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The Effect of Geometric Road Conditions on Safety Performance of Abu Dhabi Road Intersections

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Abstract: Abu Dhabi's government has taken several initiatives to improve the safety of the city's highways, such as reducing traffic accident occurrence, red light violations, and property damage associated with traffic accidents. However, the intersections are still associated with many severe accidents, property damage associated with accidents, and red light violations. To help authorities pinpoint the major contributors to the deterioration of the safety performance of the signalized junctions, this study employed a negative binomial regression model to investigate the effect of geometric road conditions (in terms of the number of lanes of streets found in four-leg, three-leg, and different types of intersection) on property damage, red light violations, and severe accidents as safety performance indicators. The research found that, in both three-leg and four-leg intersections, most accidents and traffic light violations occur when minor streets pass through the intersection. This can be solved by converting these minor streets into major streets by increasing the number of lanes. This way, the capability of the minor street's handling of increased traffic from the major streets significantly increases. The results also show that traffic speed is a major contributor to safety performance deterioration in these intersections. This can be solved by posting speed limits at these intersections. Results have also shown that, in Direction 1, when the main street passes through the intersection, the property damage type of accident is significantly high. This may be due to the presence of a potentially hazardous property or road design flaws on that side of the road. This effect needs further investigation to determine the hazardous property or the road design flaws causing these accidents.

Keywords: geometric design; red light violation; negative binomial regression; safety performance; property damage; severe accidents

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1. Introduction

1.1. Background

The government of Abu Dhabi, through traffic police departments and integrated transport centers, is implementing various safety programs and regulations, and plans to improve the safety performance of intersections [1]. The goal is to protect people and their property against traffic-related accidents and incidents. This, in turn, safeguards the nation, its people, and its economic components against traffic-related accidents and incidents [1]. However, for these efforts to work effectively, the major contributors towards the deterioration of the safety performance of the roads need to be identified and eliminated or minimized [2–7].

Several theoretical models have been employed in the previous studies to help identify the factors that affect the safety performance of roads. Examples of theoretical models are: Poisson's regression, negative binomial regression, Nested Logit regression, and multiple linear regression [8–13]. These models are collectively known as crash-based models, and they can predict crashes on highways and intersections [14–18].

1.2. Literature Review

1.2.1. Crash-Based Model

The safety performance of roads and highways has been examined using crash-based models such as Poisson's regression, negative binomial regression, nested logit regression, and multiple linear regression [19–32]. These models are mainly applied when determining the relationship between traffic safety performance and suspected contributing factors [15,33,34]. The idea behind these models is to determine the probability of reduction of road safety performance as a result of the action of several contributing factors, such as geometric road conditions (number of lanes, curvature, gradient, and length) and operating conditions (age, sex, drunkenness, health, and speed of the vehicle) [3,35–39].

1.2.2. The Effect of Geometric Design on Highway Safety Performance

Studies have shown that the geometric design of intersections plays a critical role in road safety (which can be measured in terms of traffic accident occurrence, red light violation, and property damage). When Vayalamkuzhi [40] employed Poisson regression and negative binomial regression to examine the effect of geometric design on road safety performance, the results indicated that geometric conditions such as road gradient, road curvature, and the number of lanes negatively affect the safety performance of the road. The researchers measured safety performance in terms of road crashes (accidents).

Zewde [7] also applied negative binomial regression to examine the effects of geometric road design on the safety performance of Ethiopian roads and found that there is a positive relationship between the number of traffic accident occurrences and the length of road (the researchers used road length as a proxy for geometric road design). Their results also showed that road safety performance could be negatively affected by the sharpness of curvatures and the number of curvatures associated with a road. This is such that an increase in curvature sharpness increases traffic accidents and property damage.

Other than Vayalamkuzhi [40] and Zewde [7], Agent [2] also investigated the effect of geometric road conditions on the safety performance of highways in Kentucky, the United States of America. The geometric road condition examined by Agent was the number of lanes [2]. The study found that of all the numbers of lanes investigated, four-lane undivided roads (the highest number of lanes invested by the study) were associated with the highest volume of fatal accidents and injuries. The study also showed that in two-lane highways, the highest number of accident fatalities and injuries occur at sharp curvatures.

