GRID OR LIMITED ACESS ROADS: EFFECTS OF STREET PATTERN ON ROAD CRASHES

Shakil Mohammad Rifaat
Dr. Richard Tay
University of Calgary

Introduction

Road crashes are a leading cause of deaths and serious injuries in many countries and extract a high cost on society. In Canada, for example, there were 7.6 road users killed and 609 injured in traffic collisions everyday in 2003, resulting in an estimated daily social cost of about $26 million (Transport Canada, 2006). As the Canadian and the Albertan economies continue to grow, the increase in the demand for transportation infrastructure and mobility will put more pressure on the road network which will have serious implications for the safety of road users.

Moreover, there are also increasing public concerns about the effects of transportation on the environment in general and the living environment of their own neighborhood in particular. To address natural and human environmental concerns while maintaining safety and mobility, context sensitive design (CSD) has been introduced. The main idea of CSD is to meet local environmental needs by allowing flexibility in following the road design guidelines. Several studies have been done recently which discussed various issues related with CSD (Stamatiadis, 2005; Garrick et al. 2005).

Although the role of the road system has evolved over time, including the introduction of CSD, road safety engineering is still primarily focused on the detail design of road links (Abdel-Aty and Radwan, 2000) and intersections (Tay and Rifaat, 2007; Chin and Quddus, 2003) with little attention devoted to neighborhood factors at a more macro level which has traditionally been a domain of social science research. However, there are some road design factors at the macro level that transportation engineers need to be aware of which has significant implications for road safety.

In the past, the main purpose of urban road streets was to serve as thoroughfares for carrying people and goods from one place to another in a safe and reliable way and with minimum delay. One common network design that is able to provide a high degree of efficiency and reliability is the traditional grid design with intersecting streets that are mostly straight thoroughfares. The basic rectilinear grid found in suburban communities remained generally unchanged until after World War II.

Over the past fifty years, limited access roads have become the basic building block of modern suburbia in many western countries (Southworth and Ben-Joseph, 2003). Residents prefer this design pattern because it offers quiet and safe streets with little fear of fast-moving vehicles. These types of streets are safer and quieter because there is hardly any through traffic and local traffic are forced to move slowly due to the design pattern of these roads. Moreover, this design pattern is popular with developers not only because it sells well, but also because the infrastructure costs are significantly lower than the traditional interconnected grid pattern. Limited access roads also adapt better to topography and can work around areas of high ecological or historical value.

Perhaps due to its intuitive appeal, few studies were conducted to examine the impact of this design on road crashes. In the only publicly available study, Mark (1957) found that 50% of all intersections in Los Angeles between 1951 and 1956 within the traditional grid pattern had at least one accident whereas only 8.8% of the intersections in limited access pattern had accidents during that period. However, the results of this study have to be interpreted with caution because it examined only intersection crashes and ignore all non intersection crashes. It also ignored the frequency and severity of crashes. Moreover, it does not control for many important influences such as traffic volume, land use, neighborhood density, economic, social and demographic composition. In addition, this study also limited the type of crashes examined to right angle crashes which is more likely to occur in the grid pattern.

The objective of our study is to compare the safety effects of different neighborhood road designs using Calgary as a case study. Since the focus of this research is on the effects of different road design on crashes, it will use the neighborhood as the unit of analysis instead of the actual road segments or intersections which is commonly used in engineering analyses. It will also account for the confounding effects of non engineering factors like neighborhood characteristics. Besides these contributions to the research literature, this study will provide evidence based recommendations to policy makers and developers on the optimal type of neighborhood to design in terms traffic safety. Like many cities in Alberta, Calgary is undergoing rapid expansion and many new communities are being developed.

Data

The basic unit of analysis is the different community areas defined by the population census 2001. Data on their total areas, population, education, income, households and other socioeconomic information for each of the 227 units were compiled from the census data. In addition, the land use classification of each community was obtained from the City of Calgary. Furthermore, Arc View 3.2 was also used to compile other spatial attributes such as streets, schools, gas stations, liquor stations, train stations in each community. The GIS road network database was used to obtain different road infrastructure features. The number of schools in each community is identified from interactive maps (eMaps) maintained by City of Calgary. Liquor stores, gas stations and Light Rapid Transit (LRT) stations in each community was positioned by geocoding their addresses.

