Road Traffic Crashes and Road Configuration; A Space Syntax Application

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Abstract

Transport provides a range of benefits to society in terms of mobility, access and economic growth. However, there are negative impacts of transport, not least in terms of environmental degradation, damage to property, traffic accidents and loss of life. In Sri Lanka, Road Traffic Crashes *(*RTCs*) are responsible for a substantial fraction of morbidity and mortality and are responsible for more years of life loss than most of human diseases. Taking its cues, this paper focuses on* RTCs*, the reduction of which is an important aim of suitable transport policy worldwide. In this study, the authors have tried to delineate road specific factors that collectively represent the principal cause of three (people, vehicle and road) out of* RTCs *and which is less concerned in Sri Lankan transport researchers. In that context, the primary objective of this paper is to identify a series of relationships between* RTCs *and road pattern focusing road configuration by using space syntax.*

Road Network Configuration is examined based on four different road configuration parameters that is (i.) Choice, (ii.) Connectivity, (iii.) Integration and (iv.) Line length in two levels (Local & Global) using Space Syntax. The RTCs *data along the A1 road (from Peliyagoda to Kegalle, Sri Lanka) was collected from the Traffic division of Sri Lanka Police and entered in to Geographic Information System (GIS) database. Then statistical analysis have been conducted to identify the relationship between* RTCs *and* Road Configuration *Parameters. The results show notable/noticeable relationship between* RTCs *and Local level variance of Integration values ($r = 0.874$, $p < .01$); Connectivity ($r = 0.768$, $p < .01$) and Global Level Choice ($r = 0.759$, $p < .01$). Further regression analysis indicated that combination those three variables have more than 90% of impact for* RTCs.

With that notable relationship between RTCs *and road configuration, this study highlights the need for preventive efforts that incorporate road pattern specific strategies in road network planning and design to create sustainable built environment rather than focusing only on human factors.*

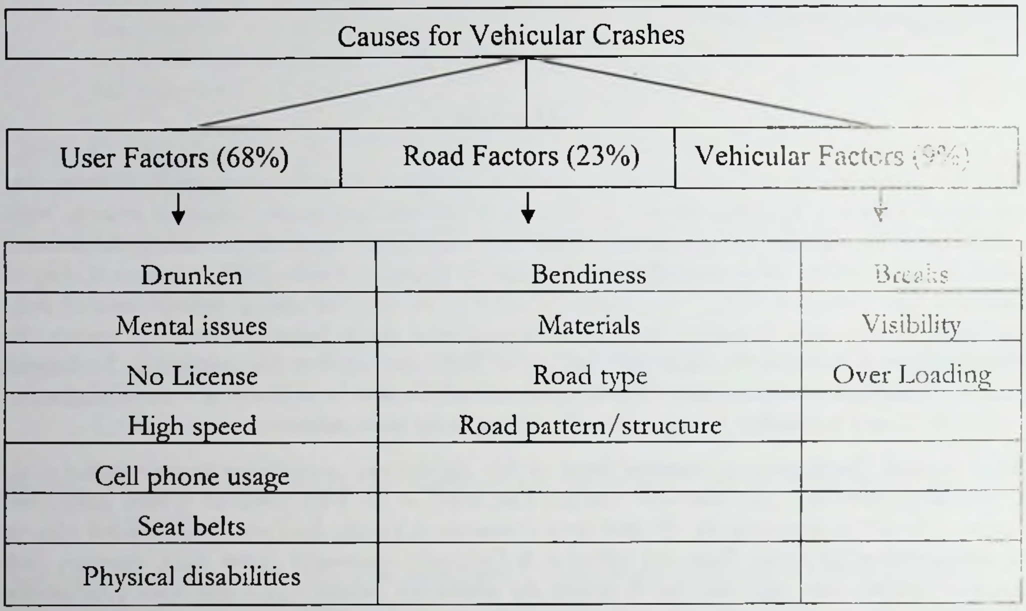
Keywords: *Road Traffic Crashes, Road Configuration and Space Syntax*

1. Introduction

"Unsustainable increase in private *vehicle ownership* in urban cities has created several problems in increased traffic congestion, road accidents and air pollution in the city centers" (Draft National Transport Policy, 2008 ,Sri Lanka). In Sri Lanka, about 33,721 crashes were reported in year 2010. Out of those crashes 2,225 caused loss of lives. The highest number of crashes reported in Nugegoda, Kelaniya and Gampaha Police Divisions (respectively 3149, 3112, and 1570). 40,887 crashes were reported in year 2011 out of those accidents 2,471 caused loss of lives. The highest number of crashes reported in Nugegoda, Kelaniya and Gampaha Police Divisions (respectively 3709, 3515, and 2038). (Police Headquarters, Colombo, 2011).

