1 **A LONGITUDINAL ANALYSIS OF LIGHT RAIL AND STREETCAR SAFETY IN THE**
2 **UNITED STATES**
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1   **ABSTRACT**
2   Many American cities have launched or expanded light rail or streetcar services recently, which
3   has resulted in a 61% increase in light rail and streetcar revenue miles nationwide during the period
4   2006-2016. Moreover, light rail and streetcars exhibit higher fatality rates per passenger miles
5   traveled compared to other transit modes. In light of these trends, this study explores light rail and
6   streetcar collisions, injuries, and fatalities using data obtained from the National Transit Database.
7   This study applies a two-part methodology. In the first part, descriptive statistics are calculated for
8   light rail and streetcar collisions, injuries, and fatalities, and a comparative analysis of light rail
9   and streetcars is performed. In the second part, multilevel negative binomial regression models are
10   used to analyze light rail and streetcar collisions and injuries. Three key findings emerged from
11   this study. First, the results generally align with findings from prior studies that show the majority
12   of light rail and streetcar collisions occur in mixed right-of-way or near at-grade crossings. Second,
13   this analysis revealed an issue predominantly at stations: 42% of light rail injuries were people
14   waiting or leaving. Third, suicide was the leading cause of light rail fatalities, which represents
15   28% of all light rail fatalities. The implications of this study are important for cities that currently
16   operate these modes or are planning to introduce new light rail or streetcar service to improve
17   safety.
18
19
20   **Keywords:** Light Rail, Streetcars, Safety, Collisions, Injuries, Suicide

1 **BACKGROUND AND MOTIVATION**
2 The history of streetcars in the United States goes back to the 19th century when the first streetcar
3 service was introduced in Cleveland in 1884 (1). Electric streetcar systems continued to expand
4 until World War I. After World War I, metropolitan areas started to replace them with rubber tire
5 transit modes until they were nearly obsolete by the 1960s (2). Recently, this trend has reversed as
6 streetcars and light rail have begun to gain popularity in American cities. The number of new
7 streetcar and light rail systems reached 10 and 22, respectively in 2014 (2), and light rail and
8 streetcar vehicle revenue miles increased by 61% from 2006 to 2016 (3).
9 Streetcars (SR) are defined by Vuchic as "one, two, and occasionally three rail vehicle
10 trains operated mostly on streets in mixed traffic but sometimes also with limited separation from
11 street traffic by preferential treatment or separate [rights-of-way] ROW", while he defines light
12 rail (LR) as "electrically powered, high-capacity, quiet vehicles with high riding quality operating
13 in one- to four-car trains on predominantly separated ROW" (1). These two definitions show that
14 the main differences between light rail and streetcars are the type of ROW and the number of
15 vehicles. However, the American Public Transportation Association (APTA) adds additional
16 differences between these two modes, which are higher speeds, longer routes, and more developed
17 stations with platforms for light rail compared to streetcars (2). Although there are differences
18 between light rail and streetcars, they both typically have interactions with other road users along
19 some or all of their routes in mixed ROW or near at-grade crossings, which could increase the
20 possibility of crashes with other road users.
21 Preliminary analysis of nationwide safety outcomes suggests that streetcars and light rail
22 may have higher fatality rates compared to other transit modes like heavy rail, bus, and bus rapid
23 transit, as shown in Figure 1. Figure 1 shows that in 2016 light rail and streetcars had 15.2 and
24 9.85 fatalities per billion passenger miles traveled (PMT), respectively, while bus, bus rapid transit,
25 and heavy rail each had around five fatalities per billion PMT.
26 The recent growth in light rail and streetcar service combined with their relatively high
27 fatality rates suggest that more research into the safety of these two modes is necessary. However,
28 to the best of the authors' knowledge, no recent study has explored the safety trends of light rail
29 and streetcars in the United States. This study aims to begin to fill this gap in the literature by
30 conducting a nationwide analysis of safety performance for light rail and streetcars using data
31 obtained from the National Transit Database (NTD). This nationwide analysis consists of
32 descriptive statistics and multivariate analysis to explore trends in collisions, injuries, and fatalities
33 for light rail and streetcars in the United States for the period 2002-2017.
34 This paper proceeds as follows: first, prior research about light rail and streetcar safety is
35 summarized; the following section discusses the data and method used in this study; results follow
36 this section; and the final section is conclusions, limitations, and future research.
37
38 **PRIOR STUDIES**
39 Various prior studies have explored different aspects of light rail and streetcar safety. These studies
40 considered aspects like light rail safety in shared ROW, light rail crashes near at-grade crossings,
41 the safety of light rail stops, pedestrian safety at light rail at-grade crossings, and safety challenges
42 that face streetcar operators. These studies are summarized chronologically below in three groups.
43 The first group explores light rail safety on shared ROW and near at-grade crossing. The second
44 group focuses on pedestrian safety in the presence of light rail. The last group reviews
45 miscellaneous studies pertaining to light rail and streetcar safety.
46

1 **Light Rail and Streetcar Safety on Shared Right of Way and At-Grade Crossings**
2 The first six prior references focus on safety implications of light rail operations in mixed ROW.
3 Transit Cooperative Research Program (TCRP) Report 17 studied light rail crashes in ten cities in
4 the United States and found that the majority of light rail crashes occurred in shared ROW;
5 depending on the city, 70% to 100% of these crashes occurred in shared ROW (4). This study also
6 found that the failure of motor vehicle drivers and pedestrians to perceive and obey warning
7 devices is a common cause of light rail crashes (4). While this report is very relevant to the analysis
8 that follows, it is over 20 years old, and there have been numerous light rail and streetcar
9 expansions and new systems since then, which necessitates revisiting this topic.
10 TCRP Document 53 studied the operations of light rail through ungated crossings at speeds
11 over 35 mph. The results showed that the potential impacts of higher operational speeds are an
12 increase in the number of crashes, the rate of minor injury crashes, and crash severity. This study
13 also recommended some actions to improve safety at crossings, such as increasing the awareness
14 of left-turning drivers about train arrivals and increasing the sight distance for left-turning drivers
15 (5).
16 Fischhaber and Janson (2012) studied light rail crashes in Denver, Colorado using data
17 obtained from the Regional Transportation District for the period 1999-2009. This study applied
18 traditional railroad crash prediction models to predict light rail at-grade crossing crashes. The
19 results showed that there are significant differences between the characteristics of light rail at-
20 grade crossings and traditional railroad crossings that warrant further investigation for light rail at-
21 grade crossings. Furthermore, this analysis showed that in areas where light rail at-grade crossings
22 have similar characteristics to traditional railroads and commuter rail, light rail experienced more
23 crashes, which also warrants further investigation (6). In a follow-up study, Fischhaber and Janson
24 (2015) proposed safety performance functions (SPFs) for light rail at-grade crossings using an
25 empirical Bayes method with data from ten transit agencies for the period 2000-2009. This study
26 showed that the proposed models improved crash predictions for light rail at-grade crossings over
27 the existing U.S. Department of Transportation models (7).
28 Naznin et al. (2016) used a random effect negative binomial model to investigate the
29 impacts of different traffic, transit, and route factors on streetcar (also known as tram) crash
30 frequency using safety data from seven streetcar routes in Melbourne, Australia for the period
31 2009-2013. This study showed that route section length, service frequency, speed, and annual
32 average daily traffic tend to increase streetcar crash frequency, while platform stops, stop spacing,
33 streetcar signal priority, and streetcar lane priority typically reduce streetcar crash frequency (8).
34 Similar findings about streetcar signal priority and streetcar lane priority were found in another
35 study that used an empirical Bayes safety evaluation to investigate these two aspects (9).
36
37 **Pedestrian Safety at Intersections in the Presence of Light Rail**
38 This section focuses on previous research about pedestrian safety at intersections in the presence
39 of light rail. Fitzpatrick et al. (2017) investigated pedestrian needs at light rail at-grade crossings
40 for vulnerable groups like children, senior citizens, and people with disabilities. This study
41 recommended different types of treatments at light rail crossings, such as defined pedestrian
42 crossings, fencing, refuges, and automatic gates with horizontal hanging bars (10).
43 Srirangam and Pulugurtha (2018) identified factors that influence pedestrian safety at
44 intersections within a catchment area of 0.25 mile around light rail stations and studied the change
45 in crash patterns before and after the operation of light rail service in Charlotte, North Carolina.
46 The results revealed that a higher number of pedestrian crashes is expected at intersections with a