Alghafli [1] also applied Poisson and Multi-Nominal Logit regression models to examine how operational and geometric road conditions affect the safety performance of different types of intersections in Abu Dhabi. The author used the number of lanes associated with different intersection configurations as a proxy for measuring geometric road conditions. The study found that most traffic accidents occur when a minor road passes through an intersection. Even though the study examined the relationship between the geometric road conditions and safety performance intersections in Abu Dhabi, the study only concentrated on severe traffic accidents. The effect of geometric road conditions on other safety performance indicators, such as property damage and red light violations, was never investigated in the study. The current study bridges this gap by investigating the effect of geometric road conditions on severe accidents (accidents associated with at least one fatality) and property damage accidents.

Additionally, despite the efforts taken by the Abu Dhabi Government to minimize accidents on the city's roads, road intersections in this city are still associated with a high number of severe accidents, property damage associated with accidents, and red light violations. This research bridges this gap by investigating the relationship between intersections' geometric conditions (measured in terms of the type of streets passing through, left or right of the intersection, and number of lanes in these streets) and the safety performance of these intersections.

2. Materials and Methods

2.1. Research Data Source

The data sources for the research included the Abu Dhabi Police, the Department of Transport (DoT), and the Department of Urban Planning and Municipalities. The Abu Dhabi Police stores all accidents data in a Federal Traffic Database, the source of traffic accident data; DoT has data regarding signal phasing plans and was the source of data regarding signal phasing at the intersections; the Department of Urban Planning and Municipalities was the source of data associated with road works and the redesign of the intersections. The quantitative data regarding traffic accident volume and red light violations at the intersections were obtained from Abu Dhabi traffic accident database. The data regarding the geometric conditions of the four-leg and three-leg intersections were obtained from the field survey where the number of lanes associated with the main and minor roads going through the intersection or turning left at the intersection was obtained. The data regarding the traffic volume were obtained from Abu Dhabi's Integrated Transport Center database. The data covered a period of 5 years (2015–2020). The quality of Abu Dhabi's database, compared to other databases around the world, is shown in Table 1 below. The table shows that Abu Dhabi's database competes well with other databases around the world.

Table 1. Abu Dhabi traffic accident database when compared to other databases; adapted from Casado-Sanz [41].

Variable	Abu Dhabi	EU	US	Australia
Crash location	Yes			
Crash narrative	Yes	No	No	Yes
Sketch	Yes	No	No	Yes
Crash type	Yes	Yes	Yes	Yes
Collision type	Yes	Yes	Yes	Yes
Weather conditions	Yes	Yes	Yes	Yes
Light conditions	Yes	Yes	Yes	Yes
Definition of fatal and non-fatal injury levels	Yes	Yes	Yes	Yes
Fatalities	Yes	No	Yes	Yes
Link with hospital data	No	No	No	Yes
Contributing factors	Yes	No	Yes	Yes
Speed limit	Yes	Yes	Yes	Yes
Surface conditions	Yes	Yes	Yes	Yes
Road curve	No	No	Yes	Yes
Road segment	No	No	Yes	No
Age	Yes	Yes	Yes	Yes
Gender	Yes	Yes	Yes	Yes
Nationality	Yes	Yes	No	Yes
Injury status	Yes	No	Yes	Yes
Driver actions	Yes	Yes	Yes	Yes
Annual average daily traffic (AADT)	Yes	No	Yes	No
Pedestrian action	Yes	Yes	Yes	Yes
Violating codes	Yes	No	No	No
Safety equipment	Yes	Yes	Yes	Yes
Sitting position	No	No	Yes	Yes
Curve radius	No	No	Yes	Yes
Length	No	No	Yes	Yes

2.2. The Model Employed

Several crash-based models have been applied to investigate factors affecting safety performance of roads and associated intersections: Examples of these crash models are: Poisson's regression, negative binomial regression, nested logit regression, and multiple linear regression [8–13]. These crash-based models investigate how certain factors, such as geometric road and operational conditions, influence the safety performance of road intersections or the road itself [41,42]. The safety performance roads and road intersections are measured in terms of number of traffic accidents, property damage, and red light violations [1].