Recent researchers have investigated that land use, population, employment, road length, land-use mix, area deprivation (i.e. poverty) and alcohol consumption as key factors of road casualties (or accidents) and Chao Wang et al (2009), Hadayeghi et al. (2006), Milton and Aljanahi et al. (1999) and Mannering (1998) emphasized that road geometry or configuration of the road as key factors of road crashes. It indicates that a not only socio economic characteristics of the drive but also Road Network Configuration is one of the important factors for road crashes.

The number of road crashes and fatalities has increased over the years. Major reasons for these are poor conditions of infrastructure, traffic congestion in the urban areas, undisciplined behaviors of road users including drivers, riders, passengers and pedestrians in Sri Lanka (Hewage, P, 2000). Furthermore, following factors were identified and published in news paper articles from 2004 to 2011 as the causes for vehicular crashes.



Causes for Vehicular Crashes

User Factors (68%)	Road Factors (23%)	Vehicular Factors (9%)
Drunken	Bendiness	Breaks
Mental issues	Materials	Visibility
No License	Road type	Over Loading
High speed	Road pattern/structure	
Cell phone usage		
Seat belts		
Physical disabilities		

Figure 1 Courses for Vehicular crashes, Source : Based on News paper Articles from 2004-2011

Out of those causes, 68% was mentioned as user factors like drunk, mental issues, no license, high speed, cell phone usage, no seat belts, physical disabilities and 23% mentioned as road factors like bendiness, materials use in roads, road type and road patterns. Furthermore, breaks, visibility and overloading are recorded as vehicular factors (9%).

Although most researchers (professionals) have identified user factors (68%) as the major causes for vehicular crashes, it emphasizes that lower consideration in road factors and there are limited studies related to road network configuration and vehicular crashes in Sri Lanka. Therefore, there is a need to see whether there is relationship between road network configuration and vehicular crashes in the context of Sri Lanka and if so, to what extent? How can it be measured in road networks? How can it be useful in planning and decision making process in Sri Lankan context? In such a situation, this study focused on the factors that affect on vehicular crashes which have been considered less in Sri Lankan context. Thus, this study attempts to cater the need by carrying out the research on finding correlation between road configuration and vehicular crashes.

2. Literature review

2.1 Road traffic crashes

" Traffic collision is as an unforeseen event , also known as a traffic accident, motor vehicle collision, motor vehicle accident, car accident, automobile accident, Road Traffic Collision or car crash, occurs when a vehicle collides with another vehicle, pedestrian, animal, road debris, or other stationary obstruction, such as a tree or utility pole." *(L.G.Norman*-1962*)*

2.2 Factors affecting to the Vehicle crashes

Chao Wang et al (2009), Hadayeghi et al. (2003), Milton and Aljanahi et al. (1998) and Mannering (1998) emphasized that road geometry or configuration of the road as the key factors of road accidents. It indicates that a not only socio economic characteristics of the drive but also road network configuration is one of the important factors for road accidents."Speed is one of the basic risk factors in traffic" (Wegman & Aarts, 2006). The combination of horizontal curves or "bendiness" of a length of road contributes to traffic crash occurrence. This gives rise to the notion of "curviness" or "bendiness", which is traditionally known as the cumulative variation in horizontal direction along a length of road (McLean 1989).

The human factor appears in the literature as being the prevalent contributing factor of road traffic crashes .This includes both driving behavior (e.g., speeding, drinking and driving, traffic law violations) and impaired skills (inattention, fatigue, physical disabilities, impaired sensory perception, and so on).*(Hermann Nabi, Silla M. Consoli, Jean-Francxois Chastang, Mireille Chiron, Sylviane Lafont, and Emmanuel Lagarde, 2005)* Furthermore F.D Hobbes classified the different factors affecting the road crashes. Those factors affect with different scales and different scopes .Out of those factors, the road factors are the major causes for occurrence of road accidents. *(*Hobbes F.D, 1974*)*. Therefore the patterns of roads andphysical characteristics of roads may have direct relationships with these road crashes causing factors.