1 pedestrian signal compared to intersections without a pedestrian signal. The findings also showed
2 that an increase in the speed limit and the number of bus stops within 200 feet from the intersection
3 would increase the number of pedestrian crashes (11).
4
5 **Other Safety Studies**
6 This section summaries studies that considered other miscellaneous aspects of light rail and
7 streetcar safety. Currie and Reynolds (2010) studied the safety effects of a new design of streetcar
8 stops in Melbourne, Australia. This study showed that more than 80% of streetcar incidents were
9 auto-pedestrian conflicts, which suggest that the safety of pedestrians at the streetcar stops is a
10 major concern. The results also revealed that a new platform design for streetcar stops reduced the
11 automobile-pedestrian and automobile-streetcar stop crashes by 62% and 12%, respectively.
12 However, the authors also concluded that "tram–pedestrian collisions did not change except at the
13 busiest stop, where total incidents were reduced by 53%, but tram–pedestrian rates increased" (12).
14 Another study about the safety effects of platform streetcar stops on pedestrian found that platform
15 stops improved pedestrian safety significantly (13).
16   Naznin et al. (2017) explored the safety of streetcars from the perspective of the streetcar
17 drivers, which is a crucial perspective for streetcars, since they run mainly on a mixed ROW. This
18 study conducted five focus groups that involved thirty streetcar drivers in Melbourne, Australia.
19 The results revealed the challenges that streetcar drivers face while operating streetcar vehicles,
20 such as ensuring the safety of all people in and around streetcars, handling pressure to be on-time,
21 predicting other road users' behavior to avoid crashes, accepting the operational constraints of
22 streetcars, and managing fatigue (14).
23   This brief review of prior literature highlights various aspects of light rail and streetcar
24 safety; however, none of these prior studies investigated recent trends in light rail and streetcar
25 safety in the United States, which is the focus of the following analysis. In light of this, the
26 objective of this study is to conduct a longitudinal analysis of light rail and streetcar safety,
27 focusing on collisions, injuries, and fatalities for the period of 2002-2017.
28
29 **DATA AND METHOD**
30 This section discusses the data source, modeling approach, and the methodology used in this study.
31
32 **Data Source**
33 The main data source for the following analysis is the National Transit Database (NTD). NTD
34 collects data about transit safety and security, assets, expenses, fares, ridership, and service from
35 American transit agencies that receive funding from the Federal Transit Administration (FTA)
36 (15).
37   The following analysis primarily uses NTD safety and security data, which is presented in
38 a time series format that includes collisions, injuries, and fatalities. It also includes vehicles
39 operated in maximum service (VOMS), vehicle revenue miles, vehicle revenue hours, unlinked
40 passenger trips, and passenger miles traveled. The NTD safety and security time series database
41 contains data separated by transit mode beginning from 2002 (15). It has data for 36 cities
42 nationwide that offered light rail and/or streetcar service during the period 2002-2017, and all these
43 cities are included in the follow analysis except the city of Newark, NJ. The city of Newark was
44 excluded from the analysis since light rail and "hybrid rail" were reported as one mode prior to
45 2012; however, this study does not consider hybrid rail. Figure 2 shows a map of the 35 cities
46 nationwide included in this analysis.

1 **Modeling Approach**
2 This section discusses the modeling approach used in this study. The number of collisions is a
3 nonnegative integer; therefore, it is modeled using a count model. The Poisson regression model
4 is commonly used to model collision frequency for different transportation facilities (16). Poisson
5 regression models represent the relationship between explanatory variables and the Poisson
6 parameter (λ), as shown in Equation 1 (17).
7
8 $\lambda_i = EXP(\beta X_i)$ (1)
9
10 In Equation 1, β is a vector of estimated parameters and X_i is the vector of explanatory
11 variables. The Poisson model assumes the mean and the variance are equal; however, this
12 assumption does not hold when the data are over-dispersed. In this study, the calculated variance
13 was greater than the mean, which makes the Poisson model inappropriate. Therefore, the negative
14 binomial regression model will be used. The negative binomial model is a generalization of the
15 Poisson model that assumes the variance is larger than the mean. The negative binomial model
16 equation is derived by adding a Gamma-distributed disturbance term with a mean equal to one and
17 variance equal to α to the Poisson model as shown in Equation 2 (17).
18
19 $\lambda_i = EXP(\beta X_i + \varepsilon_i)$ (2)
20
21 Adding the Gamma-distributed term will allow the variance to differ from the mean as shown in
22 Equation 3, where α is the overdispersion parameter (17).
23
24 $Var[y_i] = E[y_i] * (1 + \alpha E[y_i])$ (3)
25
26 Different negative binomial regression models have been used to handle other issues, such
27 as the zero-inflated negative binomial regression, random effects and fixed effects negative
28 binomial regression, multilevel negative binomial regression, and random parameter negative
29 binomial regression (16; 17). This study applies the multilevel negative binomial regression
30 approach, which uses hierarchical clusters to model collisions. This assumes that collisions
31 occurring in the same location may be correlated due to unobserved characteristics related to that
32 specific location, which is the city in the following analysis (16; 18). The multilevel negative
33 binomial model equation with *u* random effects is shown in Equation 4 (18).
34
35 $E(y_{ij}|x, u_j) = EXP(\beta x_{ij} + z_{ij} u_j)$ (4)
36
37 In Equation 4, y_{ij} is the count response of the *i*th observation from the *j*th cluster, which
38 represents the number of collisions in year *i* in city *j* in this study. Also, in Equation 4, *x* represents
39 explanatory variables such as the number of at-grade crossings and mixed ROW miles, u represents
40 the random effects, β represents the regression coefficients, and z is a vector of the random-effects
41 covariates, which is equal one in this study since a two-level model is used.
42 In this study, a two-level random-intercept negative binomial model was estimated for light
43 rail and streetcar collisions. Collisions were identified as the first level, and cities represented the
44 second level. Collisions were clustered by the city to control for unobserved correlation within the
45 city (16). The first set of models uses the number of collisions as a dependent variable, while the

