The role of street intersection design on crash injury severity in Philadelphia

Zihan Zhao zhaozih@design.upenn.edu

Supervisor: Elizabeth Delmelle delmelle@design.upenn.edu

Key Questions:

- **What are the questions we tried to answer?**

  1) Are crashes at intersections more likely to result in higher injury severity? 2) Which street design variable is significantly associated with crash severity? 3) Will intersection infrastructures such as transportation islands help reduce the crash injury severity and improve the safety condition at intersections?

- **What are the new findings?**

  crashes at intersections are more likely to result in higher severity.

  Among the crashes related to intersections, the speed limit of intersections, the vehicular lane direction, and the street angle are significantly associated with the crash injury.

  There is a significant association between the traffic islands and the diagonal intersections, but there is no significant relation between traffic islands and crash injury.

- **What do the new findings imply?**

  Intersections must handle different types of transportation and conflicts between vehicles, bikes, and pedestrians. Therefore, we should always keep updating the design of intersections. The diagonal street intersections will make people involved in the crashes more vulnerable, which reminds us to consider more security factors when designing diagonal intersections. the design of traffic islands is mainly for lane channelization. We are not sure if traffic islands can serve as pedestrian shelters.

I. Introduction

Safety is a big concern in transportation design. This report studied the association between street intersection design variables and vehicle crash severity in Philadelphia, Pennsylvania. In previous studies on traffic accidents, people often pay more attention to the vehicle and natural factors, such as the road and weather conditions, whether there is drunk driving or speeding, etc. However, this report focused more on the urban/ transportation design factors, especially the street intersection design variables. Compared with midblock streets, intersections must handle more complex traffic conditions. Therefore, street intersections are also more prone to unreasonable design, resulting in potential safety hazards. According to previous crash data, more than one-third of traffic accidents occurred near the intersection. Therefore, this research addressed three main research questions focusing on the street intersection design in Philadelphia: **1) Are crashes at intersections more likely to result in higher injury severity? 2) Which street design variable (intersection angle, vehicle lane direction, or intersection speed limit) is significantly associated with crash severity? 3) Will intersection infrastructures such as transportation islands help reduce the crash injury severity and improve the safety condition at intersections?**

This research divided the data into collection and measurement data. The crash data mainly came from the annual crash police report from the Pennsylvania Department of Transportation (PennDOT), the most critical information of which is the latitudes, longitudes, injury severity, and intersection types of the location where the accident occurred. The environmental data, including the streets centerline shapefile and curbs shapefile, was from Open Data Philly. The street infrastructure data was from the City of Philadelphia, including the street speed limit and the vehicular lane direction. The geographic information system (GIS) facilitates the location of a crash on a map as aggregate geographic data.[1] By visualizing the crash data on the map in ArcGIS Pro, we can calculate, filter out, and store the street design variables - intersection angle, the street width, and the traffic islands' existence of the crash location. Additional variables, including drunk driving, speeding, and unbelted conditions, were also from the PennDOT crash police report. This study integrated crash data from Philadelphia over three years, from 2019 to 2021. Besides, this research used a multivariate logistic regression model as a statistical analysis approach to examine the associations between injury severity and all the independent variables.

This research has multiple social and economic implications for individuals, streets, communities, and the city. Initially, traffic accidents directly affect people engaged and their families. The tragedy of a fatal crash can never be overstated, and a severe injury crash can emotionally and financially destabilize an individual - or an entire family.[2] This study will help pedestrians and cyclists better understand different street conditions and encourage them to make safer choices, reducing the risk of crashes. By focusing on the environmental configurations of the street intersection, our conclusion can also be a guideline for drivers to drive safely. For example, slow down when approaching a meeting with an acute angle, pay attention to the bicycle in the blind point, etc.

In addition, for community development, good street design and a safe community environment are also crucial. Crash severity is both a traffic safety issue and a community equity issue. The Department of Public Health analysis found the rate of dying from traffic crashes among residents of Philadelphia's lowest-income ZIP codes is 57% higher than the rate of dying from traffic crashes among residents of Philadelphia's highest-income ZIP codes.[3] The research results can provide reliable street safety design guidance for Philadelphia communities. Optimizing the street design to enhance the community's safety helps promote the equitable development of Philadelphia's neighborhood.

Finally, improving the overall traffic safety situation is also the common expectation of all relevant departments in Philadelphia. This study can help PennDOT, Vision Zero and other related planning teams improve their proposals and policies. Knowing the details of traffic violence in Philadelphia is necessary to direct time, energy, and funding where needed most. [4] In recent years, Philadelphia's Green Stormwater Infrastructure (GSI) team, Vision Zero, and Center City District (CCD) have released a series of plans to enhance traffic safety and improve the design of traffic islands in Philadelphia. Hence, this report can provide relevant theoretical support and suggestions for future design directions for these proposals.

