TRAFFIC SAFETY DEVELOPMENT MODELING IN DUHOK CITY ROAD NETWORK USING GIS TECHNIQUE

Dr. A. M. AL-Taei
Mosul University
Remote Sensing Center
Assistant Professor
Transportation Engineering
khalik_abdel@yahoo.com

Dr. A. Abdulmawjoud
Mosul University
College of Eng./Civil Dept.
Assistant Professor
Transportation Engineering
aymanmawjoud@yahoo.com

Ziyad N. Al-Doski
Duhok Roads Administration.
Consultant Engineer
M. Sc Transportation Engineering
endaziar@gmail.com
key word: Duhok, GIS Safety

ABSTRACT

Traffic Crashes are one of the main problems in Kurdistan Region. Many people die or are injured because of traffic crashes taking place every day at very high cost. Crash data, collected for many years, serve as the ground base for programs designed to reduce the number of traffic crashes. The study was achieved by collecting, preparing, and analyzing the crashes, traffic and geometric data that were related to Duhok urban street network.

Crash data were taken from 529 traffic crash reports for the four years (2006-2009). Traffic and geometric data were obtained through on-site investigation and field studies in the study area.

In order to decrease the rate of traffic crashes, traffic crashes analysis carried out, for the collected data during the four years study period, for different identified hazardous locations (i.e., Street Sections, Intersections and Local Zones) by using various statistical and numerical methods and using the techniques of GIS (Geographic Information System) for Spatial Association.

After the identification of different hazardous locations, a step-wise multiple linear regression analysis was applied to the collected data from the selected hazardous locations by the aid of some computer programs packages such as SPSS and Minitab software to drive the most appropriate empirical models that could satisfy the best representative relationships, implementing the available correlation matrices obtained between the dependent and the independent variables .It was found that the average daily traffic volume, running speed and truck percentage are strongly correlated with the crashes occurrence on the street sections and intersections, while population density and distance between local zones are very well correlated with crashes occurrence on zones in the study area.

The study concluded that, using GIS technique resulted in detecting HALs was compatible with the results obtained by the traditional methods currently used in the identification of hazardous locations in urban areas. Other recommendations are proposed in this study for further and continuous future studies .

INTRODUCTION

Traffic safety is recognized as a critical social and huge economic loss issue in Kurdistan Region. The rapid economic growth in the region has induced to increase motorization, especially in urban areas. In parallel, the improvements in the infrastructure have enhanced high traffic mobility and speed. As a result of lack of comprehensive traffic safety countermeasures by the government and people's low awareness of traffic safety, the number of traffic crashes and fatalities had constantly increased over the last five years.

Crashes, in general, had created worldwide problems, which necessitates comprehensive and realistic understanding of the causes and the assignment of efficient means for reduction and prevention of these crashes. The crashes involve tragic loss in effort, time, money, property and human lives. Moreover, they create growing feelings of a great lack of safety in all facilities of human lives.

Americans say that their loss in the World War as deaths and injuries were less than that in automobile crashes. So it is clear, that there is no difference to construct weapons or engines, only weapons are mainly used in wars outside the country, and engines are used in so called "Civil War".[1]

Crash data, collected for many years, serve as the ground base for programs designed to reduce the number of traffic crashes.

In order to decrease the rate of traffic crashes, traffic crash analysis should be carried out to determine which section of a street is faulty in other words a hazardous location. Those locations which should be determined by means of computerized methods such as frequency, crash rate, frequency rate, rate quality control and crash severity methods. However in recent years GIS technology has also been used in traffic crashes identification and analysis.

Many of the required analysis have strong location element, and as such they may suggest some form of geographic computer based data management system. GIS has been identified as an excellent system for storing and managing these types of data and also as a potential tool for improving crash analysis process. One of the reasons is that it provides an efficient system of linking a large number of disparate databases. It provides a spatial referencing system for reporting the output at different levels of aggregation. Even though traffic safety seems to have many easy and logical connections to GIS, and its applications which have been proposed before, the development of a useful GIS database proved to be more difficult than anticipated. [2]

PURPOSE OF THE STUDY

The main purpose of this study is to re-formulate traffic safety program in the City of Duhok through the following points:

1-Identification, classification and diagnosis of HALs by analyzing crashes data collected during time period between years (2006-2009) for selected urban street network of Duhok City using different methods.

2-Developing required statistical models between traffic, geometric characteristics and the number of crashes in selected HALs.

In addition to the above purpose, this study also aims at proposing suggestions to:-

i. Reduce traffic crashes and enhance the regional economy, either by reducing loss of lives, or damage of vehicles.

ii. Reduce travel time and delay of traffic flow due to those crashes.

iii. To investigate the public's traffic-safety-related knowledge, attitude, behavior, and experience.

iv. To foster dialogue about traffic safety and how to improve it.

v. Developing and authorizing further partnerships with schools, colleges, universities, health centers, and other organizations in the undertaking of traffic safety activities.

STUDY METHODOLOGY

This study was achieved by collecting, preparing and analyzing the crash, traffic, and geometric data related to Duhok urban street network. The traffic crash data were taken from Directorate of Traffic Police which was collected for the time period between years (2006 - 2009) traffic crashes from 529 reports. The methods followed in this study, are divided into two phases. The first phase includes the theoretical methods to identify the hazardous locations with the aid of crash data records and computerized database by using GIS technique. Meanwhile the second phase deals with the theoretical part and developing relationship models between traffic characteristics and traffic crash data.