1 second set uses the number of injuries as the dependent variable. These models were estimated
2 using maximum likelihood in Stata 15 software.
3
4 **Methodology**
5 For the purpose of this study, NTD safety and security time series data were downloaded from the
6 NTD website in March 2019. This study used data from 2002 to 2017 since 2018 data were not
7 complete when the data were obtained. The NTD safety and security time series data were
8 combined with other NTD data, including light rail and streetcar infrastructure data like ROW
9 classification and the number of stations.
10 In this analysis, the city was used as a unit of analysis; therefore, all variables used in this
11 analysis were aggregated at the city level. This included combining LR records and SR records for
12 cities that operate both modes, combining Directly Operated (DO) and Purchased Transportation
13 (PT) if part of the service was offered by a third party, and combining different transit operators
14 that offer service in the same city.
15 This study used a two-part analysis method to investigate light rail and streetcar collisions,
16 injuries, and fatalities as shown in Figure 3 and discussed in the following paragraphs.
17 In the first part, descriptive statistics were calculated for light rail and streetcar collisions,
18 injuries, and fatalities. Since NTD used to define light rail and streetcars as one mode until 2011,
19 this part explores light rail and streetcar collisions, injuries, and fatalities combined as one mode
20 for the period 2002-2017. Collisions, injuries, and fatalities were also compared between light rail
21 and streetcars for the period 2012-2017 to explore the safety challenges for each mode separately.
22 In the second part, multilevel negative binomial regression models were estimated to
23 explore light rail and streetcars collisions and injuries for the period 2002-2017. The aim of the
24 multivariate analysis is to identify the significant predictors of light rail and streetcars collisions
25 and injuries. In this part, collision and injury models were estimated for two panel datasets. The
26 first panel is the "unbalanced panel" that contains data from all 35 cities that offered light rail
27 and/or streetcar service during the period 2002-2017. In this panel, cities have different number of
28 records since some cities introduced their services during the analysis period. The other panel is
29 the "balanced panel" that contains data from 19 cities that offered continuous light rail and/or
30 streetcar service during the period 2003-2017. This panel starts from 2003 to have more cities with
31 15 years since two agencies started reporting light rail or streetcar safety data in 2003. In this panel,
32 each city has 15 years of data. Multilevel negative binomial regression models were estimated for
33 these two panels to investigate if there were any differences between agencies that offered
34 continuous service and agencies that introduced new light rail and streetcar services recently. Table
35 1 shows the descriptive statistics for these two panels, including the mean, standard deviation (SD),
36 minimum (Min) and maximum (Max).
37
38 **RESULTS**
39 The results of this analysis are divided into three sections. This first section presents findings of
40 the light rail and streetcar collisions analysis, the second section discusses injuries, and the last
41 section focuses on fatalities.
42
43 **Light Rail and Streetcar Collisions**
44 NTD defines reportable rail collisions as "collisions that:
45 • meet an injury, fatality, substantial damage, or evacuation threshold;
46 • include suicides or attempted suicides that involve contact with a transit vehicle;

1   • occur at a rail grade crossing;
2   • involve a rail transit vehicle and a second rail transit vehicle; or
3   • involve an individual in the right-of-way" (19).
4   The collisions of light rail and streetcars were investigated for the period 2002-2017. They
5   were categorized based on NTD definitions into collisions with a person, with a motor vehicle,
6   with a rail vehicle, with fixed objects, and with other things such as buses, bicycles, and animals.
7
8   *Descriptive Statistics for Collisions*
9   This section presents the descriptive statistics of light rail and streetcar collisions. The bar chart in
10   Figure 4 shows that for the period 2002-2017, 5,390 light rail and streetcar collisions were recorded
11   in 35 cities nationwide. Almost half of these collisions (48%) were collisions with motor vehicles,
12   while 19% of them were collisions with a person. This high percentage of collisions with motor
13   vehicles is not surprising since these two modes often use mixed ROW and have many at-grade
14   crossings. Around 30% of light rail and streetcar collisions occurred in the period 2002-2017 were
15   "Others".
16   The pie charts in Figure 4 compare light rail collisions to streetcar collisions for the period
17   2012-2017, since the two modes were reported separately to NTD beginning in 2012. During this
18   period, 1,143 light rail collisions were reported to NTD compared to 322 streetcar collisions. The
19   main two differences between these modes are the portion of collisions with a person and the
20   percent with motor vehicles. Collisions with a person represented 42% of light rail collisions
21   compared to 19% for streetcars. On the other hand, streetcar collisions with motor vehicles were
22   76% compared to 54% for light rail. This higher percentage of streetcar collisions with a motor
23   vehicle is likely due to the fact that streetcars typically run on mixed ROW, which could increase
24   the chances of collisions (4).
25   Moreover, the percentage of "Other" dropped in the period 2012-2017 for both light rail
26   and streetcars due to some changes in NTD thresholds and classifications, which is a limitation of
27   NTD safety data. However, this limitation is not expected to affect the multivariate analysis for
28   light rail and streetcar collisions since the proposed models that follow consider the total number
29   of collisions.
30   This part of the analysis also compared the annual collision rate per vehicles operated in
31   maximum service (VOMS) for light rail and streetcars in the period 2012-2017. The annual light
32   rail collision rate per VOMS ranged from 0.1 to 0.15, with an average of 0.13 collisions per VOMS.
33   On the other hand, the annual collision rate per VOMS for streetcars ranged between 0.21 to 0.37
34   with an average of 0.25 collisions per VOMS (results not shown). The annual collision rate for
35   light rail was lower than the streetcar annual collision rate for all analysis years. This comparison
36   indicates that light rail is safer than streetcars for the same level of service, although the total
37   number of light rail collisions in the period 2012-2017 is higher compared to streetcars.
38   *Multivariate Analysis of Collisions*
39   This part presents the results of multilevel negative binomial models for light rail and streetcar
40   collisions. Table 2 shows the proposed models for both the balanced and the unbalanced panels.
41   Column (1) in Table 2 shows the preferred model specification for the balanced panel using speed,
42   the number of at-grade crossings, mixed ROW miles, and VOMS as explanatory variables of the
43   number of annual collisions. The results of the model show that the average speed has a positive
44   significant effect on number of collisions (β=0.0677). This finding is consistent with a previous
45   study from Australia that found higher streetcar speeds tend to increase the number of collisions
46   (Naznin et al., 2016). Moreover, this analysis shows that speed has the largest effect on the

1 expected number of light rail and streetcar collisions, as indicated by the magnitude of the
2 coefficient. Column (1) in Table 2 also shows that the number of mixed ROW miles has a positive
3 significant effect on number of collisions (β=0.0131), which is expected since mixed ROW miles
4 increase the exposure of light rail and streetcars to other modes of transportation. Similarly, the
5 number of vehicles operated at maximum service (VOMS) has a positive significant effect on
6 number of collisions (β=0.00652). This finding about VOMS is expected since higher VOMS
7 indicate higher exposure to risk. Finally, this model also suggests that the number of at-grade
8 crossings has a positive significant effect on number of collisions (β=0.00137). This positive
9 association is anticipated since at-grade crossings are possible conflict points with other modes.
10 These findings align with early findings that the number of at-grade crossings and mixed ROW
11 miles increase the probability of light rail and streetcar collisions (4; 5; 8).
12   It is also worth noting that neither crossing ROW miles or exclusive ROW miles were
13 significant predictors for collisions; therefore, they were not included in the preferred model.
14   The results from the unbalanced panel model shown in column 2 in Table 2 are similar to
15 the findings from the balanced panel, suggesting that the safety trends in cities that launched their
16 service during the analysis period are similar to cities that offered continuous service.
17
18 **Light Rail and Streetcar Injuries**
19 NTD defines reportable injuries as " injuries that require immediate transport away from the scene
20 for medical attention" (19). Injuries were classified based on NTD categorizations into passengers,
21 people waiting or leaving, transit employees, other workers, pedestrians in crossings, pedestrians
22 not in crossings, pedestrians walking along tracks, bicyclists, other vehicle occupants, suicides,
23 and others. The transit employee category includes transit employees and operators, while the other
24 workers category represents non-transit workers. It is worth mentioning that NTD considers
25 injuries due to both safety and security events in these categories.
26
27 *Descriptive Statistics for Injuries*
28 This section presents the descriptive statistics for injuries. The total reported light rail and streetcar
29 injuries during the period 2002-2017 was 14,207 injuries. 41% of these injuries were passengers,
30 and 30% were people waiting or leaving (results not shown). These findings suggest that the
31 majority of the injuries occur to the users of these two systems.
32   Figure 5 compares light rail injuries to streetcar injuries for the period 2012-2017, since
33 the two modes were reported separately to NTD beginning in 2012. This comparison revealed that
34 42% of light rail injuries were people waiting or leaving compared to only 11% percent of streetcar
35 injuries. This indicates that a considerable portion of light rail injuries is likely occurring at
36 stations. This finding was not anticipated since light rail stations are typically more developed
37 compared to streetcar stations (2). Future research should explore safety and security at light rail
38 stations and why the highest portion of light rail injuries is people waiting or leaving. As shown in
39 Figure 5, more than half of streetcar injuries (56%) were passengers. Furthermore, it can be noticed
40 that 17% of streetcar injuries are other vehicle occupants. This finding generally aligns with the
41 results of the collision analysis that showed about three quarters of streetcars collisions were with
42 motor vehicles.
43   This analysis also compared the annual injury rate per VOMS for light rail and streetcars
44 during the period 2012-2017. The annual light rail injury rate per VOMS ranged between 0.54 to
45 0.67 with average of 0.63. On the other hand, the annual injury rate per VOMS for streetcars ranged

