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URBAN GRID AND TRAFFIC SAFETY:

Using space syntax as an assessmenttool

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ABSTRACT

In this paper, Space Syntax methods of analysis have been applied to analyse the syntactic configuration of 28 high-risk streets in three Jordanian cities in order to explore the contribution of syntactic characteristics on accidents occurrence at these streets. The study incorporated Space Syntax - axial and segment analysis to produce a set of key syntactic measures including connectivity, integration, relative asymmetry, and choice. Syntactic measures were compared to traffic accidents data that were collected through the Central Traffic Department at Jordan. Statistical analyses were performed using three types of analysis; Correlations, One-Way ANOVA, and Regression. Statistical analysis showed that local measures Connectivity, Integration R3, and real relative asymmetry R3 were major syntactic properties that explain part of traffic accidents occurrence at high risk streets. The paper concludes that despite the differences in the street network density among the three cities, there is no significant difference in the syntactic characteristics of their high-risk streets. This study will help planners and designers to focus their efforts on improving streets where high rates of accidents are expected. Space Syntax provides a tool for assessing cities' urban grid and develop transportation project when needed tools and resources are rare.

KEYWORDS

Space Syntax, Urban Grid, High Risk Streets, Traffic Volume, Jordan

1. INTRODUCTION

The growing traffic problems facing many urban areas today have resulted in a significant number of studies that seek to address the issue of traffic accidents. The Space Syntax (SS) is one approach that have been incorporated in transportation studies to investigate the influence of the urban configuration on patterns of pedestrian and vehicle flow throughout the city. Making it possible to predict the distribution of movement in the city's streets, based solely on the street network and the nature of streets connections (Jayasinghe, Sano, & Nishiuchi, 2015; Lerman, Rofè, & Omer, 2014; Raford & Ragland, 2004). Predicting patterns of movement in the city helped in developing accident models to visualize the distribution of traffic accidents through-out the city and to define the locations of high level of risk (Greene-Roesel, Diogenes, & Ragland, 2007; Obeidat & Al-Hashimi, 2015).

This paper is an extension to previous researches that integrates Space Syntax theory with transportation studies by investigating how the streets network in the city as seen from a syntactic perspective corresponds to traffic accidents occurrence at high risk streets. The study involves twenty-eight streets chosen from three Jordanian cities; Irbid, Madaba, and Ramtha. Streets under-investigation are classified as high-risk or hazardous streets by the department of traffic at Jordan. It is important to note here that classifying a street as a high-risk differs from one country to another, depending on the rate of fatalities or injuries.

In this paper, we assume that there is an association between the way high-risk streets are articulated in the urban grids and the potential incidence of traffic accidents found in each street. The research offers specific recommendations for areas that are considered high at risk or are associated with high rate of traffic accidents.

1.1. INSIGHTS FROM TRANSPORTATION STUDIES

A number of publications approach the issue of accident prevention through the physical design of urban streets. For example, Dumbaugh and Rae (2009) in "Safe Urban Form" reviewed some of the basic design ideas to increase safety on streets. The main principles include (1) increasing the sight distance and (2) designing streets with limited access. Increasing the sight distance incorporates widening and straightening streets to enhance drivers' ability to see the hazard before physically encountering it. While, the limited access principle minimizes the number of intersections along the street in order to decrease the opportunities of encountering vehicles and pedestrians with each other. Some researchers sought to examine the validity of these principles on their studies. For example, Choueiri, Lamm, Kloeckner, and Mailaender (1994) found a negative relationship between available sight distance and accident risk. The accident rate decreases with the increase of sight distance of more than 750 m (2,450 ft). In addition, studies showed that an increase in streets width leads to a decrease in accident frequency (Abdel-Aty & Radwan, 2000; Watanabe & Nakamura, 2016).

At the urban scale, the view of the relationship between the urban form and accidents occurrence is widely confirmed by many studies. For instance, Marks (1957) found that neighbourhoods with through traffic and gridiron patterns witnessed higher number of crashes than the limited access communities. Rifaat, Tay, Perez, and Barros (2009) found that contemporary patterns with loops and cul-de-sac were associated with lower crash rates than gridiron patterns. Lovegrove and Sun (2010) also found that irregular patterns were safer than grid, and cul-de-sac patterns. These studies draw attention to the notion that streets organization within the urban form can either limit or regulate the potential encounters among different vehicles or pedestrians. For example, gridiron patterns might increase the number of traffic causing more accidents to happen unlike limited access patterns.