Study Criteria for Identifying High Crash Locations

The criteria behind the methodology based on several basic methods were used to identify and prioritize high crash locations; can be classified into several categories as listed below: [3]

1. Spot Map Method.
2. Crash Frequency Method. (Number Method).
3. Crash Rate Method.
4. Frequency Rate method.
5. Rate Quality Control Method.
6. Crash Severity Method.
7. Local Indicator Spatial Association Method(LISA), (For Zones)[4].

The first three methods above are quite simple and readily adaptable to the smaller highway and street systems. Data requirements are minimal, crash recording is simple and analysis could be made manually. While the methods 4, 5, and 6 are recommended for larger systems with higher and wider variations in traffic volumes, [5] and method 7 is used for identified Hazardous Zones. [4]

Local Indicator Spatial Association Method (LISA)

There are several tools available in GIS to analyze point features such as road traffic crash occurrences. Two of the very common point pattern detector tools available in GIS are: [3]

I-Quadrant analysis or density analysis tool, and

ii-The LISA method analysis tool.

In this study (LISA) method was used, that depends on Moran's I index. The equation of Moran's I index is as following: [4]

$$I_i = \frac{N}{(N-1)S^2}\,(X_i - \bar{X})\sum_{j}^{n} W_{ij}(X_j - \bar{X}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (1)$$

Where:

I = Moran's I Index.

N= Total number of zones under study.

n= total number of j zones surrounded by zone i.

Xi = Total number of crashes in zone i.

Xj = Total number of crashes in zone j.

$\bar{X}$ = Average number of total crashes in all zones.

Wij = Weights representing proximity relationship between location i and neighboring location j.

The three weight functions used in this study are the following:

1- $W_{ij} = \frac{1}{(d_{ij})2}$

2- $W_{ij} = \frac{1}{(d_{ij})}$

3- $W_{ij} = \frac{1}{\sqrt{(d_{ij})}}$ …………..where

dij = Distance between zone i and its nearest neighbors zone j.

S2= Variance of the observed values given by:

$$S^2 = \frac{1}{(N-1)} \sum_{i=1}^{N} (X_i - \overline{X})^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \; (2)$$

The adaptations to previous application of local Moran's I in traffic safety proposed that, it is important to use the index in a correct way. This means that account for zero observations must be taken into consideration (instead of only taking into account locations with at least one crash). [4]

This local measure of spatial association can be regarded as being a traffic safety index, since for each basic spatial unit (BSU) of road, the local Moran index can be regarded as a measure of association between the BSU under study and the neighboring BSU's that are similar to the one under study concerning the number of crashes. A negative value of the local autocorrelation index at location i indicate opposite values of the variable at location i compared to its neighboring locations. A positive value, on the contrary, indicates similar values at location i and its neighborhood. This means that, location i and its weighted neighborhood could both have values above , or both having values below the average value. In the application area of traffic safety, however, one is usually interested in locations that have: [4]

1-A high number of crashes in regard to the total average number of crashes (i.e.$(X_i - \overline{X}) > 0$), and

2-Where the neighborhood also shows more crashes than expected on average (i.e.$(X_j - \overline{X}) > 0$),

To determine the hot spots, it was decided to filter out the locations with a high number of crashes contiguous with high neighboring values. For this subsample of locations, the 95% percentile confidence limit (P_{95}) of the distribution of the remaining Moran values was determined. This value will be utilized as the cut-off value to determine an crash hot spot in the study area. If the local Moran's I value of a location of the true data also has similar high values between the location under study and its contiguous locations and exceeds this 95% percentile ,then this location is considered to be hazardous, and hence a hot spot location

Crash Data

In most developed countries, traffic crash data could be collected by responsible agencies and authorities according to well specified standards and detailed procedures.[4] while in our country, crash report forms, which are filled by the traffic police officers, are the only source for obtaining crash data, in the meantime not all crashes are reported. This kind of traffic crash data has many deficiencies such as:

- The form doesn't contain sufficient information which is needed for engineering analysis.

- The filling process adopted by police officers who have no engineering sense, therefore some times; they do not fill report forms completely.
- In some cases, the crash location name is unidentified in the report.
- Some crashes were not recorded at all because the drivers agreed to solve the problem in a fraternal way and they did not contact the police administration.

In the same time, collecting the crash data was a difficult process because of the existing routine problems, decision makers administrations especially due to the time restraint of the study

Coding System

In this study, Link – Node method coding system was setup for all variables in the study area for the purpose of avoiding complexity and getting simplicity for computer analysis. The coding system was carried out in two stages as follows:

1-Coding system of variables related to crash characteristics was setup before the data collection process.

2-A coding system of Duhok street network was set up after the data collection process. Figure (1) shows the study area coding system for the street network. Local zones coding are shown in Figure (2).