2.3 Road Patterns

Streets connect the private with the public domain and also link different parts of a neighborhood. These linkages support social interaction and exchange—both vital functions. Street design contributes significantly to the quality and character of a community since appropriately designed streets create safe, quiet and healthy environments. Current thinking on street pattern design appears to be divided between concern for the efficiencies of infrastructure and traffic flows. The different patterns of street networks may affect the physical and social functions of the city. The traditional grid patterns that predate the automobile have required major adaptations such as one-way streets and traffic lights in order to achieve a good automobile traffic flow. (Street Patterns, source Marshall , 2005)

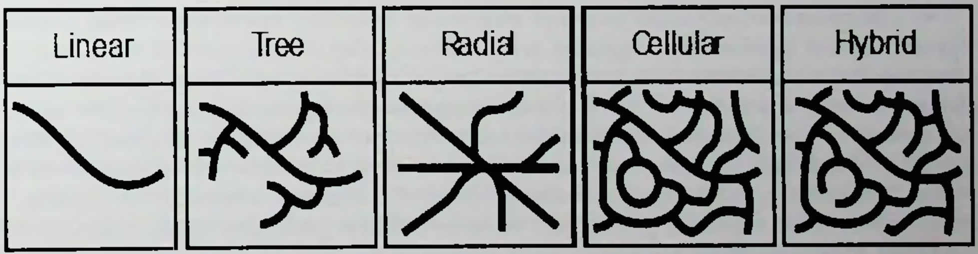


Figure 2 Road network patterns, Source F. Heinzle , K.-H. Anders, M. Sester, 2005

There are four main important patterns. Such as strokes – as a linear configuration, grids – as a cellular configuration, stars – as a radial configuration and ring roads – as a cellular configuration. The Composition, Configuration and Constitution are the major concerning attributes for the road design (Heinzle , Anders, Sester, 2005)

2.4 Different types of Configuration Measures

There are different types of configuration measures which are explained by different experts.

- ***Connectivity (complexity):*** Connectivity refers to the density of connections in path or road network and the directness of links. A well-connected road or path network has many short links, numerous intersections, and minimal dead-ends. As connectivity increases, travel distances decrease and route options increase, allowing more direct travel between destinations, creating a more accessible and resilient system. A Connectivity An index can be used to quantify how well a roadway network connects destinations.

$$\mathrm{ctrl_i} = \sum_{j=1}^{k} \frac{1}{Cj}$$

where, k = number of direct connections ,
C_j = connect value of the directly linked line '*j*' *(Hillier, 1984)*

- ***Mean Depth:*** Distances always mean topographical distance and refer to it as "depth or D". Depth is measured in steps. The depth between two lines that intersect is 1. In every other case it is the maximum number of life that must be costed to get one line to the other, plus 1.The sum of the deaths of a line to all the other lines of the axial map is called the Total Depth or D_T of that line. The D_T Value tends to get very large and is not easy to work with. Therefore, the analysis works with Mean Depth or MD of lines.

$$\mathbf{MDi = 1/(n-1)\sum_{j=1}^{n-1} dij, i \neq j}$$

M distance of the i-th axis from all the other n – 1. (Hillier, 1984)

- ***Bendiness (*Bend density, BD)*:*** This gives rise to the notion of "curviness" or "bendiness", which is traditionally known as the cumulative variation in horizontal direction along a length of road (McLean 1989). **Bend density** is defined as the number bends per kilometer of a road. This does not include the bends at intersections, i.e. includes only vertices which are not also nodes in its analysis. Bend density is calculated by using bellow equation: (Megan Fowler,2007)

$BD = (N_v\text{-}N_n) \;/\; (a+b+c+d)$ where: Nv = number of vertices within the study region;

Nn = number of nodes within the study region; and
a,b,c,d = road link lengths.