This study employed the negative binomial regression model in an attempt to understand the effect of geometric road conditions on the safety performance of four-leg, three-leg, and different intersections in Abu Dhabi. The safety performances investigated in this research include: number of traffic accidents, property damage, and red light violations. Different types of intersections in this context are other types of intersections other than four-leg and three-leg intersections. An example of such type of intersection is roundabouts.

The Negative Binomial model is often defined by the equation below:

$$\mathrm{Prob}[Y = y_i|\varepsilon] = \frac{\exp[-y_i \exp(\varepsilon)]\left(\lambda_i{}^{\lambda_i}\right)}{y_i!}$$

$$y = 1, 2, 3, \ldots$$

$$\lambda_I = \exp\,(\beta Xi) + \varepsilon, \text{ for the ith observation}$$

where:

i. λi = The number of safety performance indicators (number of accident occurrences, property damage, or red light violations) at any given time interval, I [43–46];
ii. Xi = Geometric road conditions (main through, main left, minor through, and minor left). "Main through" means the main road passes through the intersection, "main left" means the main road turns left at the intersection, "minor through" means it passes through the intersection without making any turns, and "minor left" represents a minor road turning left at the intersection [20,47–50].
iii. ε = Error term [1,43,47,49,50].

It is important to note that the exponential associated with error term has a gamma distribution.

The number of safety performance indicator (traffic accidents, red light violations, and property damage) is represented by k; its probability distribution at any given time, t, is represented by:

$$P(k_i) = [(e^{(\lambda i)t}) \times ({}^{\lambda}i)^k] \div k!$$

where:

i. e = Exponential of the error term;
ii. k = The number of safety performance indicators (traffic accidents, red light violations, and property damage) at any given time, t [1,49–55].

2.3. Research Limitations

Just like any other research, the research is also associated with several limitations. The research employed two types of data: primary data (which was collected at the intersection) and secondary data, which was collected from archives. The limitation of using archival data is the lack of the author's participation and the fact that the accuracy of the result of the research is dependent on the accuracy of the collected data, which the author had no control over.

2.4. Validity and Reliability

The research employed a negative binomial regression model in determining the relationship between geometric road conditions and safety performance of Abu Dhabi road intersections. This method has been applied by many previous researchers and has been proven to be reliable and valid. Additionally, all the steps followed in achieving the study's objectives have been stated in the article.

3. Results and Discussion

3.1. Descriptive Statistics

A total of 49 signalized intersections were examined for safety performance. This consisted of 33 four-leg intersections, 11 three-leg intersections, and 5 different intersection types, such as five-leg signalized intersections and raised islands at the midblock of the intersection. In terms of geometric road conditions, the number of lanes associated with four configurations (main road through the intersection, main road turning left at the intersection, minor road passing through the intersection, and minor road turning left at the intersection) was examined.

In total, from 2015 to 2020, the total number of severe accidents recorded (accidents with at least one fatality or injury) was 199, the total incidents of property damage recorded during the study period were 42, and the total number of red light violations recorded was 76,842. The total number of severe accidents recorded at four-leg intersections was 162, resulting in five severe accidents per intersection. The total number of severe accidents at three-leg intersections was 21, resulting in two severe accidents per intersection. At different types of intersections (such as roundabouts), a total of 16 severe accidents were recorded, resulting in 3.2 severe accidents per intersection. This result indicates that the most dangerous type of intersection in Abu Dhabi is a four-leg intersection followed by different types of intersection.

The total number of property damage accidents recorded at four-leg intersections was 26. This means that four-leg intersections recorded 0.8 property damage accidents per intersection. The total number of property damage accidents recorded at three-leg intersections was 14, resulting in 1.3 property damage accidents per intersection. Different types of intersections recorded only two property damage types of accidents, representing 0.4 property damage accidents per intersection. These results indicate that accidents associated with property damage are far more common in three-leg intersections, followed by four-leg intersections, and are least common in different types of intersections.

