recorded in the data.

As such, we are not confident that the data support the conclusion that the operation of Lynx service had a meaningful safety benefit. As the before-after results for the SunRail intersections showed significantly more total crashes and KAB crashes in the after period, and as the Lynx system reports far more crashes than does SunRail, all we can confidently ascertain is that SunRail had a negative influence on safety near stations and along at-grade intersections, and that the Lynx system reports higher numbers of crashes than does SunRail.

Table 22: Total and KAB Crashes within 250 feet of a Lynx Grade Crossing

	KAB Crashes (one year)		Total Crashes (one year)	
Type	**Before**	**After**	**Before**	**After**
Pedestrian	n/a	0	n/a	1
Bicyclist	n/a	0.33	n/a	0.67
Rail-vehicle	n/a	0	n/a	0.33
Parked car	n/a	0	n/a	0.33
Multiple Vehicle				
- Rear-end	n/a	1.33	n/a	22
- Head-on	n/a	0	n/a	1.33
- Angle	n/a	2	n/a	20
- Sideswipe	n/a	0	n/a	6.67
- Other multiple vehicle	n/a	0	n/a	2.33
Fixed object	n/a	0	n/a	2
Other/unknown	n/a	2	n/a	8.67
Total	6	5.67	78	65.33

Note: "n/a" indicates not available.

Table 23: Intersection Crashes: SunRail vs. Lynx (Three-Year After Period)

Type	**SunRail Total**	**Lynx Total**	**Difference**	**SunRail KAB**	**Lynx KAB**	**Difference**
Pedestrian	0.08	0.20	165.71%	0.06	0.00	-100.00%
Bicyclist	0.12	0.13	12.73%	0.08	0.07	-11.43%
Rail-vehicle	0.18	0.07	-63.53%	0.02	0.00	-100.00%
Parked car	0.17	0.07	-61.25%	0.01	0.00	-100.00%
Multiple Vehicle						
- Rear-end	2.37	4.40	86.00%	0.15	0.27	77.14%
- Head-on	0.09	0.27	210.00%	0.02	0.00	-100.00%
- Angle	1.45	4.00	175.56%	0.22	0.40	86.00%
- Sideswipe	0.69	1.33	93.75%	0.02	0.00	-100.00%
- Other multiple vehicle	0.51	0.47	-7.66%	0.04	0.00	-100.00%
Fixed object	0.78	0.40	-49.04%	0.06	0.00	-100.00%
Other/unknown	0.23	1.73	667.62%	0.03	0.40	1140.00%
Total	6.66	13.07	96.32%	0.72	1.13	57.31%

Discussion: Factors Influencing Crashes along Lynx At-Grade Intersections

Compared to SunRail, Lynx is a shorter system with fewer at-grade intersections (93 vs. 15, respectively). An examination of the data for individual intersections revealed that the overwhelming majority of the crashes occurred at just four locations. Figure 8, below, shows these four locations and reports the total crashes occurring at each, as well as the number of angle and rear-end collisions, the crash types for which meaningful data are available. An examination of the configuration of these intersections shows a clear pattern: in all four cases, the track is located parallel to a cross street at a signalized intersection, and in all four cases, additional track was built to support the new rail service. The high rate of angle and rear-end crashes at these locations is almost certainly a product of these configurations and the signal control used at the intersection. It is unclear how, if at all, the yellow change and all-red clearance intervals have been adjusted in response to the track addition, but the high concentration of angle collisions suggest the need to lengthen these intervals at these locations. Considered as a whole, this strongly suggests the need for greater attention to intersection design and signal control when adding passenger service to existing freight lines, particularly when such service is accompanied by track expansions.