- ***Integration:*** Integration measures how many turns one has to make from a street segment to reach all other street segments in the network, using shortest paths. If the amount of turns required for reaching all segments in the graph is analyzes, then the analysis is said to measure integration at radius 'n'. The first intersecting segment requires only one turn, the second two turns and so on. The street segments that require the least amount of turns to reach all other streets are called 'most integrate' and are usually represented with hotter colors, such as red or yellow. Theoretically, the integration measure shows the cognitive complexity of reaching a street, and is often argued to 'predict' the vehicular accident probability of the street. *(J.A.F Teklenburg, H.J.P Timmermans, 1993)*

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$$0 \leq ND_i := \frac{2(MD_i - 1)}{k-2} \leq 1.$$

Where,MD_i is given by the total depth divided by $k-1$, k is the total number of nodes in the graph

Local Integration and **Global Integration** are two Space syntax parameters; indicate the integration of the line with the rest of the lines in the graph. It can be measured by Relative Asymmetry (RA). Relative Asymmetry is the ratio between the actual depths of the system from a particular line to the theoretical depth of the same.

- ***Straightness*:** Straightness is defined as the same direction throughout its length, having no curvature or angularity. Straightness, originates from the idea that the efficiency in communication between two nodes i and j is equal to the inverse of the shortest path length δi,j . The straightness centrality of node i is defined as:

$$C_i^S = \frac{\sum_{\substack{j\in V \\ j\neq i}} \frac{\delta_{i,j}^{Eucl}}{\delta_{i,j}}}{n-1}$$

CSi = Straightness centrality of node i
&ij = Cumulative no of straight link between nodes i and j
LijEucl = the Euclidean distance between nodes i and j, N = all nodes in the network

The straightness values express the level of straightness of the streets and the high and very low levels of straightness are causes for vehicular accidents.

2.5 Axial lines and Road-centre lines in global and local context

Axial analysis is one of the fundamentals of space syntax. Hillier has proposed that it picks up qualities of configurational relationships between spaces which are not illuminated by other representations. However, critics have questioned the absolute necessity of axial lines to space syntax, as well as the exact definition of axial lines. An often asked question is: why there is not another representation? In particular, why there are not road-centre lines, which are easily available in many countries to use within geographical information systems .The major difference between road-centre line networks and axial networks is that road-centre lines are broken across junctions, and therefore graph measures of the corresponding road-centre networks tend to vary with physical distance rather than the changes of direction as measured within axial networks. As a solution it is has been proposed that we abandon both changes of direction and physical distance as graph measures: instead we should use the angular change between segments.

There are strong theoretical and cognitive arguments for this new approach (*Alasdair Turner, 2005*). However, the axial networks make accurate measures for the pedestrian movement patterns, yet the vehicular movement measures make some errors because the vehicle movements patterns are related to the center line in both directions and the axial lines always start from one side of the road and end up again in the side of the road(consider only one direction). The road center line measures make accurate analysis for the vehicular movement of both directions. Therefore in order to analyze accidents, we may have to consider the above both methods because the accident risk means both vehicular crashes and pedestrian crashes risk.

Global and local road network analysis have been done to measure the road network configuration. The high lengthy road segments analyze in global analysis and its make expected accurate results for the analysis like prediction of the future land uses, land values using configuration values which came from the global road segment analysis. In the case of accidents, the analysis must consider the local context. These studies clearly define how earlier studies measured these factors and the methods to find the relationship of these factors and crashes probability. Further, it also provides the limitations which should be considered in these studies.