In terms of the number of red light violations, four-leg intersections recorded 42,812, representing 1297 red light violations per intersection during the study period. Three-leg intersections recorded 19,679, representing 1789 red light violations per intersection. Different types of intersections recorded 14,351 red light violations, which represents 2870 red light violations per intersection. The results indicate that red light violations are far more common in different types of intersections, followed by three-leg intersections, and are least common in four-leg intersections.

3.2. Regression Results

3.2.1. The Effect of Geometric Conditions on the Safety Performance of Four-Leg Intersections

Table 2 shows the effect of the number of lanes (a measure of geometric conditions) on the performance of four-leg intersections.

Table 2 shows the regression results (negative binomial regression) of the relationship between the geometric conditions (measured in terms of the number of lanes of streets entering the intersections) of Abu Dhabi's four-leg intersections and the safety performance of the intersections (measured in terms of the number of severe accidents, the number of property damage accidents, and the number of red light violations). The results show that at four-leg intersections, when a minor road passes through the intersection, the number of lanes in that street has a significant impact on the red light violations compared to severe accidents and property damage. This is such that there is a positive relationship between the number of lanes and the number of red light violations. Such a relationship was also noted with severe accidents in this street. This means that at four-leg intersections, when a minor street (street with a small number of lanes) passes through the intersection, the chances of red light violations and severe accidents occurring are high. An opposite relationship was noted when the main street passes through (main through) the intersection. It was found that when a major street passes through a four-leg intersection, the chance of a red light violation occurring significantly reduces. This is proven by the negative relationship between the number of red light violations and the number of lanes of the major through streets in four-leg intersections.

Table 2. Effect of geometric conditions on safety performance of four-leg intersections.

Variables	No. of Violations	Severe Accidents	Property Damage Accidents
Direction 1 (No. of lanes and geometry)			
Main through	−0.543 **	0.233	0.014
	(0.345)	(0.415)	(0.408)
Main left	0.271	−0.084	−0.401
	(0.388)	(0.393)	(0.416)
Minor through	0.577 ***	0.409 **	0.269
	(0.173)	(0.189)	(0.189)
Minor left	−0.622 *	0.592 *	0.791 *
	(0.347)	(0.349)	(0.357)
Main speed	0.060 ***	0.053 ***	0.008
	(0.020)	(0.020)	(0.025)
Average traffic volume per hour	−0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)
Constant	3.736 **	−4.460 **	−1.929
	(1.639)	(1.815)	(2.051)
Observations	33	33	33
Direction 2 (No. of lanes and geometry)			
Main through	−0.843 **	0.277	0.218
	(0.334)	(0.390)	(0.381)
Main left	0.376	−0.134	−0.719
	(0.404)	(0.459)	(0.555)
Minor through	0.841 ***	0.215	−0.329
	(0.272)	(0.280)	(0.315)
Minor left	−0.379	0.395	1.087 *
	(0.499)	(0.505)	(0.568)
Main speed	0.079 ***	0.043 **	−0.014
	(0.020)	(0.021)	(0.025)
Average traffic volume per h	−0.000	−0.000	0.000
	(0.000)	(0.000)	(0.000)
Constant	2.163	−3.050 **	0.572
	(1.413)	(1.511)	(1.854)
Observations	33	33	33

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ (Standard errors in parentheses).

Another factor that was found to significantly affect the safety performance of these streets is traffic speed. In both traffic directions (Direction 1 and Direction 2 of the traffic flow), it was found that traffic speed was positively related to the number of red light violations and severe accidents. High traffic speeds reduce driver reaction time and increase braking distance. These two factors often increase the chance of severe accidents and red light violations occurring. It is, however, important to note that no relationship was noted between traffic speed and property damage.

3.2.2. The Effect of Geometric Conditions on the Safety Performance of Three-Leg Intersections

Table 3 shows the effect of the number of lanes (a measure of geometric conditions) on the performance of three-leg intersections.

Table 3. Effect of geometric conditions on safety performance of three-leg intersections.