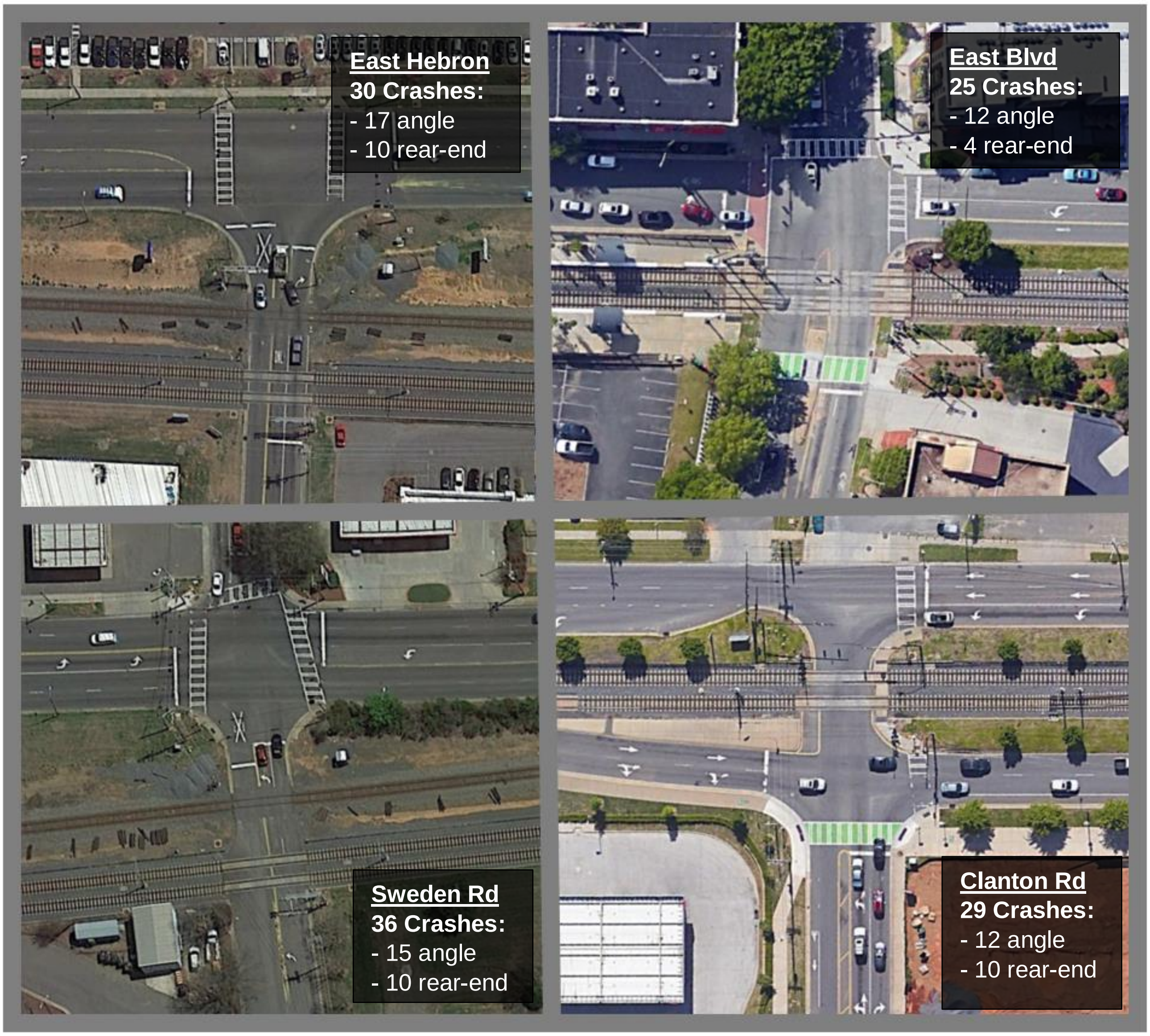

Figure 8: High-crash Intersections along the Lynx System

Conclusion: The Traffic Safety Effects of At-grade Rail Transit Systems

It has been asserted that rail transit service should be regarded as a safety benefit (APTA, 2016). The rationale is that transit will reduce vehicle miles travelled (VMT), and that this reduction in VMT will, in turn, reduce the incidence of traffic-related injuries and deaths. Nevertheless, there is little direct evidence to support either assertion. The principles of triple convergence and induced demand (Cervero, 2010; Downs, 1992) call into question the assertion that transit service will reduce VMT; further, the only evidence to support the assertion that transit reduces traffic-related deaths and injuries is a correlation between transit ridership and traffic fatalities. Yet correlation is not causation, and it is highly likely that such correlations are spurious; areas with high transit ridership rates also have high levels of developmental density and traffic congestion, lower overall travel speeds, and a host of other factors likely contribute to this relationship.