1   between 0.53 to 1.07 with average of 0.81 (results not shown). This comparison also showed that
2   for all years except 2012, streetcars had higher injury rates per VOMS than light rail.
3
4   *Multivariate Analysis of Injuries*
5   This section presents the results of multilevel negative binomial models for light rail and streetcar
6   injuries. Table 3 shows the preferred models, which considered speed, mixed ROW miles, VOMS,
7   and unlinked passenger trips as predictors of light rail and streetcar injuries.
8   Column 1 in Table 3 shows that the average speed has a positive significant effect on
9   number of injuries (β= 0.101). This finding was expected and is consistent with earlier findings
10 that show higher light rail speeds could lead to more severe crashes (Golembiewski et al., 2011).
11 Also, the coefficient of the speed variable has the largest magnitude in this model, which indicates
12 that speed has the largest impact on light rail and streetcar injuries.
13   The model in Column 1 of Table 3 also shows that increasing the number of vehicles
14 operated at maximum service (VOMS) is expected to increase the number of injuries (β= 0.0193).
15 Similarly, the model shows the number of the mixed ROW miles has a positive significant effect
16 on number of injuries (β= 0.00948). These findings about VOMS and mixed ROW miles were
17 expected, since increasing either of these two factors yields higher exposure to risk (Korve et al.,
18 1996).
19   Column 2 in Table 3 explores the impact of unlinked passenger trips on injuries in addition
20 to the previous variables used in Model 1. The results of this model suggest that unlinked passenger
21 trips have a positive significant effect on number of injuries (β=0.0292). This finding is expected
22 since increasing the number of onboard passengers is likely to result in more injuries in the case
23 of a collision. This finding aligns with the finding from the descriptive statistics section that
24 showed more than 40% of light rail and streetcar injuries in the period from 2002-2017 were
25 passengers. Also, comparing Models 1 and 2 reveals that the coefficients and significance levels
26 of the other variables are comparable.
27   Models 3 and 4 shown in columns (3) and (4) in Table 3 present the estimated models for
28 the unbalanced panel with the same specification as Models 1 and 2. The main difference between
29 the balanced and the unbalanced model is that mixed ROW miles are not a significant predictor of
30 the number of injuries in the unbalanced models. This unexpected result for the unbalanced models
31 could be attributed to the fact that in the unbalanced model, some cities have fewer observations
32 since they introduced a light rail or streetcar service recently. However, this unexpected result
33 should be further explored in future studies as more data becomes available.
34
35 **Light Rail and Streetcar Fatalities**
36 NTD defines transit-related fatalities as deaths or suicides happening within 30 days of an event
37 that is reportable to NTD (19). Descriptive statistics for light rail and streetcar fatalities are
38 presented in this section. Additional analysis for light rail suicides is also presented in this section.
39 Similar to injuries, NTD considers fatalities from both safety and security events.
40
41 *Descriptive Statistics of Fatalities*
42 In total, 476 light rail and streetcar fatalities were reported to NTD in the period 2002-2017. 4%
43 of these fatalities were passengers, 12% were people waiting or leaving, 25% were suicide, and
44 59% were "Other" (results not shown). The "Other" category was less detailed in NTD database
45 prior to 2008, which limits the ability for further investigation. However, light rail fatalities are
46 discussed in more detail for the period 2012-2017.

1   Figure 6 shows that there were 250 light rail fatalities in the period 2012-2017. This figure
2   reveals that a large number (28%) of these fatalities were suicides, which represents the highest
3   portion of light rail fatalities. Figure 6 also shows that 14% of light rail fatalities were people
4   waiting or leaving, which is consistent with early findings from the injury analysis that many of
5   light rail injuries were people waiting or leaving. Other vehicle occupants, pedestrians in crossings,
6   and bicyclists represent 12%, 8%, and 7%, respectively, of light rail fatalities in the period 2012-
7   2017. It is also worth noting that since almost 30% of the total fatalities were suicide, further
8   exploration of suicide trends was conducted instead of a multivariate analysis of the fatalities. Last,
9   there were only seven streetcar fatalities during the period 2012-2017 (results not shown). This
10   was not explored further due to the small number of fatalities.
11   Similar to collisions and injuries, the annual fatality rates per VOMS for light rail and streetcars
12   were also compared for the period 2012-2017. This comparison revealed that the annual fatality
13   rate per VOMS for light rail ranged between 0.024 to 0.033 with an average of 0.03, while the
14   streetcar annual fatality rate per VOMS for streetcars ranged from 0.0 to 0.014 with an average of
15   0.01 (results not shown). It should be noted that in 2013, there were no reported streetcar fatalities
16   so the rate in that year was zero. This reveals that light rail generally has higher fatality rates
17   compared to streetcars for the same level of service. This higher fatality rate for light rail compared
18   to streetcars could be attributed to two factors. The first factor is the number of suicides, which are
19   substantially higher for light rail, and the second factor is the operational speed, which is also
20   higher for light rail compared to streetcars.
21
22   *Light Rail Suicide*
23   The previous analysis showed that almost 30% of light rail fatalities in the period 2012-2017 were
24   suicides, as shown in Figure 6, which necessities further investigation.
25   The suicide rate for light rail per PMT was investigated for the period 2012-2017. The rate
26   increased from 4.87 in 2012 to 6.42 in 2017, which represents a 19% increase. This increase may
27   be interpreted as part of nationwide trends. From 1999 to 2016, suicide rates increased between
28   6% and 58% in 49 states. (20). Furthermore, the nationwide suicide rate per 100,000 people
29   increased 31% in the period 2001-2017 (21). Light rail suicide statistics were then compared to
30   heavy rail suicides for the period 2012-2017 using data from NTD. Suicide fatalities represent
31   28% of light rail fatalities compared to about 53% of heavy rail fatalities. The suicide rate per PMT
32   for light rail was higher than heavy rail for most of the years, but the total number of heavy rail
33   suicides was higher than light rail suicides for all years (results not shown). This comparison shows
34   that suicide is a common issue for both heavy rail and light rail operators.
35
36   **AREAS FOR IMPROVEMENT AND FUTURE RESEARCH**
37   There are some noteworthy limitations of this analysis and important areas for future research that
38   emerged from this study. First, the NTD data used in this study considered light rail and streetcars
39   as one mode until 2011; therefore, the multivariate analysis considered them one mode. A separate
40   multivariate analysis for each mode should be conducted as more data becomes available for each
41   mode separately. Also, this analysis explored the crash, injury, and fatality rates per VOMS.
42   However, this study did not explore collision, injury, and fatality rates by type of ROW because
43   the data were not available for the different types of rail ROW. Future studies should explore the
44   crash, injury, and fatality rates for the different ROW types, if more detailed information become
45   available. Another limitation of this analysis is that NTD changed some of the collisions and
46   injuries categories. Specifically, in 2008, NTD added new person types to injuries and fatalities