Variables	No. of Violations	Severe Accidents	Property Damage Accidents
Direction 1			
(No. of lanes and geometry)			
Main through	−0.187	−1.115	5.234 ***
	(0.679)	(0.759)	(0.533)
Main left	−0.213	−0.986	1.558 *
	(0.521)	(0.727)	(0.933)
Minor through	−1.222 ***	0.654 **	1.011 *
	(0.343)	(0.260)	(0.593)
Minor left	−0.074	−0.136	1.310 ***
	(0.251)	(0.292)	(0.345)
Main speed	0.162 **	0.145 **	0.153
	(0.223)	(0.225)	(0.227)
Av. traffic volume/h	0.000	0.001 **	−0.000
	(0.000)	(0.000)	(0.000)
Constant	8.483 ***	3.210	−19.810
	(2.545)	(2.637)	(0.000)
Observations	11	11	11
Direction 2			
Main through	−0.966 *	−0.438	1.793
	(0.545)	(0.636)	(1.831)
Main left	0.105	3.515	9.941
	(0.626)	(9.223)	(92.929)
Minor through	−1.314 ***	0.700 ***	−0.205
	(0.311)	(0.256)	(0.962)
Minor left	0.115	−0.156	−1.173
	(0.244)	(0.355)	(1.099)
Main speed	0.092 **	0.075 **	0.085
	(0.023)	(0.025)	(0.027)
Av. traffic volume/h	0.000	0.001 **	0.000
	(0.000)	(0.000)	(0.001)
Constant	10.274 ***	−3.122	−14.442
	(1.725)	(9.384)	(93.088)
Observations	11	11	11

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ (Standard errors in parentheses).

Table 3 above shows the negative binomial regression result for the relationship between the number of lanes of streets entering the intersections (a proxy used to measure geometric road conditions) and the safety performance of the three-leg intersection. As already mentioned, the proxies used for measuring safety performance at the intersection are severe accidents, the number of property damage accidents, and the number of red light violations.

The results show that at three-leg intersections, most accidents and traffic light violations occur when minor streets pass through the intersection. This is because the number of lanes in the minor street passing through the intersection (minor through) is positively related to the number of severe accidents and red light violations (Table 2). Just like in a four-leg intersection, this result means that when a minor street (the street with a fewer number of lanes) passes through a three-leg intersection, the chances of red light violations and severe accidents occurring are high.

The results also show that in Direction 1, when the main street passes through the intersection, property damage accidents are significantly high. This is shown by the positive relationship between the number of lanes in the main street (main through) and property damage accidents. This may be attributed to the presence of a potentially hazardous property or road design flaw on that side of the road [56]. This needs to be investigated further to determine the hazardous property or the road design flaws causing these accidents.

The results further indicate that traffic speed is another factor that significantly affects the safety performance of three-leg intersections. In both traffic directions (Direction 1 and Direction 2 of the traffic flow), it was found that traffic speed was positively related to the number of red light violations and severe accidents. High traffic speeds reduce driver reaction time and increase braking distance.

4. Conclusions and Recommendations

Without a doubt, the Abu Dhabi Government has taken several initiatives to improve the safety of the city's roads, such as reducing traffic accident occurrence, reducing red light violations, and reducing property damage associated with traffic accidents. However, the intersections are still associated with many severe accidents, property damage associated with accidents, and red light violations. Investigating the effect of geometric road conditions (in terms of the number of lanes of streets found in four-leg, three-leg, and different types of intersection) on property damage, red light violations, and severe accidents as safety performance indicators, this research found that in both three-leg and four-leg intersections, most accidents and traffic light violations occur when minor streets pass through the intersection. This can be solved by converting these minor streets into major streets by increasing the number of lanes in these streets. This way, the capability of the minor streets' handling of increased traffic from the major streets significantly increases. Results also show that traffic speed is another major contributor to safety performance deterioration in these intersections. This can be solved by posting speed limits at these intersections. Results have also shown that in Direction 1, when a main street passes through an intersection, the property damage type of accident is significantly high. This may be due to the presence of a potentially hazardous property or road design flaws on that side of the road. This effect needs further investigation to determine the hazardous property or the road design flaw causing these accidents.