The street pattern in each community is classified using a scheme adapted from Southworth and Ben-Joseph (2003). The authors classify street patterns into five categories: grid-iron; fragmented parallel; warped parallel; loops and lollipops; and lollipops on a stick. However, since there are very few communities with the fragmented parallel pattern in Calgary, this category was merged with grid iron pattern because it contains mainly straight roadways. Also, the two street patterns with lollipop designs were merged into one to simplify the classification scheme. Finally, a separate category called mixed pattern was created to allow community areas with mixed design. Of the 227 community areas, 46 are classified as grid-iron, 55 are warped parallel, 87 are loops and lollipops, and the remaining 39 are mixed pattern. Example of each type of street pattern is shown in Figure1.

Warped Parallel in Fairview

Gridiron in Forest Lawn

Loops and Lollipops in Citadel

Mixed Pattern in Altadore

Figure1: Different types of street pattern in Calgary communities

Finally, crash data for the years 2003-2004 in the City of Calgary were obtained from Alberta Infrastructure and Transportation. Crashes on arterials which form the boundaries of communities were excluded from analysis to avoid the boundary problem. During the considered 2 years time period, 35171 crashes are observed within 227 communities. Among them, 26 are fatal crashes, 3163 are injury crashes and the rest 31984 are property damages only.

Model Development and Estimation Method

Since the number of crashes is a random, discrete, non-negative and sporadic data, the most appropriate statistical technique to use is the Poisson regression model (Tay, 2006, 2005a,b). The Poisson distribution, however, suffers from an important limitation. It assumes that the mean and variance of the collision frequency is same, which is often violated in traffic collision studies. Collision data is often over-dispersed with variance much greater than mean. In such cases, the use of Poisson model may lead to biased coefficient estimates. To deal with this problem, a more general distribution, the Negative Binomial Distribution (NB), has been employed by some researchers (Tay, 2004, 2005c). Since over dispersion has been detected in our data, the Negative Binomial Regression Model is chosen for this study.

The number of crashes in each community was chosen as dependent variable of the model. As fatal and injury crashes put more economic burden on the society, these crashes were converted to Equivalent Property Damage Only (EPDO) using the conversion formula from PIARC Road Safety Manual (2003).

(1) $EPDO = 9.5*Fatal + 3.5*Injury + PDO$

The contributing factors considered in this study were selected based the results of previous studies and the availability of data. For factors that are categorical in nature, several dichotomous variables were created to represent the different categories in each factor. One variable in each factor was selected as reference case and excluded from the model to avoid over-specification. As suggested by Kockelman and Kweon (2002), variables with low statistical significance were retained in the model if they belonged to factors that had some significant effect. Although this approach may reduce the efficiency of the estimates, it was adopted for the ease of comparison and interpretation of the estimates. We adjusted for this potential decrease in efficiency by using a more liberal confidence level of 90% instead of the traditional 95%. The variables in the final model are shown in Table1 with their mean and standard deviation.

Table 1 Summary Statistics

Variables	**Mean**	**S.D.**
Dependent Variable		
Number of EPDO Crashes (2004-2005)	190.98	208.39
Independent Variables		
1. Street Pattern		
a. Grid-iron	0.203	0.402
b. Warped Parallel	0.242	0.429
c. Loops & Lollipops	0.383	0.487
d. Mixed	0.172	0.378
2. Length of Road Ramp (km)	2.64	19.93
3. Length of Collector Road (km)	5.02	37.87
4. Length of Service Length (km)	0.003	0.021
5. Number of Intersections	87.95	63.95
6. Population per Unit Area (m^2)	0.002	0.001
7. Geographical Size		
a. 0 to 1 million m^2	0.220	0.415
b. 1 to 2.5 million m^2	0.392	0.489
c. > 2.5 million m^2	0.388	0.488
8. Industrial Land Use	0.172	0.378
9. Housing Pattern (%)		
a. Single Detached	63.40	28.67
b. Semi-Detached	5.360	6.20
c. Row Houses	8.9265	13.07
d. Apartments	21.398	25.46
e. Others	0.959	6.57