1 such as bicyclists, other vehicle occupants, pedestrians not in crossings, and pedestrians in
2 crossings. These types used to be defined as "other" prior to 2008, which limits the possibility of
3 detailed exploration prior to 2008. It is also worth noting that NTD combines injuries and fatalities
4 from safety and security events, which limits the ability to explore safety and security trends
5 separately.
6   This analysis also revealed several areas for future research. First, this study only
7 considered nationwide safety trends for light rail and streetcars; future studies should conduct more
8 localized analysis to study the root causes of these challenges and how cities can response to them.
9 One important challenge identified by this study for further investigation is how light rail operators
10 can improve safety at light rail stations. Another area for future research pertains to suicide and
11 how light rail operators, cities, and mental health experts can respond to this concerning trend.
12 Also, this study compared the safety of light rail and streetcars. Another area for future research is
13 comparing the safety of the different transit modes such as comparing light rail to bus rapid transit.
14 Future studies should also compare the safety of transit to non-transit modes. It worth noting that
15 a previous study by Litman (2014) compared transit safety to automobile safety (22). However,
16 comparing the safety of transit to new emerging modes such as ridesharing and bike sharing is an
17 area for future research.
18
19 **CONCLUSIONS**
20 This study conducted a longitudinal analysis of light rail and streetcar safety in the United States
21 for the period 2002-2017 using data obtained from NTD. The main conclusions of this analysis
22 about light rail and streetcar safety in the United States are discussed below.
23   Some of the key findings of this study are consistent with prior research. For example, the
24 majority of light rail and streetcar collisions occur in mixed ROW or near at-grade crossings (4).
25 This conclusion is supported by the results of the descriptive statistics that showed 48% of light
26 rail and streetcar collisions during the period 2002-2017 were collisions with motor vehicles.
27 Similarly, the results of the multivariate analysis indicate that the number of at-grade crossings
28 and mixed ROW track miles have a significant positive effect on the number of light rail and
29 streetcar collisions. These findings suggest that light rail and streetcar operators should focus on
30 at-grade crossings and mixed ROW safety improvements to reduce light rail and streetcar
31 collisions with vehicles. Light rail operators could also use innovative awareness campaigns to
32 improve the safety of at-grade crossings (23). Also, the multivariate analysis showed that speed
33 has the highest impact on the expected number of collisions and injuries. This finding is also
34 consistent with prior research that showed higher speeds can increase the number of collisions and
35 injuries (5; 8).
36   This study also revealed some surprising findings. One noteworthy example from the
37 descriptive statistics is that 42% of light rail injuries were people waiting or leaving transit stations.
38 These results were not expected, since light rail stations are typically more developed stations (as
39 compared to streetcar or bus service); moreover, recent findings from Australia suggest that
40 platform stations have positive impacts on safety (8; 12). These results suggest that light rail
41 operators should further investigate safety and security at the stations in the United States. For
42 example, light rail operators should consider both infrastructure improvements and passenger
43 awareness to enhance both the safety and the security of the users at stations. Light rail operators
44 can improve the safety and the security at stations by installing cameras and emergency alarms
45 (22; 24). Also, operators could use mobile applications to provide access to police in real time in
46 case of emergency (22).

1   Another surprising finding was suicide is the leading cause of light rail fatalities; suicides
2 were 28% of all light rail fatalities in the period 2012-2017. Light rail operators should work with
3 cities and local public health experts to explore how they can reduce the number of suicides. For
4 example, light rail operators can install barriers around stations, install suicide warning signs at
5 stations, provide information about suicide prevention resources, and participate in awareness
6 campaigns about suicide (25).
7 In summary, this study highlights important safety challenges for light rail and streetcar operators
8 in American cities.
9

18 **AUTHOR CONTRIBUTIONS**
19 The authors confirm contribution to the paper as follows: study conception and design:
20 A. Ziedan, C. Brakewood; data collection: A. Ziedan; analysis and interpretation of results: A.
21 Ziedan, C. Brakewood; draft manuscript preparation: A. Ziedan, C. Brakewood. All
22 authors reviewed the results and approved the final version of the manuscript. The authors do not
23 have any conflicts of interest to declare.

REFERENCES

1. Vuchic, V. R. *Urban Transit Systems and Technology*. John Wiley & Sons, 2007.
2. Furmaniak, T. B., and J. W. Schumann. *Light Rail & Streetcar Systems: How They Differ; How they Overlap.* American Public Transportation Association, 2014.
3. Bureau of Transportation Statistics. *2019 Pocket Guide to Transportation,* , U.S. Department of Transportation, 2019.
4. Korve, H. W., J. I. Farran, D. M. Mansel, H. S. Levinson, T. Chira-Chavala, and D. R. Ragland. *TCRP Report 17: Integration of Light Rail Transit into City Streets.* Transportation Research Board, Washington, D.C., 1996.
5. Golembiewski, G., Z. Sabra, K. Pecheux, and J. Boorse. *TCRP Web-Only Document 53: Operation of Light Rail Transit through Ungated Crossings at Speeds over 35 MPH.* Transportation Research Board, Washington, D.C., 2011. http://dx.doi.org/10.17226/22822.
6. Fischhaber, P. M., and B. N. Janson. Preliminary Analysis of Light Rail Crashes in Denver, Colorado: Implications for Crash Prediction and Hazard Index Models based on Railroads. *Transportation Research Record: Journal of the Transportation Research Board,* 2012. 2275: 12-21.
7. Fischhaber, P. M., and B. N. Janson. Light Rail Crossing Safety Performance Functions. *Transportation Research Record: Journal of the Transportation Research Board,* 2015. 2476: 94-100.
8. Naznin, F., G. Currie, D. Logan, and M. Sarvi. Application of a Random Effects Negative Binomial Model to Examine Tram-involved Crash Frequency on Route Sections in Melbourne, Australia. *Accident Analysis & Prevention,* 2016. 92: 15-21.
9. Naznin, F., G. Currie, M. Sarvi, and D. Logan. An Empirical Bayes Safety Evaluation of Tram/Streetcar Signal and Lane Priority Measures in Melbourne. *Traffic Injury Prevention,* 2016. 17: 91-97.
10. Fitzpatrick, K., B. R. Sperry, J. E. Warner, B. L. Bentzen, and M. A. Brewer. Understanding Pedestrian Needs at Light Rail Transit Grade Crossings. Presented at 96th Transportation Research Board Annual Meeting Compendium of Papers, Washington, D.C., 2017.
11. Srirangam, L. P., and S. S. Pulugurtha. Modeling Pedestrian Crashes at Intersections Near Light Rail Transit Stations and Comparing Before–After Patterns. Presented at 97th Annual Meeting on the Transportation Research Board Washington, DC, 2018.
12. Currie, G., and J. Reynolds. Vehicle and Pedestrian Safety at Light Rail Stops in Mixed Traffic. *Transportation Research Record: Journal of the Transportation Research Board,* 2010. 2146: 26-34.
13. Naznin, F., G. Currie, D. Logan, and M. Sarvi. Safety Impacts of Platform Tram Stops on Pedestrians in Mixed Traffic Operation: A Comparison Group Before–After Crash Study. *Accident Analysis & Prevention,* 2016. 86: 1-8.
14. Naznin, F., G. Currie, and D. Logan. Key Challenges in Tram/Streetcar Driving from the Tram Driver's Perspective–A Qualitative Study. *Transportation Research Part F: Traffic Psychology and Behaviour,* 2017. 49: 39-48.
15. Federal Transit Administration. *The National Transit Database (NTD).* https://www.transit.dot.gov/ntd. Accessed 06-30-2019.
16. Lord, D., and F. Mannering. The Statistical Analysis of Crash-frequency Data: a Review and Assessment of Methodological Alternatives. *Transportation Research Part A: Policy and Practice,* 2010. 44: 291-305.