The effect of traffic volumes on traffic safety has been examined by Scholars, but they reported different conclusions. Some studies reported that streets and intersections with high volumes were found to be associated with increased crash incidence (Abdel-Aty & Radwan, 2000), while others found them to be associated with significantly fewer crashes (Obeidat & Al-Hashimi, 2015). In general, all of these studies concluded that traffic volume is an important indicator for risk.

During the last few years, space syntax has been applied in transportation studies to model the distribution of movements in the city's streets and to predict traffic flows. The results show a clear correlation between the dispersal of movements and the streets' degree of spatial integration (Greene-Roesel et al., 2007; Lerman et al., 2014; Raford & Ragland, 2004) . Data generated by space syntax analysis were employed to model pedestrian accidents and to define high risk streets (Obeidat & Al-Hashimi, 2015; Raford & Ragland, 2004). However, what is missing is a genuine understanding of the relationship between streets' spatial characteristics with accidents occurrence focusing on high risk locations. More precisely, we need to know how streets with high rate of accidents are placed in relationship to the configurative structure of the city. Using space syntax analysis, we can identify underlying spatial conditions of the high-risk streets whether they are segregated streets (that are visually broken up with urban grids with less accessibility and connections to all other streets in a city) or integrated ones. We can provide an evidence as to how the streets' spatial characteristics could be held responsible of causing a high rate level of accidents.

2. RESEARCH METHODOLOGY

The analysis of three cities; Irbid, Madaba, and Ramtha have been incorporated in this study to investigate the spatial characteristics of their high-risk streets. The cities ranged between high to low- street network density as shown in Figure (1) below. Traffic accidents data for each city were collected through the Central Traffic Department at Jordan. In 2015, a total of 1750 traffic accidents were reported in these three cities. 54.2% of these accidents involved pedestrians. In addition, accidents in these cities have resulted in 93 fatalities (15.3 % of total fatalities in Jordan) and 3068 injuries (19.0 % of total injuries in Jordan) (Central Traffic Department, 2015). Due to the growing accidents problem, the Jordanian Central Traffic Department worked to define accidents' locations or streets that pose a high risk to their users at different cities in Jordan. More than 557 streets that classified between low, medium, to high risk were identified from this investigation (Central Traffic Department, 2015). Figure (1) shows the locations of high risk streets on the map of each city that is incorporated in our study.

A separate analysis was conducted on the street grid for each city using UCL-DepthMap software to derive the syntactic values (including connectivity, integration, relative asymmetry, and choice) for the 28 high-risk streets. The study then used a correlation analysis to explain the relationship between the various syntactic parameters and the number of accidents occurring on each street.

Irbid City (High Density) | **Madaba City** (Medium Density) | **Ramtha City** (Low Density)

Figure 1 - Locations of Different High Risk Streets at Each City Map

2.1. SPACE SYNTAX ANALYSIS

Space Syntax' Axial and Segment analyses were performed in this study. Axial lines represent the longest and fewest possible lines of sight that cover all routes of movement in the city (Hillier, 2007). While, segment lines are axial lines that are broken down into smaller segments at each intersection. The relationship between the lines and their connections provides a number of spatial indices of street grids that describe movement flows through streets. Indices include integration, connectivity, choice, and relative asymmetry. (1) Integration indicates the number of directional changes from one line in a network to all of the other lines. This measure can offer a description of the level of accessibility of a high-risk street to other streets in the network. (2) Connectivity reflects the number of axial lines directly intersecting with a specific line. This measure can describe the number of neighbouring streets directly intersecting with a high-risk street. (3) Choice measures the likelihood that a certain line is most used for traveling between different spaces in a city. This measure can describe whether a high-risk street allows traffic from all other routes to pass through it to all other spaces in the entire system. And (4) Relative asymmetry measures (RA and RRA) are standardized and inverse measurements of integration, which calculate the deepness of an axial line from a certain line without considering the number of lines in the system. These measures are helpful in defining integration measures without considering the size of the cities in comparison.