3. Study Area

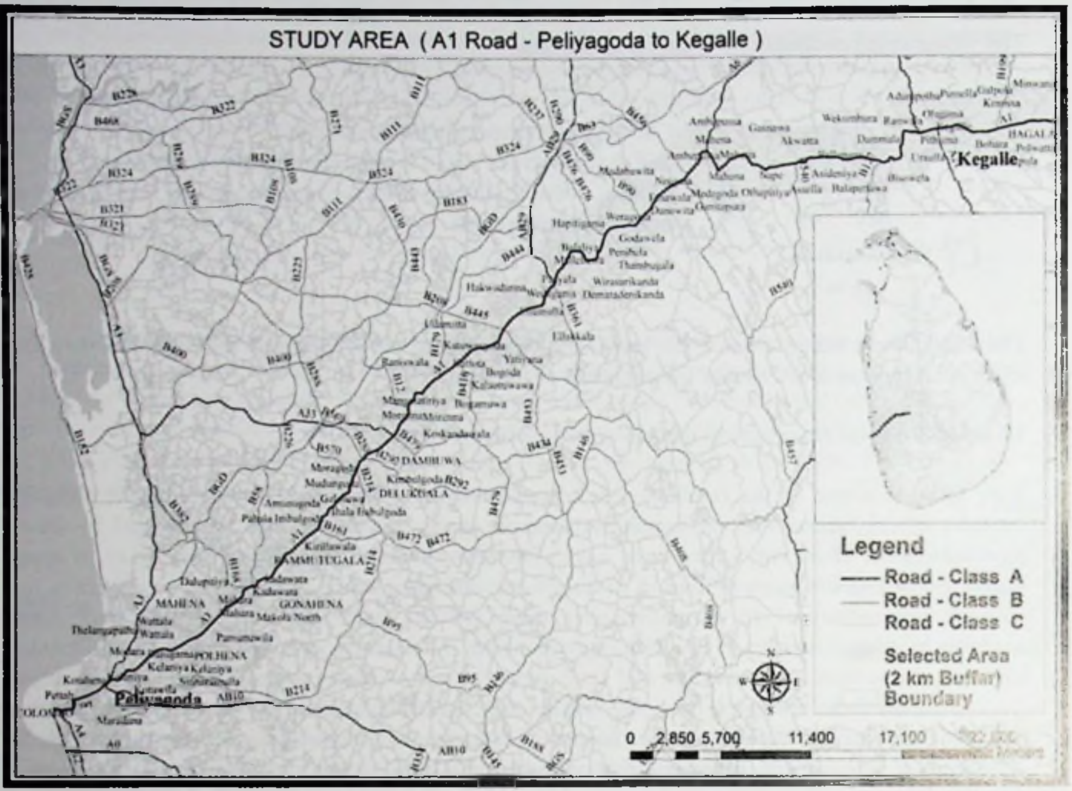


Figure 3 study area ,Colombo –Kandy road from peliyagoda to Kegalle

	2010	2011
Division	Accidents	Accidents
Nugegoda	3141	3709
Kelaniya	3112	3515
Gampaha	1570	2038
Kurunagala	1158	1530
Panadura	774	1119
Kegalle	1179	953
Negombo	945	1078

Table 1 Accident data, Source Police Headquarters Sri Lanka

Case study conducted at Colombo-Kandy A1 road which is the road where highest accidents were recorded. The highest number of accidents has occurred in the following police divisions in last two years; Nugegoda, Gampaha and Kelaniya *(Accident data from police Headquarters Sri Lanka)*. Furthermore, Gampaha and Kelaniya Police Divisions are directly related to Colombo-Kandy A1 road which displays the highest crashes records. Therefore, Kandy-Colombo Road was selected as the most suitable road for this study.

4. Methodology

The research methodology employed for the study included five-steps (Figure-3). A special feature of the methodology is that it attempted to develop simple and affordable methodological framework to measure the relationship between traffic crashes and road network configurations.

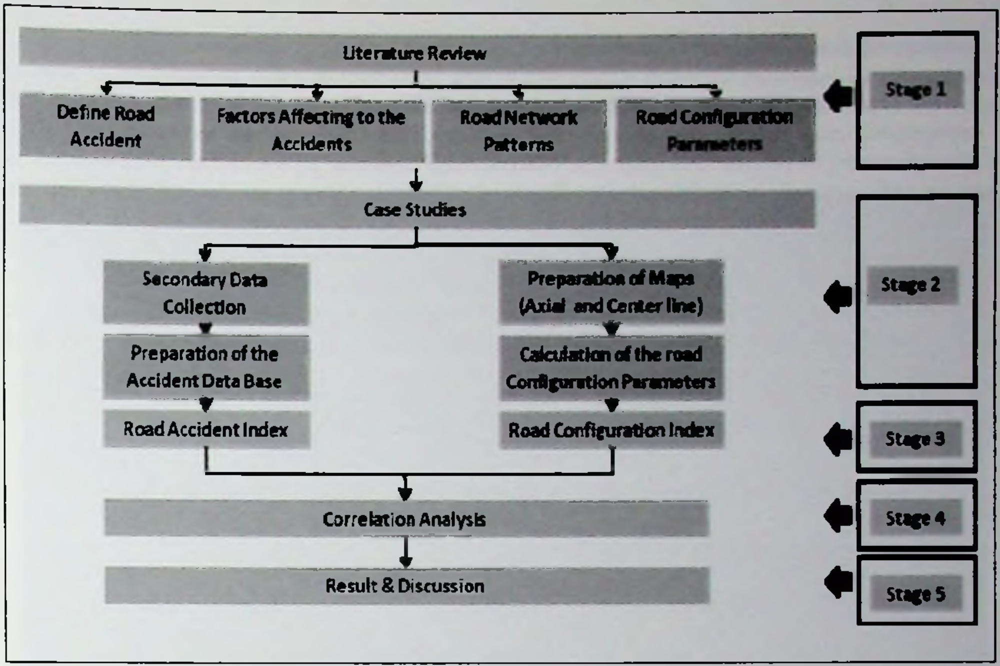


Figure 4: The research methodology

Step 1: Literature Review of the relationship between road network configuration and vehicular accident

A literature review was conducted on vehicular accidents, factors affect in accidents, different road patterns, concept of road network configuration, configuration parameters.