1   17. Washington, S. P., M. G. Karlaftis, and F. Mannering. *Statistical and Econometric Methods*
2   *for Transportation Data Analysis*. Chapman and Hall/CRC, Boca Raton, FL, 2010.
3   18. StataCorp LLC. *Stata Multilevel Mixed-effects Reference Manual: Release 15*. Stata Press,
4   College Station, Texas, 2017.
5   19. National Transit Database. *Safety & Security Reporting Manual.* Washington, D.C., 2018.
6   20. Centers for Disease Control and Prevention. 2018. *Comprehensive Prevention Goes beyond a*
7   *Focus on Mental Health Concerns,* [Press Release],
8   https://www.cdc.gov/media/releases/2018/p0607-suicide-prevention.html Accessed 06-20-2019.
9   21. National Institute of Mental Health. *Suicide Statistics*.
10 https://www.nimh.nih.gov/health/statistics/suicide.shtml#part_154969. Accessed 06-19-2019.
11 22. Litman, T. A New Transit Safety Narrative. *Journal of Public Transportation,* 2014. 17:
12 114-135.
13 23. Wanek-Libman, M. *Ten Transit Agencies to Benefit from Operation Lifesaver Grants.* Mass
14 Transit. https://www.masstransitmag.com/safety-security/article/21088304/ten-transit-agencies-
15 to-benefit-from-operation-lifesaver-grants. Accessed 07-12-2019.
16 24. Kennedy, D. Personal Security in Public Transport Travel in New Zealand: Problems, Issues
17 & Solutions. 2008.
18 25. Stone, D. M., K. M. Holland, B. N. Bartholow, A. E. Crosby, S. P. Davis, and N. Wilkins.
19 *Preventing Suicide: A Technical Package of Policies, Programs, and Practice.* National Center
20 for Injury Prevention and Control-Centers for Disease Control and Prevention, Atlanta, GA,
21 2017.

1 **TABLES**
2
3 **Table 1: Descriptive Statistics**

Category	Variable	Source	Balanced Panel [f] (n=285)				Unbalanced Panel [f] (n=423)			
			Mean	SD	Min	Max	Mean	SD	Min	Max
Dependent variables	Total collisions	NTD Safety and Security	14.4	43.8	0.0	409.0	12.7	39.4	0.0	409.0
	Total injuries		41.9	53.5	0.0	321.0	33.6	47.3	0.0	321.0
Explanatory variables	Number of at-grade crossings [a]	NTD Transit Way Mileage	135.5	205.9	8.0	1702.0	118.2	192.4	0.0	1702.0
	Mixed ROW miles [b]		14.7	41.1	0.0	189.2	11.2	34.9	0.0	189.2
	Crossing ROW miles [c]		29.7	29.5	0.0	125.8	24.0	27.0	0.0	125.8
	Exclusive ROW miles [d]		30.6	26.7	0.0	102.0	22.6	25.5	0.0	102.0
	Speed [e]	NTD Safety and Security	14.7	5.4	4.6	29.1	13.4	5.6	3.1	29.2
	Vehicles operated at maximum service (VOMS)		68.7	47.6	1.0	181.0	53.6	46.9	1.0	181.0
	Annual unlinked passenger trips (in millions)		21.1	19.6	0.04	80.3	16.5	18.2	.03	80.3
	Total stations	NTD Stations	36.1	20.0	0.0	79.0	29.4	20.6	0.0	79.0

[a] *NTD defines at-grade crossings as "an intersection of a roadway and a rail right-of-way that cross each other at the same level (at grade)".*

[b] NTD defines mixed ROW miles as *"where rail vehicles and rubber-tire vehicles travel in the same lanes and alignments where pedestrians may freely cross the tracks at any point".*

[c] NTD defines crossing ROW miles as *"at-grade tracks that cannot be entered by non-rail traffic except at certain crossing points".*

[d] The Exclusive ROW miles include the following types of rail way: At Grade: Exclusive ROW Track Miles, Elevated-on-Structure Track Miles, Elevated-on-Fill Track Miles, Open-Cut Track Miles, and Subway Track Miles.

[e] The authors calculated speed by dividing vehicle revenue miles by vehicle revenue hours.

[f] Newark, NJ is not included because since light rail and hybrid rail were reported as one mode prior to 2012.

4

1   **Table 2: Light Rail and Streetcar Collisions Negative Binomial Model Results**

	Balanced Panel Coefficients (Standard Error) (1)	Unbalanced Panel Coefficients (Standard Error) (2)
Speed	0.0677***	0.0797***
	(0.0231)	(0.0206)
Number of at-grade crossings	0.00137***	0.00133***
	(0.000420)	(0.000408)
Mixed ROW miles	0.0131***	0.0114**
	(0.00406)	(0.00543)
Vehicles operated at maximum service (VOMS)	0.00652**	0.00704***
	(0.00273)	(0.00257)
Intercept	-0.0489	-0.380
	(0.432)	(0.346)
Ln (conditional overdispersion parameter)	-0.968***	-0.769***
	(0.120)	(0.102)
Var (Intercept)	0.502**	1.164***
	(0.246)	(0.382)
N	285	423
Log-likelihood with constant only	-836.24	-1188.83
Log-likelihood at convergence	-823.51	-1171.03

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

2

1 **Table 3: Light Rail and Streetcar Injuries Negative Binomial Model Results**

	Injuries			
	Balanced Panel Coefficients (Standard Error)		**Unbalanced Panel Coefficients (Standard Error)**	
	(1)	**(2)**	**(1)**	**(2)**
Speed	0.101***	0.104***	0.105***	0.103***
	(0.0248)	(0.0238)	(0.0205)	(0.0202)
Mixed ROW miles	0.00948**	0.0108**	0.00771	0.00804
	(0.00449)	(0.00421)	(0.0051)	(0.0050)
VOMS	0.0193***	0.0108***	0.0209***	0.0129***
	(0.00253)	(0.00399)	(0.0023)	(0.0038)
Unlinked Passenger Trips (In Millions)		0.0292***		0.0293***
		(0.0107)		(0.0112)
Intercept	-0.0178	-0.116	-0.0781	-0.103
	(0.455)	(0.430)	(0.3360)	(0.3310)
Ln (conditional overdispersion parameter)	-0.938***	-0.954***	-0.787***	-0.805***
	(0.107)	(0.107)	(0.0942)	(0.0944)
Var (Intercept)	0.688**	0.553**	1.103***	1.040***
	(0.280)	(0.232)	(0.3330)	(0.3160)
N	285	285	423	423
Log-likelihood with constant only	-1170.13	-1170.13	-1627.53	-1627.53
Log-likelihood at convergence	-1136.74	-1133.14	-1576.63	-1573.24