Of the measures produced by UCL Depthmap, the following axial-based variables were picked as independent variables in the study: Table 1 shows the syntactic analysis for the three cities.

- Axial-based variables (topological measures):
    - Integration (global and local with a radius of 3)
    - Connectivity
    - Choice

- Segment-based variables (angular measures):
    - Integration
    - Connectivity
    - Choice

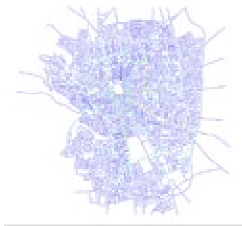
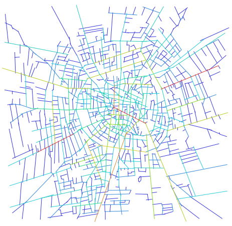
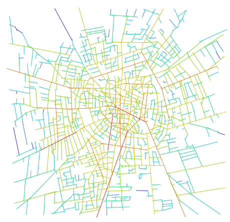
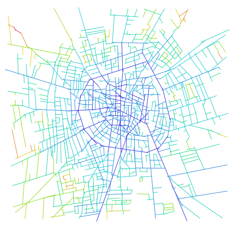
	Connectivity	Local Integration R3	Choice	RRA
Irbid City				
	C.A: 4.62 HRA: 11.55	C.A: 2.1 HRA:2.99	C.A: 361725 HRA:1203989	C.A: 1.029 HRA: 0.812
Madaba City				
	C.A: 3.62 HRA: 9.99	C.A: 1.8 HRA: 2.73	C.A:94724 HRA:547235	C.A: 1.104 HRA: 0.813
Ramtha City				
	C.A: 3.83 HRA: 12.2	C.A: 1.9 HRA: 2.97	C.A:75952 HRA:253654	C.A: 0.886 HRA: 0.68

Table 1 - The Syntactic Analysis of The Three Cities.

3. RESULTS

Using IBM SPSS 22 (SPSS, 2013), statistical analyses were performed using three types of analysis; Correlation ,One-Way ANOVA and Regression. Correlation analysis were used to describe the relationship between the number of pedestrian accidents and the various syntactical properties. Analysis of variance (One-Way ANOVA) was used to describe the variance among the three cities in relation to different variables included in the study. And Regression analysis was used to identify whether the relationship between the dependent and independent variables as a cause-effect relation.

3.1 ANALYSIS OF ALL STREETS TAKEN TOGETHER

Spearman correlational analysis is conducted here to understand the effects of syntactical properties on accidents' occurrence through the analysis of all streets taken together. The correlation coefficients presented in Table (2) show that there are insignificant and weak correlations among axial global integration and choice values and the total number of pedestrian accidents. However, the correlation coefficients show significant relationships among local axial variable: connectivity, local integration R3, and Real Relative Asymmetry values and the number of accidents at high risk streets.

The correlation coefficients show that axial connectivity (R3) had moderate negative correlation with the total number of pedestrian accidents which yields a Spearman r equal to - 0.462 (P value = 0.013). Axial connectivity values can provide an explanation of 17 percent of the total variation in pedestrian accidents at high risk streets, where high connectivity values induce lower number of accidents. The correlation coefficients show that the local Integration (R3) displays moderate negative correlation with the total number of pedestrian accidents which yields a Spearman r equal -0.524 (P value = 0.004). Local integration (R3) can explain 17.8 percent of the total variation in pedestrian accidents, high integrated streets induce lower number of accidents. The results display moderate positive correlation between real relative asymmetry R3 measure and accidents number, which yields a Spearman r equal 0.529 (P value = 0.004). This indicates that streets with low values of real relative asymmetry or low deepness at local level in streets' system would probably witness low number of accidents.

The statistical analysis did not show significant correlations between segment based variables, connectivity and integration, and the number of accidents. However, the analysis showed a significant correlation between the number of accidents and angular choice value. The correlation is moderate and positive that yields a Spearman r equal 0.418 (P value = 0.027). This indicates that streets with high choice values that allow more through traffic would probably witness high number of accidents.