Step 2: Selection of the case study , Data collection and data process

In this step, the road network was selected as the study area and accident data and other relevant details were gathered. Then the data was processed by using GIS and Depth map software's (preparation of the accident map and axial map).

Step 3: Preparation of the Accident Index and Configuration Index

Two types of indexes were generated in this step to measure the relationship between accidents and road configuration. The recorded accident data was used to calculate the accident index and the configuration values calculated using Depth map software.

Step 4: Correlation Analysis

Relationship analysis between two indexes was carried out at two stages. First, correlation analysis, and second stage was multiple regression analysis.

Step 5: results and discussions

This step brought the results and further recommendations were listed.

According to the above methodology the crashes recorded maps along the Colombo-Kandy Road from Peliyagoda to Kegalle were collected from Police Divisions (seven divisions & year 2011) after the literature review. Those maps include recorded accidents as fatal accidents, minor injuries and property damages. The data collected by secondary sources was entered and prepared in ArcGIS. First, locations of crashes were digitized as points in ArcGIS. Then crashes data were added to the respective shape-files as attributes. Attributes of points are FID, Name of the location, No of fatal accidents (High), injury (Medium), property damage (Low) and total accidents.

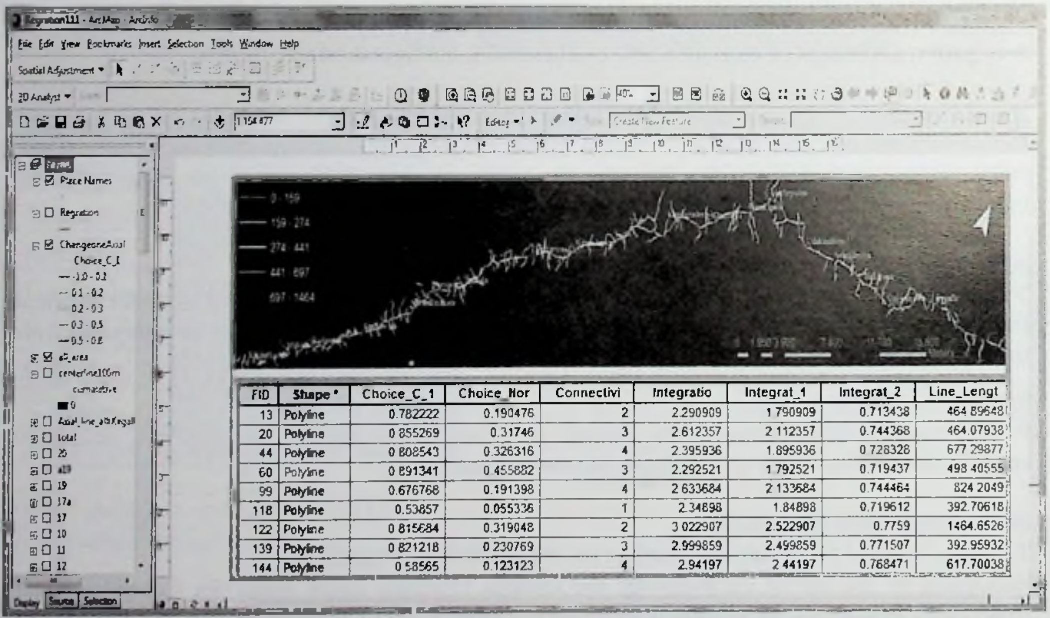
Calculation of Road Configuration Parameters

First, a base map was prepared indicating the motorable road network. A digital format 1:50000 topographic map (survey department-1984) and updated road network using satellite image (Google-earth) to prepare this map. Use "Depth map" software to convert the road network in to an axial network using "Depth map" software. Further separate road configuration values were calculated based on the axial map prepared in the above stage using Depth Map. Connectivity (Complexity), Mean Depth (length), Integration (Visibility), Straightness and Choice parameters which are based on the applicability and the scope of the study were employed in calculating road configuration of road segments. Calculations are based on two scales, local scale (n=3, compare with 3 adjacent road segments) and global scale (n=n, compare with all road segments).