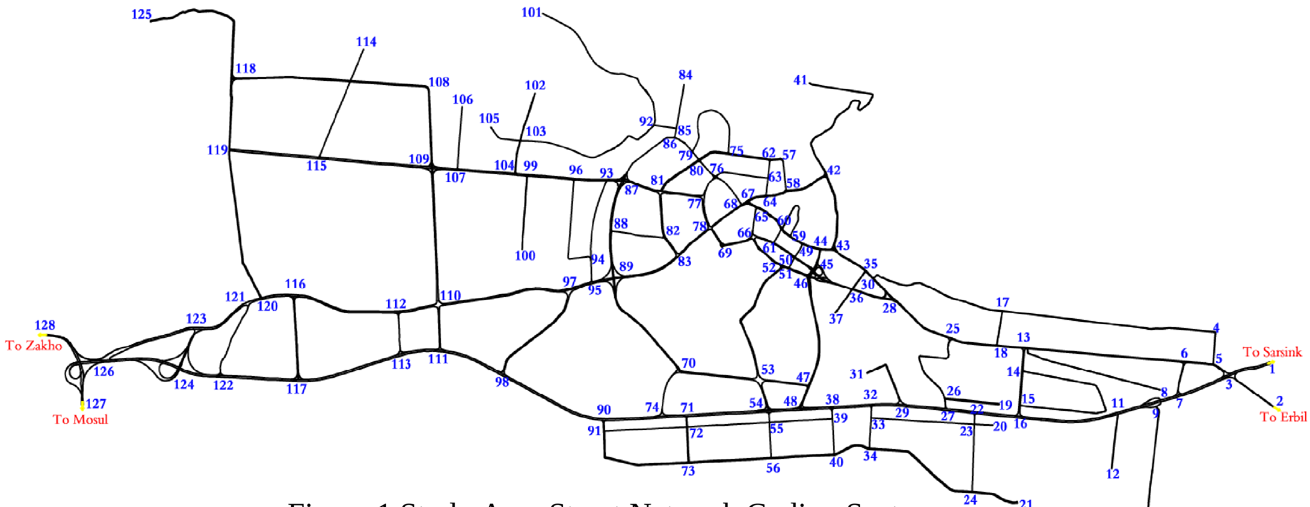

Figure 1 Study Area Street Network Coding System

Regression Analysis

Regression analysis is a statistical procedure between dependent and independent variables related to traffic crashes in the study area. The approach is mathematical, and all variables are considered random with normal distribution.

Predicate crash in future was estimated by using the statistical package (SPSS) and (Minitab).They are integral systems of statistical transform, and graphics designed to assist user in exploring and modeling data.

Based on the previous notion from different literatures, step wise multiple linear regressions was used to develop traffic crash models

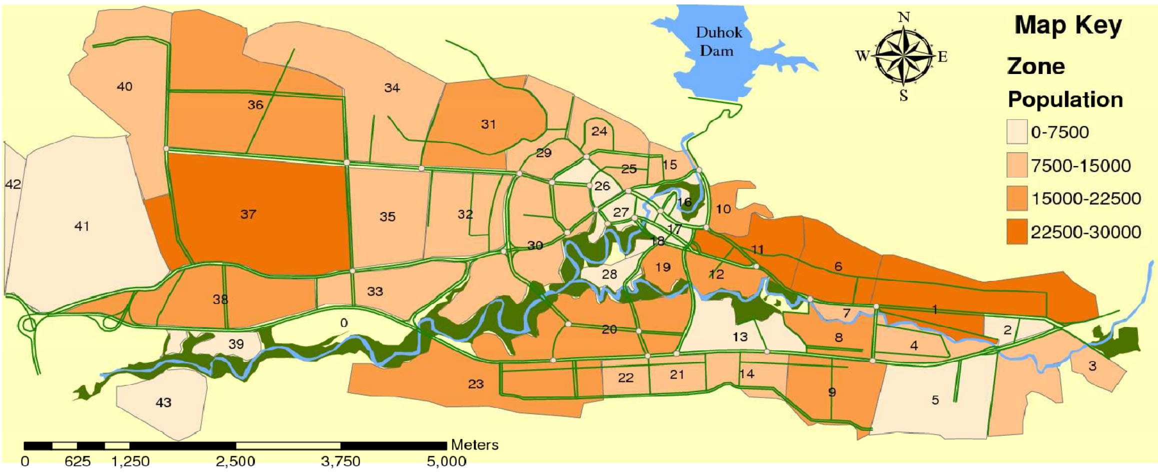

Figure 2 Study Area Zone Coding System

CHARACTERISTICS OF CRASHES ON DUHOK STREET NETWORK

The characteristics of Duhok City streets are discussed with different types of high crash locations resulted from the study through the distribution of crashes on the city street network.

The total reported number of crashes in the study area was 529 crashes during the four years period (2006-2009). The total crashes frequency recorded in street sections was (332) and on intersections was (180) crashes distributed in different locations while (17) crashes were un-identified locations.

From the total crash reports collected the first five locations having highest crash frequencies are Sarok, Peshmargah Intersections, and Amedye, Barzan(14), and Zakho(6) road sections as shown in Figures (3).

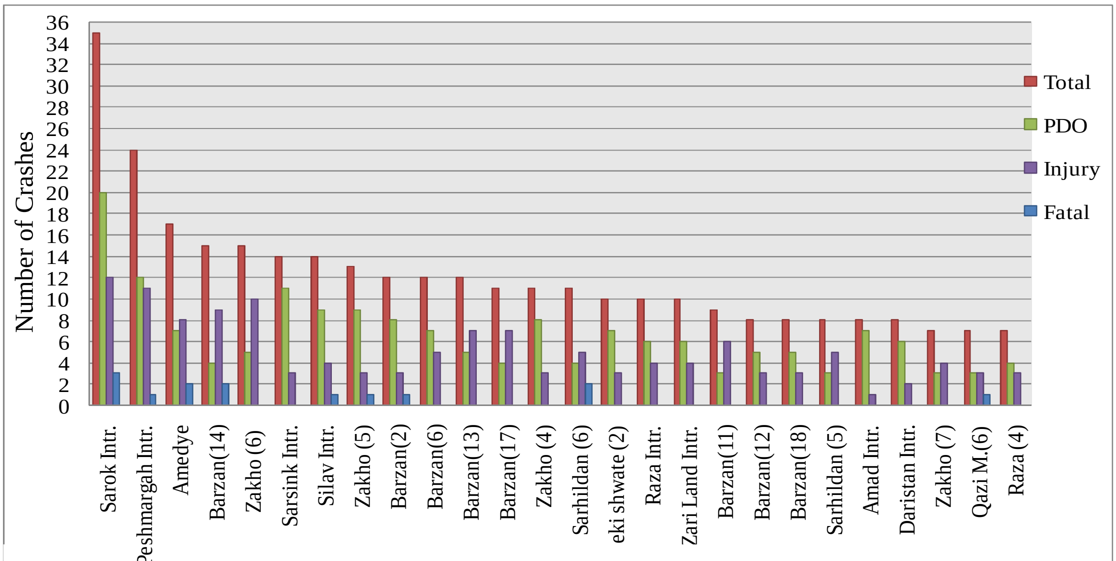

Figure 3 Location Ranking According to the Highest Crash Frequencies in Duhok Street Sections and Intersections Based on Crash Severity during Study Period