10. Number of Liquor Stores	0.9207048	1.14
11. Median Income		
a.$0 - $40,000	0.114	0.319
b. $40,000 - $ 80,000	0.669	0.472
c. $ 80,000 - $125,000	0.177	0.382
d. Greater than $125,000	0.04	0.196
12. Education (%)		
a. Less than High school	18.78	10.26
b. High School Graduation	10.63	5.55
c. Trades	11.09	4.16
d. College	24.31	5.51
e. University	35.17	16.30
13. Children by Age (%)		
a. Under 6	24.33	10.37
b. 6-14	37.21	9.16
c. 15-17	11.66	4.48
d. 18-24	17.78	8.61
e. 25 and over	8.57	5.07
14. Marital Status of 15 yrs and over (%)		
a. Married + Common Law Partner	58.58	11.35
b. Never Married	33.86	10.18
c. Separated	3.03	1.87
d. Divorced	8.24	3.71
e. Widowed	4.25	3.15
15. Mode of Transportation (%)		
a. Personalized Transport	76.64	12.80
b. Public Transit	13.49	4.67
c. Vulnerable Users	8.99	11.29
d. Taxi	0.122	0.230
e. Other methods	0.795	1.46

Discussion of Results

The results of final model are shown in Table 2. Overall, the model fitted the data well, with a very large chi-square statistic for the goodness-of-fit. Also, the over-dispersion parameter alpha was statistically significant, providing support for the choice Negative Binomial Model instead of Poisson model.

Table 2 Estimation Results

Number of observation = 174
Chi-square = 246.75
P-value < 0.0001
Alpha = 0.229
P-value for alpha < 0.001

Variable Name	**Coefficients**	**Std Err**
1. Street Pattern (Ref: Grid-iron)		
b. Warped Parallel **	-0.7199	0.1670
c. Loops & Lollipops **	-0.6243	0.1832
d. Mixed Pattern	-0.2061	0.1460
2. Length of Road Ramp **	0.0896	0.0300
3. Length of Collector Road *	-0.0365	0.0198
4. Length of Service Length *	-21.17	11.22
5. Number of Intersections **	0.0056	0.0012
6. Population per Unit Area *	98.21	52.43
7. Size (Ref: 0 to 1 million m^2)		
b. 1 to 2.5m m^2 **	0.4772	0.1373
c. > 2.5 m m^2 **	0.7656	0.1995
8. Industrial Land Use **	2.6290	0.6410
9. Housing (Ref: Single Detached)		
b. Semi-Detached	0.0014	0.0077
c. Row Houses *	-0.0102	0.0037
d. Apartments *	-0.0069	0.0042
e. Others	0.0074	0.0086
10. Number of Liquor Stores **	0.1586	0.0419

11. Income (Ref: $0-40,000 per yr)		
b. $40,000 - $ 80,000	-0.0570	0.1930
c. $ 80,000 - $125,000	-0.2656	0.2567
d. > $125,000 *	0.6668	0.3690
12. Education (Ref: < High School)		
b. High School Graduation **	0.0530	0.0217
c. Trades	0.0116	0.0231
d. College **	0.0250	0.0111
e. University **	0.0177	0.0076
13. Children Age (Ref: Under 6)		
b. 6-14 **	0.0155	0.0076
c. 15-17	0.0039	0.0124
d. 18-24	-0.0009	0.0062
e. 25 and over **	0.0259	0.0110
14. Marital Status (Ref: Married)		
b. Never Married	-0.0046	0.0084
c. Separated	-0.0470	0.0484
d. Divorced **	0.0956	0.0233
e. Widowed	0.0138	0.0195
15. Mode (Ref: Personalized Transport)		
b. Public Transit	0.0758	0.0132
c. Vulnerable Users	0.0333	0.0068
d. Taxi	0.2838	0.1921
e. Other methods	-0.1579	0.0459
16. Constant	-0.2979	0.9964
Note: * & ** denote statistically significant at α = 0.10 & 0.05		

The main objective of the study is to examine the effect of street pattern of community on road crashes. From the model results shown in Table 2, it is clear that all limited access patterns are safer than grid-iron pattern. More specifically, the warped parallel pattern was found to have the greatest safety effect (β=-0.7199; p<0.001), followed by the loops and lollipops pattern (β=-0.6243; p=0.001).