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References

1. Alghafli, A.; Shawky, M. Operational and Geometrical Conditions of Accident Occurrence and Severity at Signalized Intersections. In *International Conference on Applied Human Factors and Ergonomics*; Springer: Berlin, Germany, 2020.
2. Agent, K.R. *Relationships between Roadway Geometrics and Accidents (An Analysis of Kentucky Records)*; Kentucky Transportation Center Research Report; Kentucky Transportation Center: Lexington, KY, USA, 1974.
3. Burchett, G.D. Rural Expressway Intersection Characteristics that Contribute to a Reduced Safety Performance. Master's Thesis, Iowa State University, Ames, IA, USA, 2005.
4. Tibljaš, A.D.; Giuffrè, T.; Surdonja, S.; Trubia, S. Introduction of Autonomous Vehicles: Roundabouts Design and Safety Performance Evaluation. *Sustainability* **2018**, *10*, 1060. [CrossRef]
5. Harwood, D.W.; Council, F.M.; Hauer, E.; Hughes, W.E.; Vogt, A. *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*; Federal Highway Administration: Washington, DC, USA, 2000.

6. Lord, D.; Persaud, B.N. Estimating the Safety Performance of Urban Road Transportation Networks. *Accid. Anal. Prev.* **2004**, *36*, 609–620. [CrossRef]
7. Zewde, T. Determinants that lead drivers into traffic accidents: A case of Arba Minch city, south Ethiopia. *Sci. J. Appl. Math Stat.* **2017**, *5*, 210–215. [CrossRef]
8. Dong, C.; Shao, C.; Li, J.; Xiong, Z. An Improved Deep Learning Model for Traffic Crash Prediction. *J. Adv. Transp.* **2018**, *2018*, 1–13. [CrossRef]
9. Abdel-Aty, M.A.; Radwan, A.E. Modeling traffic accident occurrence and involvement. *Accid. Anal. Prev.* **2000**, *32*, 633–642. [CrossRef]
10. Bobermin, M.; Ferreira, S. A novel approach to set driving simulator experiments based on traffic crash data. *Accid. Anal. Prev.* **2021**, *150*, 105938. [CrossRef] [PubMed]
11. Haleem, K.; Abdel-Aty, M. Examining traffic crash injury severity at unsignalized intersections. *J. Saf. Res.* **2010**, *41*, 347–357. [CrossRef]
12. Othman, S.; Thomson, R.; Lannér, G. Identifying critical road geometry parameters affecting crash rate and crash type. In *Annals of Advances in Automotive Medicine/Annual Scientific Conference*; Association for the Advancement of Automotive Medicine: Western Region, Sweden, 2009.
13. Quddus, M.A.; Wang, C.; Ison, S.G. Road traffic congestion and crash severity: Econometric analysis using ordered response models. *J. Transp. Eng.* **2010**, *136*, 424–435. [CrossRef]
14. Mussone, L.; Bassani, M.; Masci, P. Analysis of factors affecting the severity of crashes in urban road intersections. *Accid. Anal. Prev.* **2017**, *103*, 112–122. [CrossRef]
15. Russo, F.; Busiello, M.; Dell, G. Safety performance functions for crash severity on undivided rural roads. *Accid. Anal. Prev.* **2016**, *93*, 75–91. [CrossRef]
16. Savolainen, P.T.; Gate, T.; Lord, D.; Geedipally, S.; Rista, E.; Barrette, T.; Russ, B.J.; Hamzeie, R. *Michigan Urban Trunkline Intersections Safety Performance Functions (SPFs) Development and Support*; Michigan Department of Transportation: Lansing, MI, USA, 2015.
17. Ulak, M.B.; Ozguven, E.E.; Karabag, H.H.; Ghorbanzadeh, M.; Moses, R.; Dulebenets, M. Development of Safety Performance Functions for Restricted Crossing U-Turn Intersections. *J. Transp. Eng. Part A Syst.* **2020**, *146*, 04020038. [CrossRef]