For this analysis, main three configuration parameters were considered:

- Integration (visibility level of the road segment)
- Connectivity (Complexity of the road segment)
- Choice (Vehicular flow)

These configuration values were calculated using Depth map and values calculated respective/ relevant to the particular axial line. After the calculation the output file was converted and opened in ArcGIS. The attributes of axial lines are FID, Shape, Choice, Choice_Nor (Normal), Connectivity (Complexity), Integration (Visibility).



FID	Shape *	Choice_C_1	Choice_Nor	Connectivi	Integratio	Integrat_1	Integrat_2	Line_Lengt
13	Polyline	0.782222	0.190476	2	2.290909	1.790909	0.713438	464.89648
20	Polyline	0.855269	0.31746	3	2.612357	2.112357	0.744368	464.07938
44	Polyline	0.808543	0.326316	4	2.395936	1.895936	0.728328	677.29877
60	Polyline	0.891341	0.455882	3	2.292521	1.792521	0.719437	498.40555
99	Polyline	0.676768	0.191398	4	2.633684	2.133684	0.744464	824.2049
118	Polyline	0.53857	0.055336	1	2.34898	1.84898	0.719612	392.70618
122	Polyline	0.815684	0.319048	2	3.022907	2.522907	0.7759	1464.6526
139	Polyline	0.821218	0.230769	3	2.999859	2.499859	0.771507	392.95932
144	Polyline	0.58565	0.123123	4	2.94197	2.44197	0.768471	617.70038

Figure 5 Over lay the Accident map and axial map with Configuration values using GIS

The parameters calculated using the Depth Map Software which was explained in the previous chapter. Configuration index is comprised with configuration values of axial lines based on local level Choice, Connectivity, Integration as indicated in the maps. Each map follows a color scale based on Configuration values.

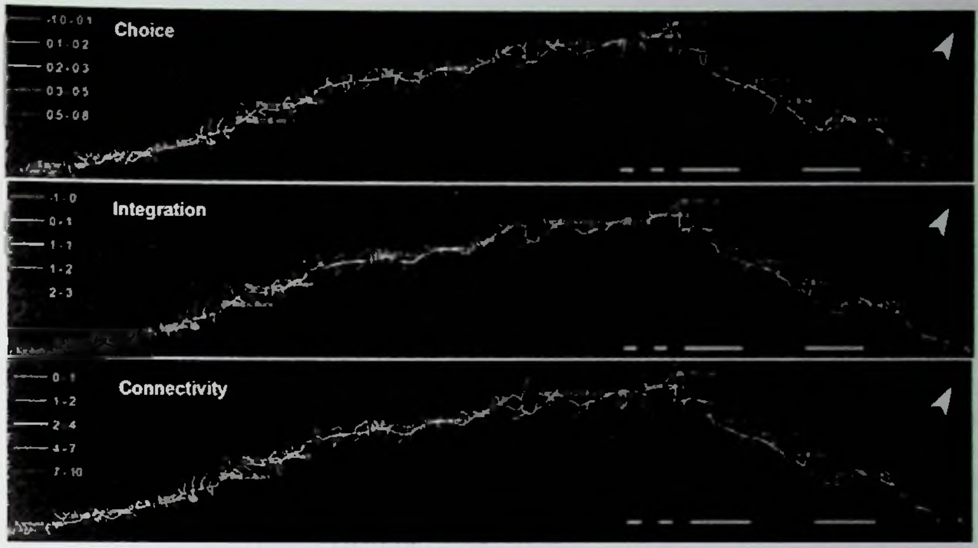


Figure 6 Variations of the Configuration values.

The parameters variance calculated using Excel and following map display the values of Choice Variance, Connectivity Variance, Integration Variance, Line length Variance with the colour variance.