CRASH SPOT MAP FOR STREET NETWORK

The crash spot maps were prepared for the study area including all links and intersections for cumulative crashes for the whole study time period as shown in Figure (4). The high crash locations were identified through a quick visual check of crashes concentrations. The prepared spot maps included crash classification into fatal, injury, and PDO crashes. These crash classifications are geo-referenced by GIS technique with different colors.

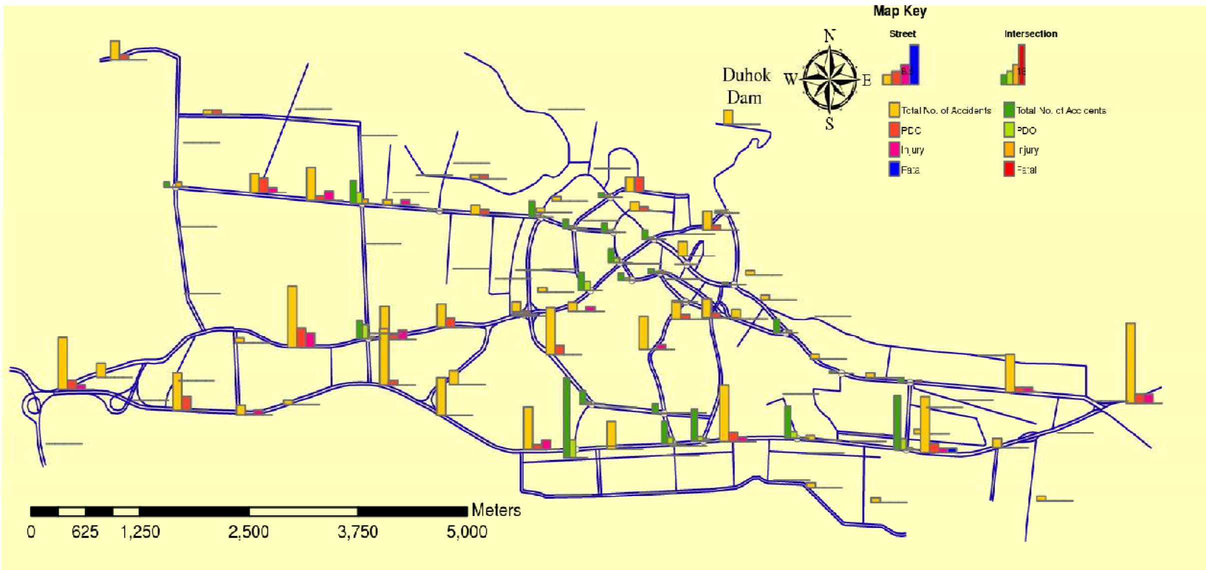

Figure 4 Total Number of Crashes Spot Map for the Study Period (2006-2009)

STREET CRASH CHARACTERISTCS

The largest number of crashes that occurred in the street sections was 332 crashes during the four years (2006 – 2009) in the City of Duhok. These crashes consisted of 181 PDO, 140 injuries, and 11 fatal crashes on the street sections, and caused the damage of 659 vehicles, injury of 355 and death of 12 victims.

The highest portion of all crashes on street sections in the study area occurred on 2-lane streets with 191 crashes, and 124 crashes occurred on 3-laned streets. The lowest was in 4-laned streets which was 17 crashes.

Identification of High Crash Street Sections.

In additional of using GIS technique for identifying and prioritizing HALs; some other criteria were based on several methods used individually or in combination with identifying HALs on street section.

Taking into consideration different street categories in the study area, different high street crashes were identified using the analysis methods and criteria mentioned before.

Zakho and Eke Shwate is considered as first HALs during study time period on 2-lane street categories, Barzan represents HALs on 3-laned street sections, while the 4-laned street categories were safe and there was no dangerous location on it.

INTERSECTION CRASH CHARACTERISTICS

The total number of crashes occurred at the intersections in the study area during four years was 180 crashes. These crashes consisted of 118 PDO crashes, 56 injury crashes, and 6 fatal ones , and caused damage of 373 vehicles, injury of 169 and death of 10 victims.
The highest portion of all crashes occurred at intersections in the study area during (2006-2009) were 35 crashes at Sarok Intersection, 24 at Peshmargah intersection. The reason is that these intersections are located at the main entrance of the City of Duhok from east and west.

Identification of High Crash Intersections

The high intersection crashes were identified with the aid of traffic, geometric and crash data that were collected by the present study, using different criteria. The results show that Sarok Intersection is the first HALs Intersection, then Peshmargah Intersection.