Given the lack of clear information on the subject, this study sought to understand the relationship between transit service and traffic safety through more direct measures: observed changes in the frequency and severity of traffic crashes occurring before and after the introduction of new service. As metropolitan areas have increasingly looked towards existing freight lines as an opportunity for reducing the initial capital costs of such service, this study specifically examined crashes occurring before and after the adoption of two such rail systems: Orlando's SunRail passenger rail system and Charlotte's Lynx light rail system. To gauge the safety effects of this service, this study examined changes in total and KAB crashes within 0.1 miles and 0.25 miles of each station, as well as changes in crashes occurring within 250 feet of an at-grade intersection.

For Orlando's SunRail system, crashes increased around stations and affected intersections following the introduction of service. Within 0.1 miles of a SunRail station, total crashes increased by 133% and KAB crashes increased by 67%. These effects tapered off as the area of analysis was expanded to 0.25 miles, with total crashes increasing by 79% and KAB crashes increasing by 9%. For at-grade intersections, total crashes increased by 213% following the start of SunRail service, and KAB crashes increased by 81%.

For the Lynx system, total crashes within 0.1 miles of a station decreased by 31% in the after period, while KAB crashes decreased by 21%. Nearly identical changes were observed within 0.25 miles of the station, with total crashes decreasing by 35% and KAB crashes decreasing by 20%. For at-grade intersections, total crashes decreased by 17%, while KAB crashes remained the same for both the before and after periods. While these findings demonstrate consistent decreases following the introduction of Lynx service, we are not as confident in the reliability of these data as we are with the data for the SunRail system. Only one-year of data for the before period was available for the Lynx system, which may introduce regression-to-the-mean bias into our findings. Further, the manner in which data were recorded changed between the before and after periods. An examination of county-level data for the before and after periods revealed a countywide reduction in crashes of 21%, suggesting that many of the perceived safety improvements associated with the Lynx system may be little more than a reflection of broader regional safety trends.

Because we were not confident in the accuracy of the before-period data for the Lynx system, we proceeded to compare the crashes in the after period against those observed for SunRail. As shown in Tables 17 and 23, Lynx reported higher numbers of total and KAB crashes following the introduction of service than SunRail. In many cases, the differences between the safety records of Lynx and SunRail are quite notable. 550% more crashes occurred within 0.1 miles of a Lynx station than a SunRail station, and nearly twice as many crashes occurred, on average, near affected intersections. These corresponded with 22% and 57% more injuries and fatalities, respectively. Despite our lack of confidence in the before-period data for the Lynx system, we can confidently state that crashes were shown to increase significantly along the SunRail system following the adoption of service, and that the areas and intersections affected by Lynx reported higher numbers of total and KAB crashes than did SunRail.

Another major finding of this study pertains to the effects of introducing transit service on existing freight lines in urban areas. Such projects are attractive from a policy standpoint in that they have the potential to reduce the initial capital costs associated with adding new transit service; transit operators can take advantage of underutilized freight corridors and right-of-way for the provision of new service. While this may seem like a desirable practice, little attention has been given to the broader safety implications of converting freight lines to transit use. Freight service is generally a disamenity for residential use, and many of the areas through which such service operates may not be designed to accommodate transit-related traffic associated with boardings, alightings, and system access. Station-area design, particularly as it relates to pedestrians and cyclists, has received a good deal of attention in the planning and urban design literature (Ewing and Bartholemew, 2013) and much is known about how to design these areas for pedestrian use. Yet comparatively little consideration has been given to the safety impacts on affected intersections.

Crashes involving rail vehicles tend to be the focus of examinations of rail safety. While both systems experienced increases in rail crashes, the total numbers proved to be quite low. Rail-vehicle crashes along the SunRail systems increased from 3 to 17 from the before period to the after period, though the number of KAB crashes remained unchanged. Lynx reported a single such crash following operation, without a single reported death or injury. In nearly every case, these tended to be isolated events, with only two locations reporting more than one such crash during the three-year after period. Of these, both lacked four-quadrant gates at the rail crossing.