II. Current Knowledge

Philadelphia and its peer cities have been committed to various research based on the crash data because these results have the most significant relationship to the safety and property of residents. This report designed three research questions based on previous research, planning theories, statistical data, and the manual.

Research Question 1: Are crashes at intersections more likely to result in higher injury severity?

Crashes police report data from PennDOT mainly has two categories for the crashes near intersections, INTERSECT_TYPE and INTERSECT_RELATED. INTERSECT_TYPE divides the crash locations into 12 types. The INTERSECT_RELATED data is for midblock crashes only. This information is about whether the crash related to the intersection ahead was due to stopped traffic or turning lane navigation (Pennsylvania Department of Transportation, 2021, p. 8). [5] These categories can only partially record the intersection configurations. Research Question 1 starts with a more precise definition of whether the crash is related to intersections, which Research Question 2 is based on.

Besides, previous studies also emphasized the importance of intersections in traffic safety research. For example, 40% of the estimated 5,811,000 crashes that occurred in the United States in 2008 were intersection-related crashes (National Highway Traffic Safety Administration, 2010). [6] The intersections identified as the most dangerous accounted for 772 total crashes involving 2,676 people in 2015. Those crashes caused 1,252 injuries and 15 fatalities (Lowenthal and Abrams, 2015). [7] Research Question 1 further refined the classification of crash injury severity. In addition to fatalities, this report included injuries in

Picture. II. 1. Crashes related to intersections

the scope of this study.

Research Question 2: Which intersection design variable (intersection angle, vehicle lane direction, or intersection speed limit) is significantly associated with crash severity?

Previous studies and planning proposals focus more on the design of street intersections for pedestrians and bike-motor vehicles. Intersections are the place where most vehicle-bike conflicts occur. [8] On many streets, large turn radii and wide lanes encouragement drivers to make sweeping, fast turns. These design decisions increase exposure and risk for people walking and biking, reduce the safety and comfort of the bike network, and discourage cycling. [9] In addition, non-standard intersections also increase the risk that pedestrians and bike-motor vehicles are in the driver's blind spot. Traffic follows the usual rules at a diagonal intersection, but it is harder for drivers to look into the diagonal cross street behind them. Some of the turns in a diagonal intersection are not very sharp, so cars may not slow down very much (Pennsylvania Department of Transportation, 2023, p. 17). [10] A study led by Dr. Morteza Asgarzadeh of Harvard's T. H. Chan School of Public Health found that non-right-angle intersections are especially prone to crashes that cause severe or fatal injuries to bicyclists. [11] This study attributed the significant association between non-orthogonal intersections and bike-motor vehicle crashes injury severity to the fact that non-90-degree intersections are more likely to reduce the driver's visibility. The intersection angle is the elements that mainly affect people's visibility. Therefore, Research Question 2 used street angle as one of the independent variables.

Interestingly, for pedestrians, diagonal intersections give people more visibility. When the angle between the streets is smaller, pedestrians can see more building facades on the diagonal street. A study published in the Journal of Asian Architecture and Building Engineering indicates that diagonal streets within a grid pattern are elements that can increase pedestrian interest. [12]

However, more is needed to focus on Philadelphia's crash data, not only the bike and motor crashes. According to news, between June 2022 and February 2023, there were three car-car collisions near the West Philadelphia 37th Street and Lancaster Avenue intersection. The reason for all these crashes is the right-turning vehicle did not have enough visibility to observe the straight-going vehicle from the left. The 37th Street and Lancaster Avenue intersection is a typical diagonal intersection, and the diagonal street Lancaster Avenue is also on Philadelphia's high injury network. Therefore, this study will comprehensively consider crashes of all vehicle types.

Research Question 3: Will the transportation island design help reduce the crash injury severity and improve the safety condition at intersections?

A traffic island is a defined area between traffic lanes that control vehicle movements. Islands serve three primary functions: (1) channelization—to control and direct traffic movement, usually turning; (2) division—to divide opposing or same-direction traffic and (3) refuge—to provide refuge for pedestrians. Most islands combine two or all these functions. [13] With this definition, we can conclude that an island has multiple physical types. This research focuses more on street intersections, so the only traffic island type we discussed is the raised curb area, which is usually a triangular-shaped island.