LOCAL ZONES DATA ANALYSIS

The distribution of highest crash frequencies are ranked in descending order in Table (1). Raza Zone has the highest number of crashes of 58 and then Sarhildan with 35 crashes. The highest zone with fatal crashes was Sarhildan of 5 fatal crashes and then Raza zone with 3 fatal crashes.
The application of GIS Technique to detect crash concentration zones in the study area

Table 1 Ranking High Accident Zones in the Study Area

Zone Name	Zone Code	PDO		Injury		Fatal		Total Accident	
		No.	%	No.	%	No.	%	No.	%
Raza	20	37	18.78	18	12.59	3	20.00	58	16.34
Sarhildan	1	14	7.11	16	11.19	5	33.33	35	9.86
Mazi	30	22	11.17	8	5.59	0	0.00	30	8.45
Malta Khare	38	13	6.60	16	11.19	1	6.67	30	8.45
Gavarke	39	14	7.11	14	9.79	1	6.67	29	8.17
Shindokha	23	15	7.61	12	8.39	1	6.67	28	7.89
Sarbasti	13	10	5.08	9	6.29	1	6.67	20	5.63
Ashti	29	15	7.61	2	1.40	0	0.00	17	4.79
Masike	34	5	2.54	10	6.99	2	13.33	17	4.79
Diyari	8	6	3.05	10	6.99	0	0.00	16	4.51
Kani Mahmadke	11	8	4.06	5	3.50	0	0.00	13	3.66
Nohadra	27	10	5.08	3	2.10	0	0.00	13	3.66
Avro City	42	9	4.57	4	2.80	0	0.00	13	3.66
Nizarke	3	5	2.54	7	4.90	0	0.00	12	3.38
Ronahi	9	6	3.05	5	3.50	1	6.67	12	3.38
Bin Tika	14	8	4.06	4	2.80	0	0.00	12	3.38
Total		197	100.00	143	100.00	15	100.00	355	100

was not possible as using available GIS version, because there was no licensed of application, and most of the order in toolbox were not functioning very well, so the required results couldn't be obtained. Therefore; manual calculations of Moran's I index is followed for the identification of the hazardous zones.

For the selected study area, 512 crashes geo referenced over 41 zones to determine the distribution of the local version of Moran's I, and three different weight functions are compared with each other. The functions are shown in Figure (5), since it was decided to look only at the locations that show a positive reinforcement with their contiguous locations in the calculation of the local autocorrelation index. Moran's I for the three function settings is shown in Table (2).

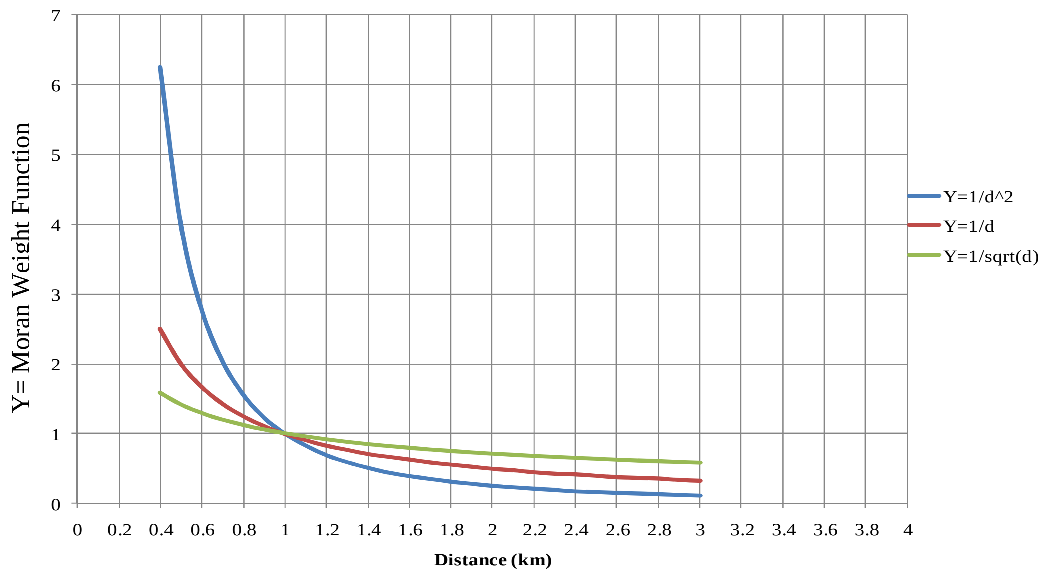

Figure 5 Different Weight Functions of Moran's I Index

Table 2 Moran's I Value in Different Weight Function

Zone Name	Zone Code	Accident No.	HS* in Set 1	HS in Set 2	HS in Set 3
Diyari	8	16	0.00	0.00	0.18
Sarbasti	13	20	0.00	0.54	1.13
Raza	20	58	0.00	0.00	3.24
Shindokha	23	28	3.22	4.20	4.79
Mazi	30	30	0.93	2.35	3.28
Masike	34	17	0.30	0.00	0.00
Malta Khare	38	30	1.28	1.03	0.75
Gavarke	39	29	1.85	2.09	2.22
Avro City	42	13	0.06	0.00	0.00
Total		241	7.64	10.21	15.59

* Hot-Spot

The results of the three weight functions show that Shindokha zone appeared to be High-Hazardous Zone out of 41 zones. This was mainly due to that, Shindokha Zone have 28 crashes which were more than the mean crash number of all zones (X`= 12.49).Other reason seems to be that, it is located nearest to Raza ,and Azadi zones with very short distance between zones centers which have large number of crashes of 68 crashes for both two neighbor zones.