Of greater concern, from an injury prevention perspective, are the changes in crashes that occur between vehicles and pedestrians following the adoption of service. Rear-end and angle collisions, in particular, increased significantly along these systems following the adoption of service. With respect to rear-end collisions, the safety problem appears to be the result of inadequate coordination between signalized intersections and nearby rail crossings. The *Manual for Uniform Traffic Control Devices* calls for signal pre-emption when a rail crossing is located within 200 feet of an intersection. Yet, as shown in Figure 4, rear-end collisions concentrate at locations where the rail crossing is located within an intersection’s area of influence, but outside of the 200’ pre-emption boundary specified in the MUTCD. The increased frequency of rear-end collisions at these locations is almost certainly attributable drivers traveling through the intersection and expecting to also traverse the nearby rail crossing, thus making them unprepared to stop quickly when a lead vehicle brakes in response to a gate closure.

The large increase in angle collisions occurring at these intersections is one that has not been identified in previous literature, but one that has profound safety implications given the severity of this crash type. For SunRail and Lynx alike, the locations where angle collisions occur has a very specific configuration, with the rail line running parallel to an adjacent signalized street (see Figures 5 and 8). In many of these locations, transit service was accompanied by adding an additional track, thus increasing the overall complexity of the intersection and expanding its area of influence. While we do not have specific information on intersection control, it is highly probably that intersection control is a contributing factor to the increased incidence of angle collisions. It is unclear how, if at all, the clearance intervals at these locations were modified as a result of the additional of transit service, and it appears that at many of these locations, permitted- or protected/permitted left-turn phasing is in use, a factor known to contribute to the incidence of angle collisions. Future research is needed into the optimal phasing of signals at these locations, as well as determinations as to whether left-turns at these locations should be converted to protected-only.

This study thus concludes by again observing that the safety issues pertaining to urban transit extend beyond crashes involving rail vehicles and other road users. As has been shown in this study, changes in the use of station areas, and the design and operation of affected intersections, can have a profound influence on multiple-vehicle and vehicle-pedestrian crashes as well. In this report, we have identified fruitful areas of future research and made suggestions to how guidance, such as that contained in the *Manual for Uniform Traffic Control Devices*, may be enhanced to address these needs.

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Appendix

This appendix presents an in-depth exploration of light rail and streetcar collisions, injuries, and fatalities using data obtained from the National Transit Database (NTD). A two-part methodology is used. In the first part, descriptive statistics are calculated for light rail and streetcar collisions, injuries, and fatalities. In the second part, multilevel negative binomial regression models are used to analyze light rail and streetcar collisions and injuries. These results are discussed in more detail in a paper entitled *"A Longitudinal Analysis of Light Rail and Streetcar Safety in the United States,"* which is currently under review.

Data

The following analysis primarily uses NTD safety and security data, which is presented in a time series format that includes collisions, injuries, and fatalities. The NTD safety and security time series database contains data separated by transit mode beginning from 2002. It has data for 36 cities nationwide that offered light rail and/or streetcar service during the period 2002-2017. Notably, NTD used to define light rail and streetcars as one mode until 2011. Therefore, some of the following analysis presents light rail and streetcar as a single mode to enable a longer time period for analysis (specifically, the multivariate analysis shown in Part 2), whereas other parts focus on the more recent data from 2012-2017 (specifically, the descriptive statistics shown in Part 1).

Results of Part 1: Descriptive Statistics

This section presents the results of descriptive statistics comparing collisions, injuries, and fatalities for light rail and streetcar during the period 2012-2017.

Descriptive Statistics for Collisions

Table 24 compares light rail collisions to streetcar collisions for the period 2012-2017, since the two modes were reported separately to NTD beginning in 2012. During this period, 1,143 light rail collisions were reported to NTD compared to 322 streetcar collisions. The main two differences between these modes are the portion of collisions with a person and the percent with motor vehicles. Collisions with a person represented 42% of light rail collisions compared to 19% for streetcars. On the other hand, streetcar collisions with motor vehicles were 76% compared to 54% for light rail. This higher percentage of streetcar collisions with a motor vehicle is likely due to the fact that streetcars typically run on mixed ROW, which could increase the chances of collisions.