In recent years, various organizations in Philadelphia have proposed many projects, mainly to improve the pedestrian experience and optimize the urban landscape. For example, in January 2021, City of Philadelphia officials released the proposed design for the reimagined intersection of Broad, Erie, and Germantown. [14] This long-neglected intersection will help better protect pedestrians, provide more green open space for the community, and manage public traffic. There are many similar proposals for the diagonal streets around Philadelphia, including Passyunk Avenue, Benjamin Franklin Parkway, and Lancaster Avenue. In addition, there are some proposals to make these islands more functional. For example, the Green Stormwater Infrastructure (GSI) planning team from Philadelphia Water Department proposed a series of programs to help manage the stormwater by transferring the traffic island pavement into more previous material. [15]

The projects above are indeed beneficial to the urban living environment. However, we still need further research on the role of traffic islands in traffic safety. This study can better guide the design and allocation of investments in these programs.

III. Project Methods

A. Research Data Time Frame and Software

This research obtains the crash data from the PennDOT crash police report from 2019 to 2021. There are a total of 31,730 items in these data before data cleaning and integration. For Question 2 and 3, there are 14,223 data after cleaning and integration based on the research questions' requirements. (The null data was all deleted.) All environmental variables, including the street centerlines shapefile (2014) and curbs shapefile (2014), are from Open Data Philly. The street infrastructure data (2016) was from the City of Philadelphia, including the street speed limit and the vehicular lane direction.

The software used for the measurement and screening of environmental variables in this research is ArcGIS Pro. The software used to establish the statistical correlation model of each variable is R.

B. Data Obtain and Integration

1. Research Question 1 Data

1) Dependent Variable: Severity of Crashes

This research obtained the crash severity data from the PennDOT policy reports. The data about the crash injury severity is "MAX_SEVERITY_LEVEL," coded by numbers. We can translate the code with PennDOT Open Data Portal Crash Data Dictionary and Field Constraints Tables (PennDOT, 2022). [16]

Here are the explanations of the MAX_SEVERITY_LEVEL: 0 – Property Damage Only; 1 – Fatal; 2 – Suspected Serious Injury; 3 – Suspected Minor Injury; 4 – Possible Injury; 8 – Injury – Unknown Severity.

When MAX_SEVERITY_LEVEL = 1 or 2we code the crash as "severe crashes"; when MAX_SEVERITY_LEVEL = 0, 3, 4, 8 or 9, we code the crash as "non-severe crashes."

2) Intersection Related Crashes

From the PennDOT crash data, this research obtained the intersection type of the crashes from "INTERSECT_TYPE", which categorized the crash locations into 14 types.

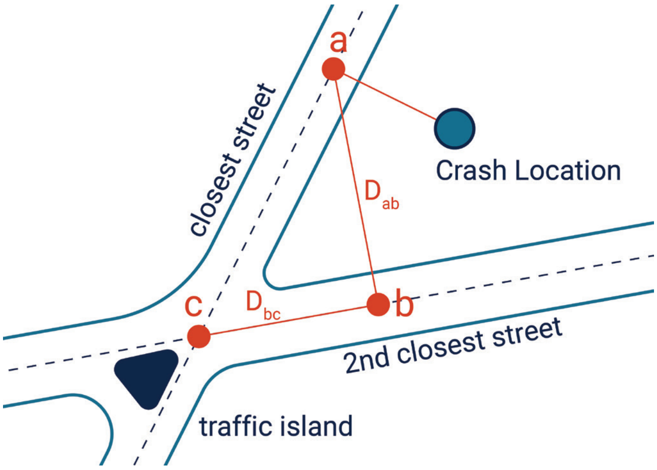
Here are the explanations of the INTERSECT_TYPE: 00 – Mid-block; 01 – Four-way intersection; 02 – "T" intersection; 03 – "Y" intersection; Begin; 08 – Crossover; 09 – Railroad crossing; 10 – Other; 11 – "L" Intersection; 12 – Traffic Circle; 13 – Roundabout; 99 – Unknown.

When INTERSECT_TYPE = 01, 02, 03, 05, and 11, we code the crash as "intersection-related crashes" and the other categories as "non-intersection-related crashes." This report does not count highway exits and entrances as intersections.

2. Research Question 2 and 3 Data

1) Dependent Variable: Severity of Crash Injuries

This research obtained the crash severity data from the PennDOT policy reports. The data about the crash injury severity is "MAX_SEVERITY_LEVEL," coded by numbers. For this research question, when MAX_SEVERITY_LEVEL = 1, 2, 3 or 4, SEVERE_CRA_INJ = 1; when MAX_SEVERITY_LEVEL =0, 8 or 9, SEVERE_CRA_INJ = 0.