STREET SECTION PREDICATION MODEL

Following dependent variables were used to disaggregate models at street sections:
Y_1 = Total number of crashes.
Y_2 =Crash per kilometer, (Acc/km).
Y_3=Crash per million vehicles-kilometers, (MVKM).
Independent variables related to the study area for street sections are:
X_2 = Running speed (km/hr).
X_3 = Design speed (km/hr)
X_4 = Traffic density (pc/km)
X_5 = Percentage of trucks.
X_6 = Road class.
X_7 = Number of lanes.
X_8 = Street width in meters.
X_9 = Stopping sight distance SSD, in meters.
Based on the selected dependent and independent variables, and using equation the general regression equation for the dependent variable Yi will be as shown

$$Yi=B_0+B_1X_1+B_2X_2+B_3X_3+B_4X_4+B_5X_5+B_6X_6+B_7X_7+B_8X_8+B_9X_9$$

Regression Analysis for Dependent Variable Y_1 (Number of Crashes)

Model Summary									
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.876a	0.767	0.737	1.69177	0.767	26.278	4	32	0.000
a. Predictors: (Constant), X_8, X_2, X_1, X_5									

ANOVA [b]						
Model		Sum of Squares	d.f	Mean Square	F	Sig.
1	Regression	300.845	4	75.211	26.278	0.000[a]
	Residual	91.587	32	2.862		
	Total	392.432	36			
a. Predictors: (Constant), X_8, X_2, X_1, X_5						
b. Dependent Variable: Y_1						

F-Test for Regression Equation

$$Y_1=B_0+B_1X_1+B_2X_2+ B_5X_5+ B_8X_8$$

H_0: $B_0=B_1=B_2=B_5=B_8=0$ at $\alpha = 0.05$
H_1: $B_0 \neq B_1 \neq B_2 \neq B_5 \neq B_8 \neq 0$

Calculated F-Test value = 26.278
At α = 0.05 and degree of freedom (df_1= 4, df_2=32), Table F-Test value = 2.668
Tabulated F-Test value =2.668 is less than calculated F-Test value for the same df1 and df2, this means that, the first hypothesis is rejected (H_0: reject), which means that $B_0 \neq B_1 \neq B_2 \neq B_5 \neq B_8 \neq 0$. So the actual Bi values are as shown in table below:

Coefficients								
Model		Un-standardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	Constant	-3.323	1.959		-1.696	0.100	-7.314	0.669
	X_1	$1..05*10^{-4}$	0.000	0.382	4.007	0.000	0.000	0.000
	X_2	0.052	0.019	0.270	2.652	0.012	0.012	0.091
	X_5	0.338	0.120	0.342	2.817	0.008	0.094	0.583
	X_8	0.285	0.209	0.156	1.361	0.183	-0.142	0.711

Multiple linear regressions between total number of crashes on street sections (Y_1) and the selected independent variables show that the most influenced independent variables are average daily traffic volume (X_1), the section running speed (X_2), percentage of trucks moving for the section (X_5) and width of the pavement street section (X_8). Figure (6) shows the effect of the average daily traffic volume on the total number of crashes .

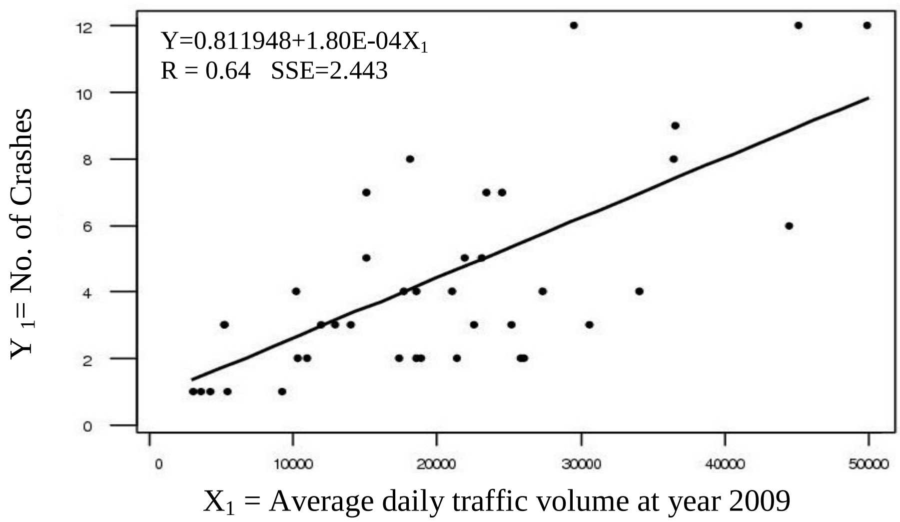

Figure 6 Relation Between Total Number of Crashes and ADT at Street Sections

The relationship between running speed X_2 and total number of crashes Y_1 is shown in Figure (7). The regression analysis shows that, the truck percentage of the total average daily traffic is

very effective on the total number of crashes occurred during the study period, even though the movements of trucks are limited in the most of the city streets, but it shows the highest correlation between total number of crashes as shown in Figure (8).
The effects of pavement width of the street section to the total number of crashes are shown in Figure (9) with (S = 2.447 R^2 = 42.8% R^2_{adj} = 41.3%)

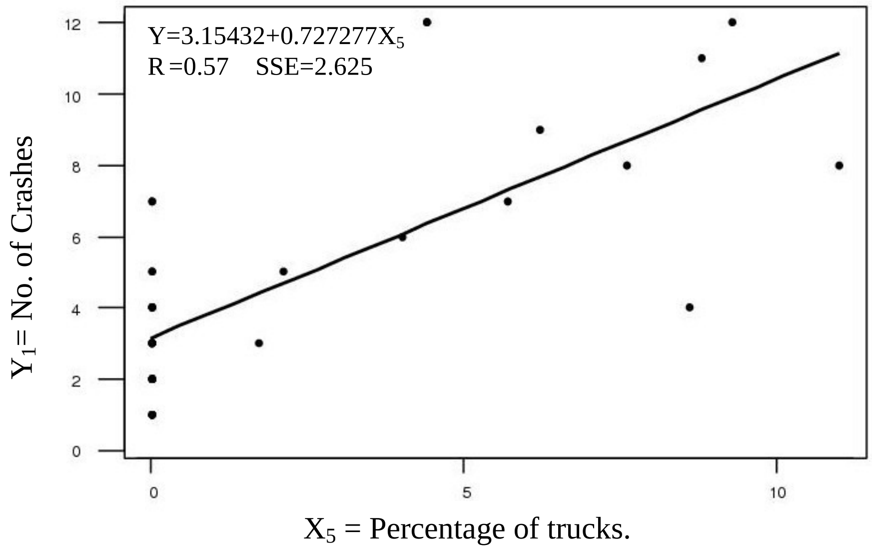

Figure 7 Relation Between Total Number of Crashes and Truck Percentage at Street Sections