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

2

Ziedan and Brakewood
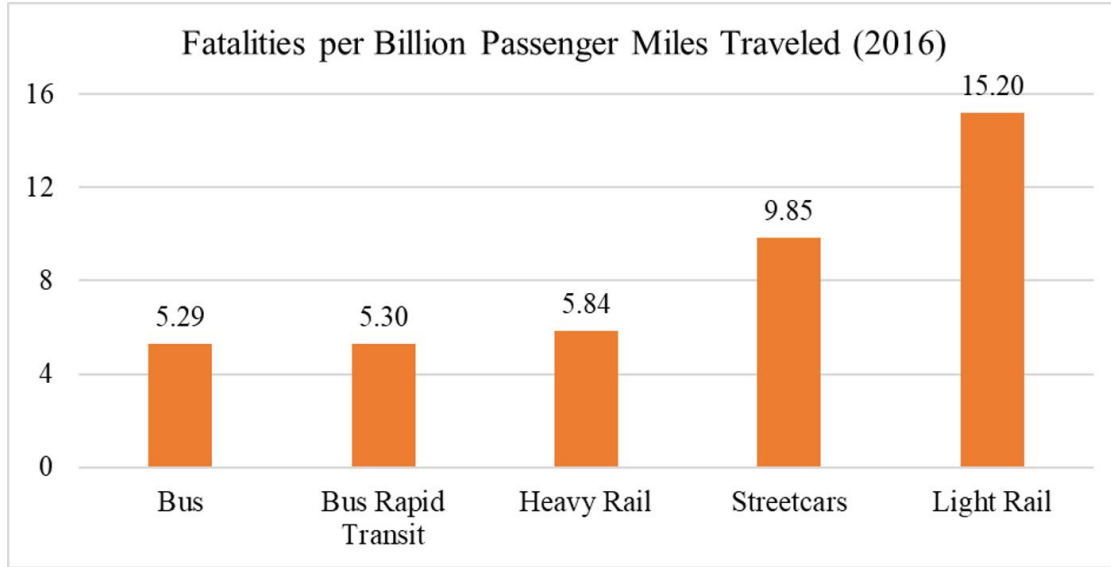
1 **FIGURES**
2

3
4
5 **Figure 1: Nationwide Transit Modes Fatality Rate** *(Calculated by the authors using data from*
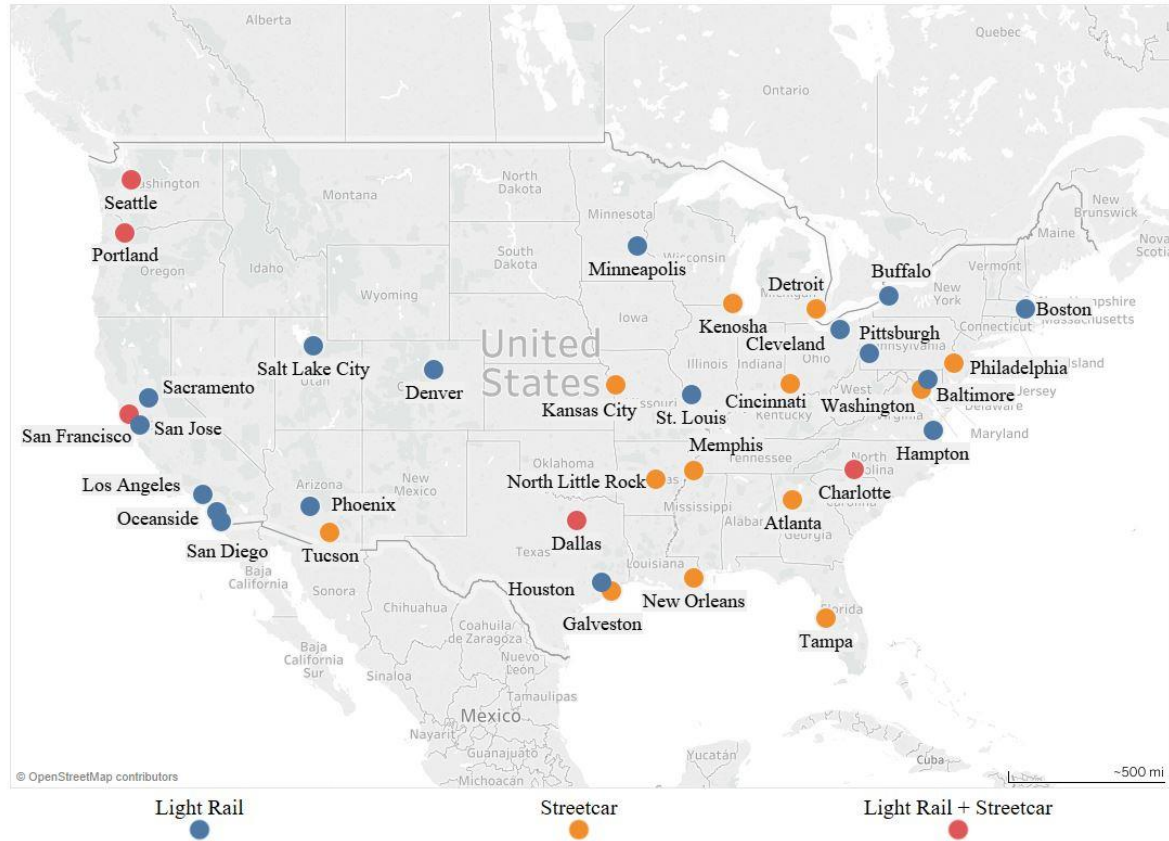6 *the National Transit Database)*

1
2
3   **Figure 2: Cities with Light Rail or Streetcars Included in this Analysis**
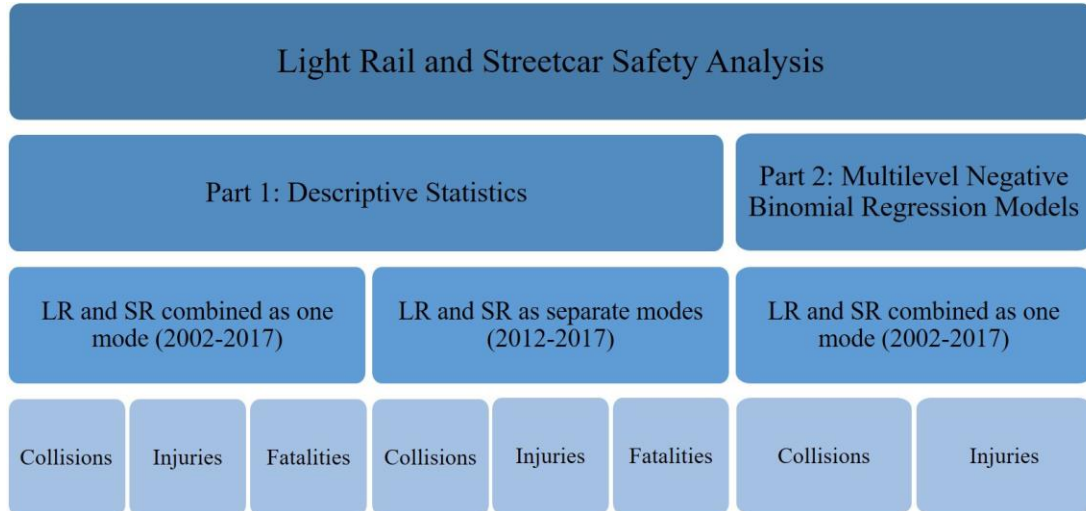
1
2 **Figure 3: Summary of the Methodology**
3
4