18. Wang, X.; Abdel-Aty, M.; Nevarez, A.; Santos, J.B. Investigation of safety influence area for four-legged signalized intersections: Nationwide survey and empirical inquiry. *Transp. Res. Rec.* **2008**, *2083*, 86–95. [CrossRef]
19. Famoye, F. On the bivariate negative binomial regression model. *J. Appl. Stat.* **2010**, *37*, 969–981. [CrossRef]
20. Famoye, F. A multivariate generalized Poisson regression model. *Commun. Stat.-Theory Methods* **2015**, *44*, 497–511. [CrossRef]
21. Garay, A.M.; Hashimoto, E.M.; Ortega, E.M.; Lachos, V.H. On estimation and influence diagnostics for zero-inflated negative binomial regression models. *Comput. Stat. Data Anal.* **2011**, *55*, 1304–1318. [CrossRef]
22. Gastaldi, M.; Rossi, R.; Gecchele, G.; Della Lucia, L. Annual Average Daily Traffic Estimation from Seasonal Traffic Counts. *Procedia-Soc. Behav. Sci.* **2013**, *87*, 279–291. [CrossRef]
23. Geedipally, S.R.; Turner, P.A.; Patil, S. Analysis of motorcycle crashes in Texas with multinomial logit model. *Transp. Res. Rec.* **2011**, *2265*, 62–69. [CrossRef]
24. Hilbe, J.M. *Negative Binomial Regression*; Cambridge University Press: Cambridge, UK, 2011.
25. Lin, L.; Wang, Q.; Sadek, A.W. A combined M5P tree and hazard-based duration model for predicting urban freeway traffic accident durations. *Accid. Anal. Prev.* **2016**, *91*, 114–126. [CrossRef] [PubMed]
26. Patil, S.; Geedipally, S.R.; Lord, D. Analysis of crash severities using nested logit model—accounting for the underreporting of crashes. *Accid. Anal. Prev.* **2012**, *45*, 646–653. [CrossRef] [PubMed]
27. Razi-Ardakani, H.; Mahmoudzadeh, A.; Kermanshah, M. A Nested Logit analysis of the influence of distraction on types of vehicle crashes. *Eur. Transp. Res. Rev.* **2018**, *10*, 1–14. [CrossRef]
28. Shamo, B.; Asa, E.; Membah, J. Linear spatial interpolation and analysis of annual average daily traffic data. *J. Comput. Civ. Eng.* **2015**, *29*, 04014022. [CrossRef]
29. Wang, T. Improved Annual Average Daily Traffic (AADT) Estimation for Local Roads Using Parcel-Level Travel Demand Modeling. Ph.D. Thesis, Florida International University, Miami, FL, USA, 2012.
30. Wu, Q.; Zhang, G.; Zhu, X.; Liu, X.C.; Tarefder, R. Analysis of driver injury severity in single-vehicle crashes on rural and urban roadways. *Accid. Anal. Prev.* **2016**, *94*, 35–45. [CrossRef] [PubMed]
31. Yang, S.; Berdine, G. The negative binomial regression. *Southwest Respir. Crit. Care Chron.* **2015**, *3*, 50–54.
32. Ye, F.; Lord, D. Comparing three commonly used crash severity models on sample size requirements: Multinomial logit, ordered probit and mixed logit models. *Anal. Methods Accid. Res.* **2014**, *1*, 72–85. [CrossRef]
33. Saito, M.; Brimley, B.K.; Schultz, G.G. Transportation safety data and analysis. In *Calibration of the Highway Safety Manual and Development of New Safety Performance Functions*; Utah Department of Transportation. Research Division: Taylorsville, UT, USA, 2011; Volume 2.
34. Strauss, J.; Miranda-Moreno, L.F.; Morency, P. Multimodal injury risk analysis of road users at signalized and non-signalized intersections. *Accid. Anal. Prev.* **2014**, *71*, 201–209. [CrossRef]
35. Chen, H.; Cao, L.; Logan, D.B. Analysis of risk factors affecting the severity of intersection crashes by logistic regression. *Traffic Inj. Prev.* **2012**, *13*, 300–307. [CrossRef]