Picture. II. 1. Crashes related to intersections

2) Orthogonal Intersections

Through the method described in III. B. 2. 1), we screen out all intersection related crashes and their locations. We use the display XY data (a tool that can visualize longitude and latitude data on the map with the same coordinate system) accurately present the location of these crashes on the map of Philadelphia.

The street centerline file depicts each street with one line that is in the center of the street. Each centerline is composed of several segments that were drawn by a cartographer when developing the centerline map. [17] In order to measure the location of these intersection related crashes for the angle of intersection, we first use the geoprocessing tool "Near" of ArcGIS Pro to find the street centerline segment closest to the crash location. Then we find the street centerline segment that is the second closest to the crash location. These two types of street centerline data were stored separately for measuring the angles. While processing the near tool, we identified a search range for each crash location, and the range was 65 feet. Therefore, if there was no street segment detected within the range, we classified the crash as outside intersection proximity.

As Figure III. B. 3. 1. shows we recorded the coordinates of Point a (the nearest point on the street segment centerline from the crash location), Point b (the nearest point on the street segment centerline from Point a, also on the second nearest street segment centerline from the crash location), and Point c (the closest street centerline intersection point within a 65 feet range). Besides, the near tool helped us calculate the distance between Point a and Point b and between Point b and Point c. Therefore, we can calculate the street angle with the equation below:

$$St_{Angle} = \arctan\left(\frac{D_{ab}}{D_{bc}}\right) \cdot \frac{180°}{\pi}$$

In this research, we did not consider whether the street intersection angle is obtuse or acute. Therefore, in the above formula we only took the absolute value of the distance. In summary, our angle calculation result X was always between 0 degrees and 90 degrees. We took ±10° as the measurement error. Hence, if the measurement of angle X is 10°≤ X ≤80°, we coded the crash intersection as "non-orthogonal intersection"; if 0°≤ X < 10° or 80°< X ≤90°, we coded the crash intersection as "orthogonal intersection".

3) Street Infrastructure Data from City of Philadelphia Open Data Resource

Using the method of III. B. 3. 1), we visualized the crash location data on the map, and can also get the data of the street centerline segment closest to the crash. Through spatial join (a tool that can merge two datasets from different attribute tables), we can find the corresponding street intersection infrastructure data, including the speed limit (SPEEDLIM) and the street vehicular lane direction (ONEWAY).

There are four categories in original speed limit data, 20 mph, 30 mph, 30 – 35 mph and above 35 mph. When SPEEDLIM = 20, 30, OR 30 – 35, we coded the intersection as "speed limit under 35" and the other categories as "speed limit above 35".

For the street direction data, there are three categories – BI (bidirectional), TF (to – from), and FT (from – to). We coded the street direction ONEWAY_BI = 1 when ONEWAY = BI, while ONEWAY_BI =0 when ONEWAY = TF or FT.

4) Other Variables from PennDOT Crash Data

This report selects three common causes of accidents in PennDOT crash data as other variables, as a model control for this study. These three variables are "ALCOHOL_RELATED", "SPEEDING_RELATED" and "UNBELTED". If ALCOHOL_RELATED = 1, it means at least one driver or pedestrian with reported or suspected alcohol use in the crash; 0 = non-alcohol related. If SPEEDING_RELATED = 1, it means that at least one vehicle was speeding in the crash; 0 = the crash was not related to speeding. If UNBELTED =1, it means that at least one person was unbelted in the crash; 0 = everyone involved in the crash was belted. We again use the attribute join method to add the above data to the dataset used in this research.

5) Traffic Islands

We filtered out the traffic island parcels based on the feature code of each parcel in the curb data and the area of each parcel. The curb data shapefile records all the parcels' information in Philadelphia. In the curb shapefile's attribute table, the feature code records the type of each parcel. Based on the definition of traffic islands in Chapter 9 of AASHTO Green Book (2001)[18], we first filtered out the parcels with an area smaller than 4,000 square feet. Then we filtered the parcels out based on their feature codes. We coded the parcel as "not an intersection traffic island" when the FEATURE_CODE = 9999 or 8888.

To define whether there was at least one intersection traffic island near the crash location, we first buffered each crash location in our dataset with 65 feet by the tool buffer in ArcGIS Pro. Then we can filter out the crash with at least one traffic island nearby by defining whether the buffered zone overlaps the traffic islands.

C. Statistical Analysis

In this research, we used logistic regression to study the association between the predictors and the crash injury severity.