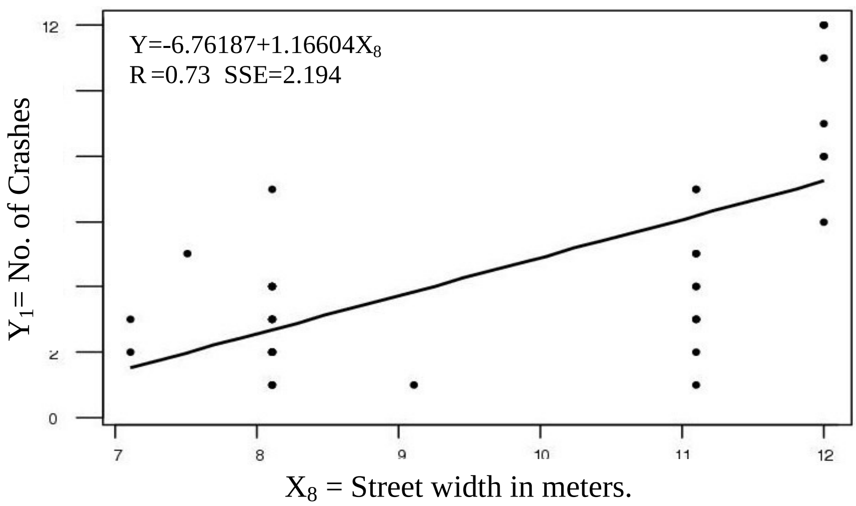

Figure 8 Relation Between Total Number of Crashes and Pavement Width of Street Sections

Other regression models for the selected independent variable Y_1 which affect the total number of crashes are as shown below, with correlation coefficient R^2_{adj} =0.74 and Standard error of estimation equals 1.69, that shows that there were other independent variables not taken into consideration like (environmental conditions, driver behavior, type of vehicles related to crashes … etc).

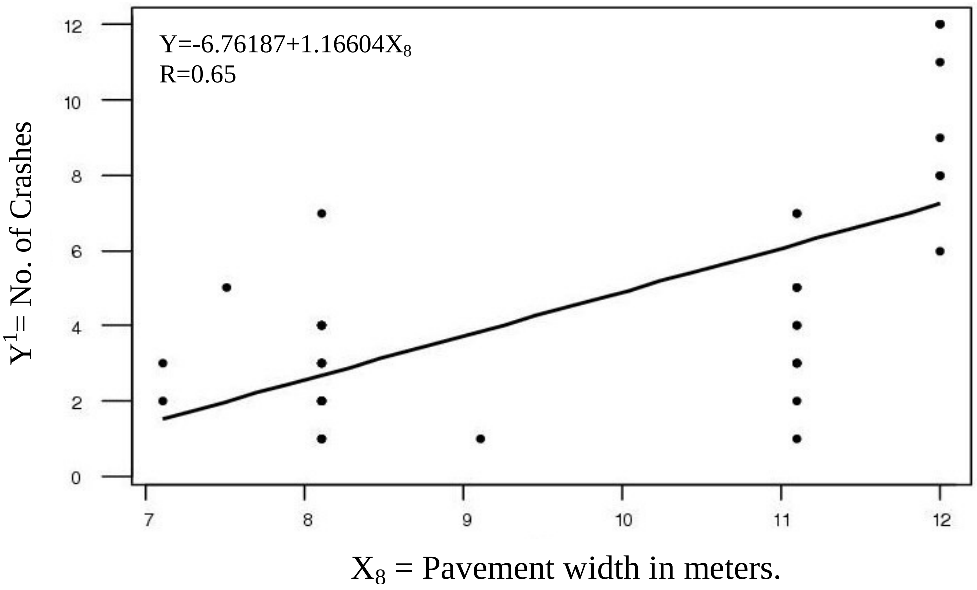

Figure 9 Relation Between Total Number of Crashes and Pavement Width of Street Sections

Total Number of Crashes	$Y_1 = -3.46 + 0.000105\ X_1 + 0.0518\ X_2 + 0.338\ X_5 + 0.298\ X_8$
Adjusted R Square	$R^2_{adj} = 0.74$
Std. Error of the Estimate	SEE = 1.69

Regression Analysis for Dependent Variable Y_2

Crash per kilometer	$Y_2 = -0.89 + 0.000093\ X_1 + 0.0035\ X_2 + 0.033\ X_5 + 0.394\ X_6 + 0.393\ X_7$
Adjusted R Square	$R^2_{adj} = 0.76$
Std. Error of the Estimate	SEE = 0.597

Regression Analysis for Dependent Variable Y_3

Crash per million vehicles-kilometers	$Y_3 = -0.276 - 0.000326\ X_2 - 0.00271\ X_4 - 0.0224\ X_5 + 0.239\ X_7$
Adjusted R Square	$R^2_{adj} = 0.58$
Std. Error of the Estimate	SEE = 0.033

INTERSECTIONS PREDICATION MODEL

Following dependent variables were used for disaggregate models for intersections:
Y_1 = Total number of crashes.
Y_2 = Crash per million vehicles,
Independent variables related to the study area for intersections are:
X_1 = Average daily traffic volume at year 2009 (pcu/day).
X_2 = Percentage of trucks.
X_3 = Intersection Area (m).