36. Dolatsara, H.A. *Development of Safety Performance Functions for Non-Motorized Traffic Safety*; Citeseer: State College, PA, USA, 2014.
37. Kanellaidis, G.; Vardaki, S. Highway geometric design from the perspective of recent safety developments. *J. Transp. Eng.* **2011**, *137*, 841–844. [CrossRef]
38. Mitra, S.; Bhowmick, D. Status of signalized intersection safety-a case study of Kolkata. *Accid. Anal. Prev.* **2020**, *141*, 105525. [CrossRef]
39. Rosolino, V.; Teresa, I.; Vittorio, A.; Carmine, F.D.; Antonio, T.; Daniele, R.; Claudio, Z. Road Safety Performance Assessment: A New Road Network Risk Index for Info Mobility. *Procedia-Soc. Behav. Sci.* **2014**, *111*, 624–633. [CrossRef]
40. Vayalamkuzhi, P.; Amirthalingam, V. Influence of geometric design characteristics on safety under heterogeneous traffic flow. *J. Traffic Transp. Eng.* **2016**, *3*, 559–570. [CrossRef]
41. Casado-Sanz, N.; Guirao, B.; Galera, A.L.; Attard, M. Investigating the Risk Factors Associated with the Severity of the Pedestrians Injured on Spanish Crosstown Roads. *Sustainability* **2019**, *11*, 5194. [CrossRef]
42. Bíl, M.; Andrášik, R.; Sedoník, J. Which curves are dangerous? A network-wide analysis of traffic crash and infrastructure data. *Transp. Res. Part A Policy Pract.* **2019**, *120*, 252–260. [CrossRef]
43. Brod, D. *Comprehensive Costs of Highway-Rail Grade Crossing Crashes*; Transportation Research Board: Washington, DC, USA, 2013; Volume 755.
44. Famoye, F.; Wulu, J.T.; Singh, K.P. On the generalized Poisson regression model with an application to accident data. *J. Data Sci.* **2004**, *2*, 287–295. [CrossRef]
45. Hayat, M.J.; Higgins, M. Understanding poisson regression. *J. Nurs. Educ.* **2014**, *53*, 207–215. [CrossRef] [PubMed]
46. Silva, J.S.; Tenreyro, S. On the existence of the maximum likelihood estimates in Poisson regression. *Econ. Lett.* **2010**, *107*, 310–312. [CrossRef]
47. Zamani, H.; Ismail, N. Functional form for the generalized Poisson regression model. *Commun. Stat.-Theory Methods* **2012**, *41*, 3666–3675. [CrossRef]
48. Flowerdew, R. Modelling Migration with Poisson Regression. In *Technologies for Migration and Commuting Analysis Spatial Interaction Data Applications*; IGI Global: Hershey, PA, USA, 2010; pp. 261–279.
49. Sellers, K.F.; Shmueli, G. A flexible regression model for count data. *Ann. Appl. Stat.* **2010**, *4*, 943–961. [CrossRef]
50. Türkan, S.; Özel, G. A new modified Jackknifed estimator for the Poisson regression model. *J. Appl. Stat.* **2016**, *43*, 1892–1905. [CrossRef]
51. Zou, G.; Donner, A. Extension of the modified Poisson regression model to prospective studies with correlated binary data. *Stat. Methods Med. Res.* **2013**, *22*, 661–670. [CrossRef]
52. Al-Atawi, A.M. Characteristics of red light running violations in urban areas in Tabuk, Kingdom of Saudi Arabia. *IATSS Res.* **2014**, *37*, 119–123. [CrossRef]
53. Mane, A.S.; Pulugurtha, S.S. Influence of on-network, traffic, signal, demographic, and land use characteristics by area type on red light violation crashes. *Accid. Anal. Prev.* **2018**, *120*, 101–113. [CrossRef]
54. Porter, B.E.; England, K.J. Predicting red-light running behavior: A traffic safety study in three urban settings. *J. Saf. Res.* **2000**, *31*, 1–8. [CrossRef]
55. Schattler, K.L.; McAvoy, P.D.; Glauber, C.M. Impact of signal mounting configurations on red-light running at urban signalized intersections. *Inst. Transp. Eng. J.* **2011**, *81*, 22.
56. Zhao, J.; Liu, Y. Safety evaluation of intersections with dynamic use of exit-lanes for left-turn using field data. *Accid. Anal. Prev.* **2017**, *102*, 31–40. [CrossRef]