The logistic regression equation for the logit model with multiple predictors is:

$$p = P(Y = 1) = \frac{e^{\beta_0 + \beta_1 x_1}}{1 + e^{\beta_0 + \beta_1 x_1}} = \frac{1}{1 + e^{-\beta_0 - \beta_1 x_1}}$$

Generally, rather than looking at the estimated coefficients, we prefer to look at the odds ratios, which are calculated by exponentiating the coefficients (). The extent to which the odds of Y = 1 change as the predictor increases by 1 unit. 1 unit in the predictor corresponds to (-1) *100% change in the odds of Y = 1.

For the correlation exam, in this report we used the Pearson correlation test to measure the associations between all the predictors (binary or continuous).

For Research Question 1, the dependent variable is CRASH_INJURY_SEVERITY (the risk ratio estimates for crash severity outcome), and the independent variables are INTERSECTION_OR_N (whether the crash is related to the intersection).

For Research Questions 2 and 3, we examined the association between the crash injury severity and the diagonal streets with the street angel data as a continuous variable. We also examined the association between the street infrastructure and the diagonal street but with the street angel data as a binary variable (orthogonal or nonorthogonal). Therefore, for the first model, the dependent variable is CRASH_INJURY_SEVERITY (the risk ratio estimates for crash severity outcome), and the independent variables are ALCOHOL_RELATED, UNBELTED, SPEEDING_RELATED, SPEEDLIM_35, ORTHOGONAL_OR_N, ONEWAY_BI, TRAFFIC_ISLAND, and St_Angle. For the second model, the dependent variable is ORTHOGONAL_OR_N (the risk ratio estimates for crash severity outcome), and the independent variables are SPEEDLIM_35, ONEWAY_BI, TRAFFIC_ISLAND, and CRASH_INJURY_SEVERITY.

IV. Results

A. Research Question 1

1) Results of The Exploratory Analysis

There are 31730 crash data in total for research question 1. The Table. IV. A. 1. shows the tabulation

	No (SEVERE_CRA=0)		Yes (SEVERE_CRA=1)		Total
	N	%	N	%	
SEVERE_CRASHES: Severe Crashes Indicator	30182	95.10%	1548	4.90%	31730

Table. IV. A. 1. Cross table of the crash severity

	Not Severe Crashes No (SEVERE_CRA=0)		Severe Crashes Yes (SEVERE_CRA=1)		Total	Chi-square Test p-value
	N	%	N	%		
INTERSECTION_RELATED = 1: Crash Related to Intersections	13717	45.40%	757	48.90%	14474	0.0078
INTERSECTION_RELATED = 0	16465	54.60%	791	51.10%	17256	

Table. IV. A. 2. Cross table of intersection related crashes and crash severity

```
Call:
glm(formula = SEVERE_CRASHES ~ INTERSECTION_RELATED_RE, family = "binomial",
    data = mydata2)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.3278  -0.3278  -0.3063  -0.3063   2.4830

Coefficients:
                        Estimate Std. Error z value Pr(>|z|)
(Intercept)             -3.03569    0.03640  -83.41  < 2e-16 ***
INTERSECTION_RELATED_RE  0.13867    0.05214    2.66  0.00782 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 12370  on 31729  degrees of freedom
Residual deviance: 12363  on 31728  degrees of freedom
AIC: 12367

Number of Fisher Scoring iterations: 5
```

```
                               OR      2.5 %    97.5 %
(Intercept)             0.0480413 0.04469837 0.0515546
INTERSECTION_RELATED_RE 1.1487406 1.03708609 1.2723290
```

Figure IV. A. 1. Results of Regression Model 1

of the dependent variable SEVERE_CRASHES (Severe Crashes Indicator), and we can see that about 4.9% of the crashes are coded as "severe crashes." Although this may not seem like a substantial proportion, we examined the association between crash severity and whether the crash was related to intersections in the regression results.

The Table. IV. A. 2. shows that there are 14474 crashes from 2019 to 2021 related to the intersections in Philadelphia (45.6%).

2) Regression Model 1

Figure IV. A. 1. shows that INTERSECTION_RELATED is a significant predictor of whether the crash is severe because its p-value<0.05. β_1=0.139 tells us a 1 unit increase in INTERSECTION_RELATED, the odd of the crash is severe changes by (e^(β_1)-1)*100% = 14.91%.