Although mixed design also performed better, this result is not statistically significant.

One can argue that since limited access design is associated with several limitations such as poorer horizontal alignment, narrower road, restricted sight distance and lower design standard (lower functional classification) as well as greater workload for drivers to due to presence of frequent curves, should therefore have more crashes than the simpler grid-iron pattern. In addition, there are more playground areas and children playing on the streets in limited access roads. However, our results did not support this hypothesis. Nevertheless, our finding is not unexpected and can be explained by risk compensation theory and risk homeostasis theory often used in the field of economics and psychology (Peltzman, 1975; Wilde 1994; Tay 2006). According to these theories, risks associated with limited access design due to presence of road hazards may be compensated by the lower traffic volume and more cautious driving behavior, for examples, reduced speed and being more alert to the presence of children and pets. This behavior adaptation is often encountered in areas where traffic calming measures are implemented.

Besides the street patterns, other road characteristics, particularly the length of different classes of roads are expected to have a strong influence on road crashes (Graham and Glaister, 2003; Noland and Quddus, 2004). As expected, an increase in the length of collector road and service lane was found to be associated with a reduction in the number and/or frequency of crashes. In contrast, it was found that an increase in the length of ramps in a community increases its crash risk. Merging and diverging from the ramp to the main streets or vice versa is hazardous due to frequent speed and lane changes. Also, an increase in the number of intersection was found to be associated with higher crash risk. This result is also expected because intersections have been identified as hazardous locations on roads due to the number of conflict points and the potential for severe side impact crashes (Tay and Rifaat, 2007; Chin and Quddus, 2003).

In addition to road characteristics, various land use features and neighborhood characteristics were explored in this study. Our result showed that crash risk increases with both the size and population density of the community due, perhaps, to an increase in exposure. Also, if a community is designed for industrial land use purpose, the crash risk is higher due to a greater mix in vehicle traffic, especially the number of heavy vehicles. The housing pattern in a community also has an influence on crashes. Our study found that row houses and apartment buildings increase safety in a community compared with single detached houses. As expected, the number of liquor stores in communities was found to be positively related to crash risk.

In parallel with road and land use features, various socio-economic and demographic factors were also examined in this study. In contrast with previous studies (Valverde and Jovanis, 2006; Graham and Glaister, 2003; Noland and Quddus, 2004), this study found that income had only a minimal effect and education was negatively associated with safety. Although increases in income and education are expected to increase the demand for safety, they also increase other demands like speed and aggressive driving due to increase in value of time as well as increase in the demand for alcohol and discretionary travels. Comparing with the children aged 0-6, an increase in the number of children aged 6-14 was found to be related to an increases in crash risk. This particular age group is often associated with unsafe behavior as vulnerable road users (Lam, 2005; Agran et al, 1998). Compared with married residents, if the number of divorcee people increases in a community, it increases crash risk due to psychological issues.

Conclusion

The objective of this study is to determine the effects of different street patterns in a community on traffic safety in order to provide evidence based recommendations for the development of new urban and suburban communities in western countries. In this study, street patterns in Calgary communities were broadly classified into grid-iron and limited access which comprised of warped parallel and loops and lollipops type design. A negative binomial model was estimated using crash data from 2003 and 2004 to identify the influence of street pattern while controlling for the effects of land use and various socio-economic and demographic characteristics. Our results showed that limited access roads are associated with lower frequency and/or severity of crashes than the traditional grid-iron street pattern and should thus be encouraged from a traffic safety perspective.

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