Regression Analysis for Dependent Variable Y_1

Total number of crashes	$Y = 7.833 - 0.0000161\ X_1 + 4.96\ X_2$
Adjusted R Square	$R^2_{adj} = 0.96$
Std. Error of the Estimate	SEE = 2.0884

Regression Analysis for Dependent Variable Y_2

Crash per million vehicles	$Y = 0.328 - 0.000003\ X_1 + 0.0906\ X_2 + 0.000134 X_3$
Adjusted R Square	$R^2_{adj} = 0.88$
Std. Error of the Estimate	SEE = 0.004

PREDICATION OF LOCAL ZONES MODEL

The following dependent variable was used for local zones disaggregate models:
Y = Total number of crashes
Independent variables related to local zones were:
X_1 = Zone area in (m^2).
X_2 = Zone population.
X_3 = Moran weight function set one ($W_{ij} = \frac{1}{(d_{ij})^2}$)
X_4 = Moran weight function set two ($W_{ij} = \frac{1}{(d_{ij})}$)
X_5 = Moran weight function set three ($W_{ij} = \frac{1}{\sqrt{d_{ij}}}$)

Total number of crashes	$Y = 8.22 + 0.000731\ X_2 + 11.86\ X_5$
Adjusted R Square	$R^2_{adj} = 0.908$
Std. Error of the Estimate	SEE = 4.335

CONCLUSIONS

Crash data analysis to obtain the most effective results, in this study, was rigorous and time consuming. Out of the analysis demonstrated and the results obtained the following conclusions are drawn out:

1- In Duhok City 529 crashes took place during (2006-2009), 332 of them on street sections, 180 at intersections and 17 crashes were on un-identified locations.
2- Crash reports collected and investigated were poor and need more reliable crash form to be used for better crash statistics reporting.
3- Divided streets show more crashes than undivided, mainly due to that most streets are divided type, with high traffic volume and drivers exceed the limited speed.
4- Two-way two lanes streets inside the Duhok City show more frequency and severe crashes than the other road classes. That is because high proportions of the city streets are 2-laned streets.
5- Four-lane class roads show more fatal crashes than 2 or 3-laned type, because drivers speed is very high with high traffic flow rate. Better speed control is needed on such roads in the future.
6- Annual increase in percentage of crashes on the Duhok City road network continues. More powerful Integrated Road Safety Programs with more coordination among the related service offices in the city really needed to overcome this dilemma. Traffic management is required for road improvement too.
7- Sarok and Peshmargah intersections are found as the most two dangerous nodes within Duhok City road network.
8- Using GIS analysis on dangerous zones, Raza zone proves to be the most dangerous area for crashes to cluster with 58 crashes, whereas Sarhildan zone has lower degree of danger with 35 crashes only during three years.
9- Manual GIS computation of Moran's I spatial index reflects that the single and half weight functions are giving about the same results. Square distance weight function may give more comprehensive results about hazard degree within spatial zones.
10- Moran's I index is not considering crash severity as a criteria to weight hazard, so the results are found incompatible with conventional safety hazard evaluation methods which depend on severity.
11- Crash frequency is affected positively by the average daily traffic volume, section running speed, percentage of trucks, and width of pavement. Percentage of trucks is the most effective variable in generating crashes on sections with ($R^2_{adj} = 0.737$) only.

12- Crash rate per kilometer is widely affected by ADT, running speed, truck percentage on both road classes and lane numbers. With (R^2_{adj} = 0.746).
13- Crash rates per million vehicle-kilometers are moderately affected with the independent variables in the model obtained for step-wise regression. Running speed, traffic density, percentage of trucks and number of lanes are found to be the most effective variables in the derived model with (R^2_{adj} = 0.584).

RECOMMENDATIONS

Out of the results and conclusions written down above, the following recommendations seem to be vital in the future studies on road network safety in Duhok City such as:

1- Models can be updated and retrieved to validate their confidence in predicting future safety performance of the different parts of the network.
2- Road Safety Programs proposed by decision makers for Duhok City have to be updated and checked using the results of this study.
3- Regression-to-mean effect is needed on this study in the future. This effect is a certain statistical analysis which affects the migration of crashes from location to location after real geometric or traffic improvement needed.
4- More improvements are needed in the GIS center in Duhok City in order to update Moran's I index automatically using AirDas software developed by ESRI.
5- A new future Master Plan is needed for Duhok City road network considering the safety situation evaluation as it was not considered in the last Master Plan proposed by the German Company Voessing at 2009.

REFERENCES

1. Ilmar Pihlak, "***Road safety differences between two neighboring countries- Estonia and Finland***", Estonia, Proceedings of the conference, Traffic safety on two continents, Malmo, Sweden September 1999, Part 3.
2. Kamalasudhan, A., Mitra, S., Bo Huang, and Chin, H.C., "***An analysis of expressway crashes in Singapore using GIS***", Department of Civil Engineering, National University of Singapore, 2002.
3. Institute of Transportation Engineers, "***Identifying Hazardous Locations***." Highway Safety Improvement Program, 1977.
4. Elke M., Tom B. and Geert W., "***Improving Moran's I to Identify Hot Spots in Traffic Safety***", Transportation Research Institute, Belgium, 2008.
5. John C.L, Lonnie E.H., Jerome W.H., and Dean R.C., "***Methods for Evaluating Highway Safety Improvements***." National Cooperative Research Program Report., Washington. D.C, 1975.