Syntactical variables		Spearman r	P value
Axial Analysis	Connectivity	-.462*	.013
	Global Integration Rn	-.169	.390
	Local Integration R3	-.524**	.004
	Choice	.105	.596
	Relative Asymmetry R3	.366	.056
	Real Relative Asymmetry R3	.529**	.004
Segment Analysis	Connectivity	-.228	.244
	Integration	.178	.365
	Choice	.418*	.027

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 2 - Variables and Summary of Correlations

3.2 ANALYSIS BASED ON THE CITY

Tukey test after ANOVA is conducted here to compare the effects of syntactical properties on accidents' occurrence among the three cities.

As presented in the Table (3) below, the analysis of variance generally show insignificant differences among high-risk streets in the three cities (Irbid, Madaba, and Ramtha) in terms of the number of accidents and syntactical properties. This finding indicates a similarity in high risk streets' syntactical properties even though they are located in cities that differ in street network density (high, medium, or low).

However, the analysis of variance show significant different among the three cities in relation to their axial and segments' global integration values Rn. High-risk streets in Ramtha (a city with low density) are more globally connected to other streets in the city unlike high streets in Irbid and Madaba city. The results also showed that the three cities differ in their angular choice values. This indicates that high risk streets in Irbid city allow more through traffic than other cities.

Syntactical variables		F	P value
Axial Analysis	Accidents	.144	.866
	Connectivity	.777	.471
	Global Integration Rn	5.780	.009
	Local Integration R3	1.613	.219
	Choice	.890	.423
	Relative Asymmetry R3	1.383	.269
	Real Relative Asymmetry R3	1.442	.255
Segment Analysis	Connectivity	2.443	.107
	Integration	69.090	.000
	Choice	3.886	.034

Table 3 - Cities' Streets Comparison and Summary of ANOVA Analysis

3.3 REGRESSION ANALYSIS

Regression analysis is performed here to identify whether there is a causation between the syntactical measures and traffic accidents. A stepwise regression analysis was implemented. Based on this analysis, a model that predicts traffic accidents at high risk roads was developed. The model indicated that axial connectivity is an important variable in explaining traffic accidents at high risk roads. Connectivity values can predict 15.9 percent of total variation in traffic accidents (P value = 0.035).

Model Summary					
Model	R	R Square	Adjusted R Square	F	Sig.
1	.399a	.159	.127	4.929	.035
a. Dependent Variable: Accidents					
b. Predictors: (Constant), Axial Connectivity					

4. CONCLUSIONS

This paper incorporates Space Syntax analysis to investigate how the streets network in the city as seen from a syntactic perspective corresponds to traffic accidents occurrence at high risk streets in that city. Our results show that syntactical measures did explain part of accidents occurrence at high-risk streets. In the study, axial local measures (Connectivity, Integration R3, and real relative asymmetry R3) were major syntactic properties that explain traffic accidents occurrence at high risk streets. The findings indicate that a street with low number of connections with surroundings routes makes it more vulnerable to accidents due to the decrease of traffic volume at the street level. This finding is consistent with previous studies findings that consider traffic volumes as important indicator for accidents occurrence. When the number of traffic passing the street goes down, accidents frequency increases. Jacobsen (2003) explained that a motorist in this situation is more likely to collide with a person walking or other vehicles when there is less traffic in the street (Jacobsen, 2003).

Previous research indicates that urban areas with high network density appear to be safer than the lower-density environments (Marshall & Garrick, 2011). Our study did not find any significant differences in the syntactical properties among high risk streets that are located in different cities (with different street network density) and accident occurrence on these streets. The regression study found that the local measure of connectivity is a good predictor in explaining 15.9% of accident occurrence in high-risk streets.

We hope this study will help planner and designers to focus planning and infrastructure efforts on improving streets where a large amount of accidents takes place. Furthermore, the results can be used to develop a policy that seeks to improve traffic safety where the lowest traffic movement rates are expected. Using the space syntax approach in analysing street properties would allow planners to take more a proactive role in assessing cities' street network and develop transportation planning projects in Jordan and other countries.

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