Table 24: Descriptive Statistics for Light Rail and Streetcar Collisions

	Light Rail Collisions		**Streetcar Collisions**	
	Count	*Percent*	*Count*	*Percent*
Person	481	42%	62	19%
Motor Vehicle	616	54%	245	76%
Rail Vehicle	16	1%	4	1%
Fixed Object	10	1%	6	2%
Other	20	2%	5	2%
Total	1143	100%	322	100%

Descriptive Statistics for Injuries

This section presents the descriptive statistics for injuries. Table 25 compares light rail injuries to streetcar injuries for the period 2012-2017, since the two modes were reported separately to NTD beginning in 2012. This comparison revealed that 42% of light rail injuries were people waiting or leaving compared to only 11% percent of streetcar injuries. This indicates that a considerable portion of light rail injuries are likely occurring at stations, which was not anticipated since light rail stations are typically more developed compared to streetcar stations. More than half of streetcar injuries (56%) were passengers, and 17% of streetcar injuries are other vehicle occupants. This finding generally aligns with the results of the collision analysis that showed about three quarters of streetcars collisions were with motor vehicles. Last, it is important to note that NTD considers injuries due to both safety and security events in these categories.

Table 25: Descriptive Statistics for Light Rail and Streetcar Injuries

	Light Rail Injuries		**Streetcar Injuries**	
	Count	*Percent*	*Count*	*Percent*
Passenger	*1593*	*29%*	*583*	*56%*
People waiting or leaving	*2316*	*42%*	*117*	*11%*
Transit employee	*294*	*5%*	*92*	*9%*
Other worker	*1*	*0%*	*1*	*0%*
Pedestrian in crossing	*61*	*1%*	*16*	*2%*
Pedestrian not in crossing	*44*	*1%*	*19*	*2%*
Pedestrian walking along tracks	32	*1%*	6	*1%*
Bicyclist	56	*1%*	5	*0%*
Other vehicle occupant	452	*8%*	180	*17%*
Suicide	105	*2%*	2	*0%*
Other	551	*10%*	27	*3%*
Total	**5505**	**100%**	**1048**	**100%**

Descriptive Statistics for Fatalities

This section presents the descriptive statistics for fatalities. Table 26 shows that there were 250 light rail fatalities in the period 2012-2017. The table reveals that a large number (28%) of these fatalities were suicides, which represents the highest portion of light rail fatalities. 14% of light rail fatalities were people waiting or leaving, which is consistent with early findings from the injury analysis that many of light rail injuries were people waiting or leaving. Other vehicle occupants, pedestrians in crossings, and bicyclists represent 12%, 8%, and 7%, respectively, of light rail fatalities in the period 2012-2017. It should be noted that there were only seven streetcar fatalities during the period 2012-2017, so this was not explored further due to the small number of fatalities. Last, similar to injuries, NTD considers fatalities from both safety and security events.

Table 26: Descriptive Statistics for Light Rail Fatalities

	Light Rail Fatalities	
	Count	*Percent*
Passenger	*10*	*4%*
People waiting or leaving	*36*	*14%*
Transit employee	*0*	*0%*
Other worker	*1*	*0%*
Pedestrian in crossing	*21*	*8%*
Pedestrian not in crossing	*8*	*3%*
Pedestrian walking along tracks	15	*6%*
Bicyclist	17	*7%*
Other vehicle occupant	29	*12%*
Suicide	71	*28%*
Other	42	*17%*
Total	**250**	**100%**

Results of Part 2: Multivariate Analysis

Two-level random-intercept negative binomial models were estimated for light rail and streetcar collisions and injuries. Collisions/injuries were identified as the first level, and cities represented the second level. The first set of models uses the number of collisions as a dependent variable, while the second set uses the number of injuries as the dependent variable. Explanatory variables include factors such as the number of at-grade crossings and mixed right-of-way (ROW) miles, among others. It should be noted that fatalities were not modelled due to the relatively small sample size.