	No (SEVERE_CRA_INJ=0)		Yes (SEVERE_CRA_INJ=1)		Total
	N	%	N	%	
SEVERE_CRA_INJ: Injury Crashes Indicator	3790	26.60%	10433	73.40%	14233

Table. IV. B. 1. Cross table of the crash injury condition

B. Research Question 2 and 3

1) Results of The Exploratory Analysis

For Research Questions 2 and 3, we examined the association between the independent variables with the injury crashes indicator. We only need the crashes related to the intersections from the general crash data. Therefore, there are 14474 crash data left in total. With the method described in III. B. 2. 2), we found that 251 data had no intersection within the 65 feet search range, so in the regression model, there were 14223 crash data left.

The Table. IV. B. 1. shows the tabulation of the dependent variable SEVERE_CRA_INJ (Injury Crashes Indicator), and we can see that about 73.4% of the crashes are coded as "crashes with injuries."

The Table. IV. B. 2. shows the distribution of the crash injury indicator for ALCOHOL_RE, UNBELTED, SPEEDING_RE, nonorthogonal, SPEEDLIM_35, ONEWAY_BI and Traffic Island. From 2019 to 2021, there were 7948 (55.8%) crashes that happened near nonorthogonal intersections. Besides, there were 4103 (28.8%) crashes that happened near an intersection with at least one traffic island.

	No Injury Involved No (SEVERE_CRA_INJ=0)		Injury Involved Yes (SEVERE_CRA_INJ=1)		Total	Chi-square Test p-value
	N	%	N	%		
ALCOHOL_RE = 1: Crash involved drunk driving	159	4.20%	450	4.30%	609	0.759
ALCOHOL_RE = 0	3631	95.80%	9983	95.70%	13614	
UNBELTED = 1: Crash involved at least an unbelted person	545	14.40%	1532	14.70%	2077	0.65
UNBELTED = 0	3245	85.60%	8901	85.30%	12146	
SPEEDING_RE =1: Crash involved speeding car	693	18.30%	1801	17.30%	2494	0.156
SPEEDING_RE =0	3097	81.70%	8632	82.70%	11729	
nonOrthogonal = 1: Crash happened at a nonorthogonal intersection	2109	55.60%	5839	0.56%	7948	0.734
nonOrthogonal = 0	1681	44.40%	4594	44.00%	6275	
SPEEDLIM_35 =1: Crash happened at an intersection with speed limit under 35 mph	3672	96.90%	10202	97.80%	13874	0.002
SPEEDLIM_35 =0	118	3.10%	231	2.20%	349	
ONEWAY_BI = 1: Intersection vehicular lane direction is bidirectional	2371	62.60%	6907	66.20%	9278	5.47E-05
ONEWAY_BI = 0	1419	37.40%	3526	33.80%	4945	
Traffic_Island = 1: Crash happened at an intersection with a traffic island	1097	28.90%	3006	28.80%	4103	0.878
Traffic_Island = 0	2693	71.10%	7427	71.20%	10120	

Table. IV. B. 2. Cross table of the crash injury condition

2) Logistic Regression Assumptions

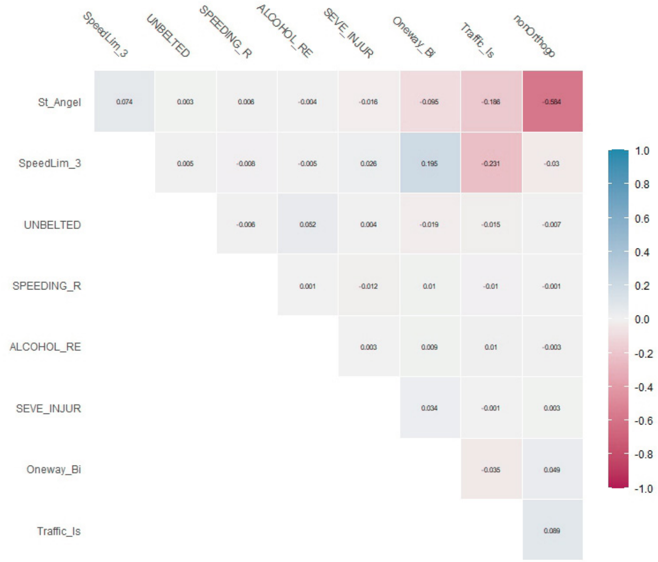


Figure IV. B. 1. Results of Pearson Correlation Test

Pearson Correlations Test

According to Figure IV. B. 1., there is no severe multicollinearity, as the correlation between any two predictors (binary or continuous) is less than 0.8 or more than -0.8.

3) Logistic Regression Results

Figure IV. B. 2. are the regression results of model 2. Model 2 examined the association between the crash injury indicator and the other independent variables. The results show that among all the predictors, SPEEDLIM_35, ONEWAY_BI and St_Angel are significant predictors of whether the crash resulted in injury, because their p-value<0.05. The other predictors are not significant predictors, because their p-value>0.05.