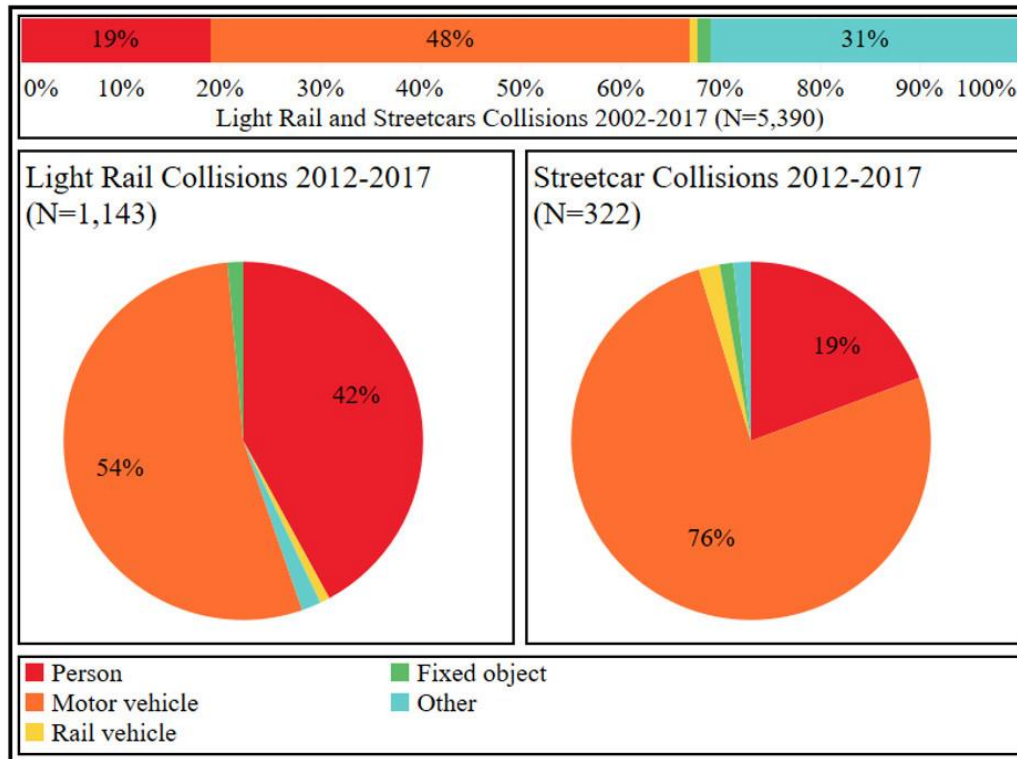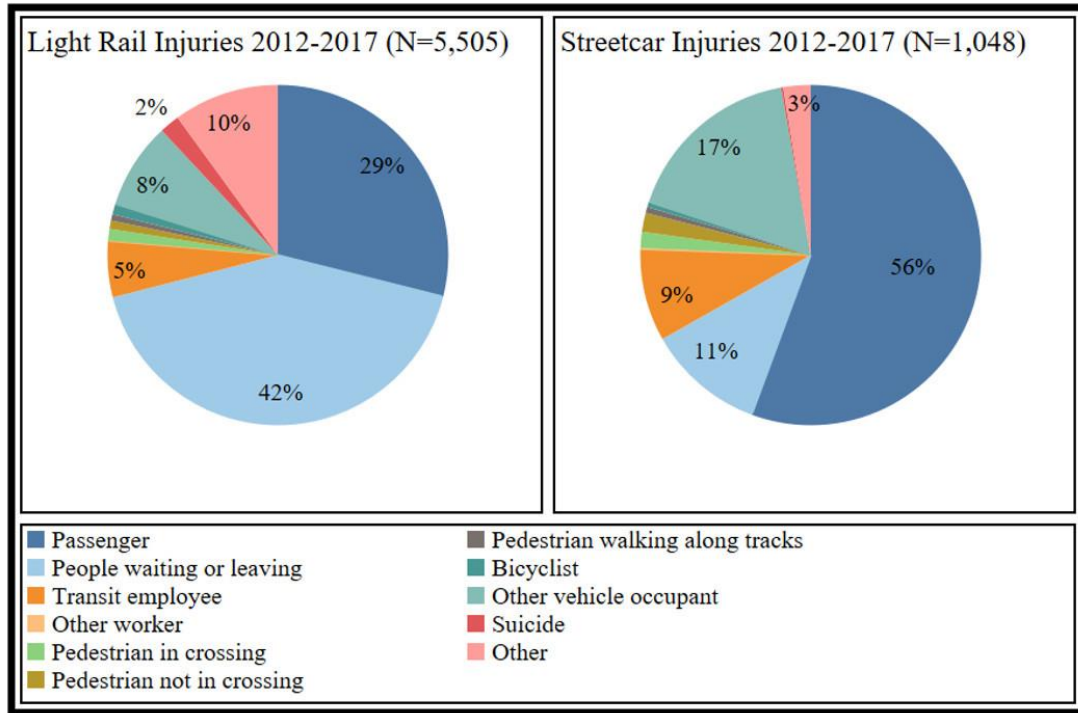Figure 4: Descriptive Statistics for Light Rail and Streetcar Collisions

1
2 **Figure 5: Descriptive Statistics for Light Rail and Streetcar Injuries**
3

Light Rail Fatalities 2012-2017 (N=250)

Legend:
- Passenger
- People waiting or leaving
- Transit employee
- Other worker
- Pedestrian in crossing
- Pedestrian not in crossing
- Pedestrian walking along tracks
- Bicyclist
- Other vehicle occupant
- Suicide
- Other

Pie chart values: 4%, 14%, 8%, 3%, 6%, 7%, 12%, 28%, 17%

* There were only 7 streetcar fatalities in the period 2012-2017. Therefore, a graphic for streetcar fatalities was not made.
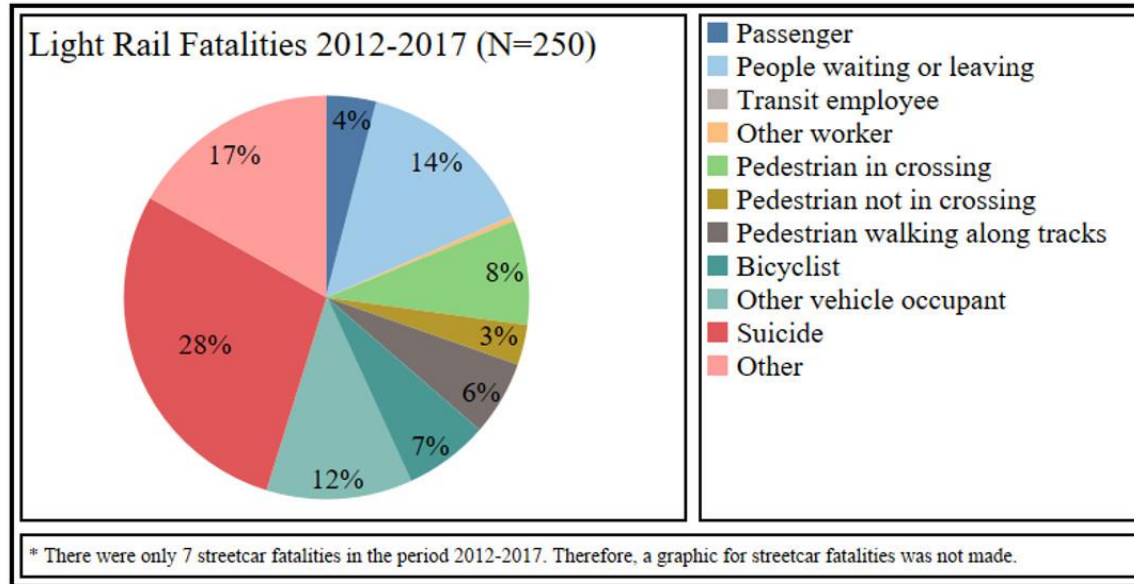
1
2   **Figure 6: Descriptive Statistics for Light Rail Fatalities**