Table 27 below shows the results of a balanced panel, which contains data from 19 cities that offered continuous light rail and/or streetcar service during the period 2003-2017. This panel starts from 2003 since two agencies started reporting light rail or streetcar safety data in 2003.

The Collisions Model shown in Table 27 presents the preferred model specification using speed, the number of at-grade crossings, mixed ROW miles, and vehicles operated at maximum service (VOMS) as explanatory variables of the number of annual collisions. The results of the model show that the average speed has a positive significant effect on number of collisions (β=0.0677). Moreover, speed has the largest effect on the expected number of light rail and streetcar collisions, as indicated by the magnitude of the coefficient. The results also show that the number of mixed ROW miles has a positive significant effect on number of collisions (β=0.0131), which is expected since mixed ROW miles increase the exposure of light rail and streetcars to other modes of transportation. Similarly, the number of vehicles operated at maximum service (VOMS) has a positive significant effect on number of collisions (β=0.00652); this was expected since higher VOMS indicate higher exposure to risk. Finally, this model also suggests that the number of at-grade crossings has a positive significant effect on number of collisions (β=0.00137); this was also expected since at-grade crossings are possible conflict points with other modes.

The Injuries Model shown in Table 27 presents the preferred model, which considered speed, mixed ROW miles, and VOMS as predictors of light rail and streetcar injuries. Speed has a positive significant effect on number of injuries (β= 0.101). This finding was expected and is consistent with prior research that show higher light rail speeds could lead to more severe crashes. Also, the coefficient of the speed variable has the largest magnitude in this model, which indicates that speed has the largest impact on light rail and streetcar injuries. Also, increasing the number of vehicles operated at maximum service (VOMS) is expected to increase the number of injuries (β= 0.0193). Similarly, the model shows the number of the mixed ROW miles has a positive significant effect on number of injuries (β= 0.00948). These findings about VOMS and mixed ROW miles were expected, since increasing either of these two factors yields higher exposure to risk.

Table 27: Light Rail and Street Car Negative Binomial Model Results (Balanced Panel)

	Collisions Model **Coefficients** **(Standard Error)**	**Injuries Model** **Coefficients** **(Standard Error)**
Speed	0.0677*** (0.0231)	0.101*** (0.0248)
Number of at-grade crossings	0.00137*** (0.0004)	- -
Mixed ROW miles	0.0131*** (0.0041)	0.00948** (0.0045)
Vehicles operated at maximum service (VOMS)	0.00652** (0.0027)	0.0193*** (0.0025)
Intercept	-0.0489 (0.4320)	-0.0178 (0.4550)
Ln (conditional overdispersion parameter)	-0.968*** (0.1200)	-0.938*** (0.1070)
Var (Intercept)	0.502** (0.2460)	0.688** (0.2800)
N	285	285
Log-likelihood with constant only	-836.24	-1170.13
Log-likelihood at convergence	-823.51	-1136.74

*Significance: * p<0.10; ** p<0.05; *** p<0.01*
Observed information matrix standard errors shown in parenthesis.
Incidence rate ratios available upon request.

Conclusions and Areas for Future Research

This study conducted a longitudinal analysis of light rail and streetcar safety in the United States for the period 2002-2017 using data obtained from NTD. Three key findings emerged from this study. First, the results generally align with findings from prior studies that show the majority of light rail and streetcar collisions occur in mixed right-of-way or near at-grade crossings. Second, this analysis revealed an issue predominantly at stations: 42% of light rail injuries were people waiting or leaving. Third, suicide was the leading cause of light rail fatalities, which represents 28% of all light rail fatalities.

There are some noteworthy limitations of this analysis and important areas for future research. First, the NTD data used in this study considered light rail and streetcars as one mode until 2011; therefore, the multivariate analysis considered them one mode. A separate multivariate analysis for each mode should be conducted as more data becomes available for each mode separately. It is also worth noting that NTD combines injuries and fatalities from safety and security events, which limits the ability to explore safety and security trends separately. In terms of future research, one important challenge identified by this study for further investigation is how light rail operators can improve safety at light rail stations. Another area for future research pertains to suicide and how light rail operators, cities, and mental health experts can respond to this concerning trend.

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