For the predictor SPEEDLIM_35, β_2=0.293 tells us a 1 unit increase in SPEEDLIM_35, the odd of the crash resulted in injury changes by (e^(β_2)-1)*100% = 34.04%, holding other predictors constant. For the predictor ONEWAY_BI, β_3=0.134 tells us a 1 unit increase in ONEWAY_BI, the odd of the crash resulted in injury changes by (e^(β_3)-1)*100% = 14.34%, holding other predictors constant. For the predictor St_Angle, β_4=-0.0035 tells us a 1 unit increase in St_Angle, the odd of the crash resulted in injury changes by (e^(β_4)-1)*100% = -0.349 %, holding other predictors constant.

Figure IV. B. 3. are the regression results of model 3. Model 3 examined the association between whether the intersection is nonorthogonal and the other independent variables. The results show that among all the predictors, SPEEDLIM_35, ONEWAY_BI and Traffic_Island are significant predictors of whether the intersection is orthogonal or not, because their p-value<0.05.

For the predictor SPEEDLIM_35, β_5=-0.286 tells us a 1 unit increase in SPEEDLIM_35, the odd of the intersection is nonorthogonal changes by (e^(β_5)-1)*100% = -24.87%, holding other predictors constant. For the predictor ONEWAY_BI, β_6=0.240 tells us a 1 unit increase in ONEWAY_BI, the odd of the intersection is nonorthogonal changes by (e^(β_6)-1)*100% = 27.12%, holding other predictors constant. For the predictor Traffic_Island, β_7=0.390 tells us a 1 unit increase in Traffic_Island, the odd of the intersection is nonorthogonal changes by (e^(β_7)-1)*100% = 47.70%, holding other predictors constant.

```
Call:
glm(formula = SEVE_INJUR ~ ALCOHOL_RE + UNBELTED + SPEEDING_R +
    SpeedLim_3 + nonOrthogo + Oneway_Bi + Traffic_Is + St_Angel,
    family = "binomial", data = mydata1)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.7880  -1.5602   0.7682   0.7946   0.9507

Coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept)  0.949142   0.198170   4.790 1.67e-06 ***
ALCOHOL_RE   0.023731   0.094511   0.251 0.801746
UNBELTED     0.026289   0.054072   0.486 0.626842
SPEEDING_R  -0.069828   0.049423  -1.413 0.157692
SpeedLim_3   0.293243   0.121178   2.420 0.015523 *
nonOrthogo  -0.046157   0.047078  -0.980 0.326875
Oneway_Bi    0.133739   0.040562   3.297 0.000977 ***
Traffic_Is   0.008628   0.043909   0.196 0.844230
St_Angel    -0.003526   0.001796  -1.964 0.049570 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 16491  on 14222  degrees of freedom
Residual deviance: 16463  on 14214  degrees of freedom
AIC: 16481

Number of Fisher Scoring iterations: 4
```

```
                   OR     2.5 %    97.5 %
(Intercept) 2.5834932 1.7558555 3.8190119
ALCOHOL_RE  1.0240145 0.8528655 1.2356279
UNBELTED    1.0266371 0.9239649 1.1421521
SPEEDING_R  0.9325538 0.8468208 1.0278749
SpeedLim_3  1.3407681 1.0546994 1.6966703
nonOrthogo  0.9548924 0.8707299 1.0472092
Oneway_Bi   1.1430948 1.0556000 1.2375302
Traffic_Is  1.0086648 0.9257154 1.0995996
St_Angel    0.9965023 0.9929722 0.9999901
```

Figure IV. B. 2. Results of Regression Model 2

```
Call:
glm(formula = nonOrthogo ~ SEVE_INJUR + SpeedLim_3 + Oneway_Bi +
    Traffic_Is, family = "binomial", data = mydata1)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.4591  -1.2658   0.9372   1.0915   1.1953

Coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept)  0.244441   0.121153   2.018   0.0436 *
SEVE_INJUR   0.007323   0.038430   0.191   0.8489
SpeedLim_3  -0.286468   0.119017  -2.407   0.0161 *
Oneway_Bi    0.240089   0.036224   6.628  3.4e-11 ***
Traffic_Is   0.389813   0.039046   9.983  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 19520  on 14222  degrees of freedom
Residual deviance: 19360  on 14218  degrees of freedom
AIC: 19370

Number of Fisher Scoring iterations: 4
```

	OR	2.5 %	97.5 %
(Intercept)	1.276907	1.0089554	1.622899
SEVE_INJUR	1.007349	0.9342113	1.086106
SpeedLim_3	0.750911	0.5932454	0.946292
Oneway_Bi	1.271362	1.1842309	1.364916
Traffic_Is	1.476705	1.3680801	1.594363

Figure IV. B. 3. Results of Regression Model 3

V. Discussion

A. Findings

After integrating the results of our regression models, our research can answer the three questions, draw conclusions, and provide simple proposals.

Research Question 1: Are crashes at intersections more likely to result in higher injury severity?

Regression model 1's result indicates that crashes at intersections are more likely to result in higher severity. Although this finding is not surprising, it is never useless to highlight the importance of intersections in traffic safety. Intersections must handle different types of transportation and conflicts between vehicles, bikes, and pedestrians. Therefore, we should always keep updating the design of intersections. Furthermore, based on the conclusions we drew from Research Questions 2 and 3, we can understand the association between infrastructures at intersections and traffic safety. These conclusions will help us choose intersection facilities and future design schemes.

Research Question 2: Which intersection design variable (intersection angle, vehicle lane direction, or intersection speed limit) is significantly associated with crash severity?

Based on regression model 2, we first found that the speed limit of intersections would impact the injury situation of crashes. To our surprise, the crash resulted in injury more likely when the street near the crash site had a speed limitation under 35 mph. However, for the city streets, the speed limit may need to be categorized in detail level for further study. After all, the speed limit sign is one of the traffic calming design tools.

Besides, the vehicular lane direction is also a vital street design factor. When the street near the crash site is bidirectional, there will be more possibility that the crash resulting in people's injuries. This is probably because the bidirectional streets create more complicated street conditions. Without an efficient signal system or traffic calming design, drivers will be more likely to be distracted by confusing traffic situations. Based on a typology study of Philadelphia streets, "Philly scale streets" usually only have two lanes for one-way traffic. Hence, we can propose more one-directional streets in the residential area to create a city with closer equitable communities.

Finally, the street angle is another essential factor that impacts the crash injury situation. The result integration indicates that the closer the street angle is to 90 degrees, the lower the chance of the crash ending up with an injury. The diagonal street intersections will make people involved in the crashes more vulnerable. This funding also reminds us to consider more security factors when designing diagonal intersections. For example, urban designers can intentionally lower the building's height at diagonal intersections and increase the setback distance of buildings to provide drivers with better visibility.

Research Question 3: Will the transportation island design help reduce the crash injury severity and improve the safety condition at intersections?

The results of regression model 2 show that whether there was a traffic island near the crash site is not significantly associated with the crash injury situation. However, the results of Model 3 indicate that the existence of traffic islands is associated with whether the street intersection is orthogonal. When there is a traffic island at the intersection, it is more likely that the intersection is nonorthogonal. This funding is interesting because the diagonal street segments are usually located at intersections with more than two legs, which may need more facilities to clarify the traffic lanes. However, comparing these two findings, we can draw a simple conclusion that the design of traffic islands is mainly for lane channelization. If we want to study whether the traffic island could be a shelter for pedestrians, we need to collect more data related to pedestrians.

B. Limitations

This study still has some limitations. The first limitation of our model is the Pearson Correlation Test for the variables. Pearson's correlation analysis is not a recommended method to test the association between the predictors, which are not continuous. In our report, we can only roughly detect whether there is multicollinearity among these predictors through Pearson's correlation matrix. The second limitation is the prediction accuracy of our models; the AUC value of the ROC curve needs to be better, which means the ability to distinguish between classes of our model is not very strong. Third, although the model 2 results show a significant association between the street angle and the crash injury, there is no significant association between crash injury and whether the intersection is orthogonal. To modify this model, we can categorize the street angel into different levels and use ordinal regression to examine the relationship between these variables. Finally, the predictors we used in this study are insufficient if we want to understand how street intersection design impacts traffic safety fully. In future research, we can also integrate other factors, such as the annual average daily traffic volume data (AADT), the street width, and the sidewalk conditions.

VI. Conclusion

We answered three questions in this report to study the role of Philadelphia's intersection design on traffic safety. This research's findings can guide us in designing future streets, building a safer traffic system, and creating more equitable communities. First, regression model 1's result indicates that crashes at intersections are more likely to result in higher severity. Besides, among the crashes related to intersections, the speed limit of intersections, the vehicular lane direction, and the street angle are significantly associated with the crash injury. Also, there is a significant association between the traffic islands and the diagonal intersections, but there is no significant relation between traffic islands and crash injury.

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