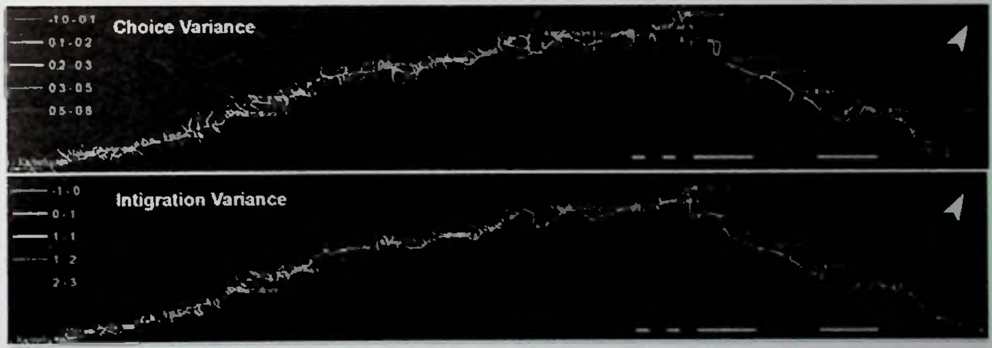


Figure 7 Variations of the Configuration values.

By using Spatial Overlay tool, overlay the Crashes point layer and axial line layer to correlate crashes and parameters. Overlaid shape file contains Attributes of FID, Shape, Choice, Choice_Nor (Normal), Connectivity(complexity), Integration(visibility), fatal accidents (High), injury (Medium), property damage (Low) and Total Crashes. Furthermore Crashes Probability Index was prepared as follows. Probability Index displays only the probability of crashes occurrence (Ex: Locations having at least one crash got 1).

Relationship analysis between Crashes Index and the Configuration Parameters

Correlation Analysis and Multiple Regression Analysis were used as analysis methods to measure the correlation between the Crashes Index and the Configuration Parameters. The analysis was carried out in two stages. At first stage correlation analysis was carried out to find out the strength of a relationship between crashes index of road segments and each configuration parameter in local and global scales. Then multiple regression analysis was carried out to find out the nature of a relationship between above two indexes as the second stage.

5. Results and Findings

Many researchers have categorized road crashes under several categories. Fatal, Injury, property damage are used as a three main categories of crashes in this study. There are 1,230 incidents recorded according to the crashes data profile of Colombo-Kandy Road in 2011. Out of those incidents further categorized 25% fatal crashes, injury 35% and property damages 40%. The highest number of fatal crashes was recorded in Galigamuwa and it was recorded 14 fatal crashes. The highest injury crashes were recorded in Ranwala, Mahara, Galoluwa, respectively 12, 12 and 10. Although the highest number of property damages occur in Thorana Junction, Kelaniya and Kadawata. There are about 24 crashes recorded. In addition to that there are above 45 total crashes recorded in Galigamuwa,Kadawatha and Morenna area which were mentioned in the previous chapter.

Relationship analysis between Configuration Parameter and Crashes Index

Relationship analysis between two indexes was carried out at two stages. First, correlation analysis was carried out to find out the strength of a relationship between Crashes Index of road segments and each Configuration Parameter. This analysis is one of the important qualitative analysis/analytical methods used in many of the recent studies. For this stage the configuration parameters were ranked based on significance of the coefficient of correlation. In the second stage, Multiple Regression Analysis was carried out to find out the nature of a relationship between above two indexes. It allowed estimating the dependent variable using more than one independent variable and increasing the accuracy of the estimation.

Correlation Analysis between Crashes Index and Configuration Parameters of Road Network

Crashes index (total crashes)

Parameter	Pearson Correlation	Sig. (1-tailed)	N	Rank
L Integration	-.874**	.000	1233	[illegible]
Connectivity	.768**	.000	1233	2
G Choice	.759**	.000	1233	2
G Integration	-.611**	.000	1233	2
L Choice	.302**	.000	1233	4

Table 2 Correlation between configuration values and crashes index (total crashes)
**Correlation is significant at the 0.01 level (1-tailed)

L Integration Parameter and Crashes Index of road segments show a highly significant coefficient of correlation when comparing to other parameters. For Local Integration Parameter: r= .874, p < .01.Further the G Choice, Connectivity and G Integration reveal a moderate significant coefficient of correlation with Crashes Index. For G Integration Parameter: r= -.611, p < .01. L Choice Parameter reveals a lowest significant coefficient of correlation. All parameters make proportionate relationships but in particular case of Integration Parameter correlates with the

Crashes Index making inversely proportionate relationship. It indicates that Configuration Parameters have 'Linear Relationship' with Crashes Index (Total crashes).

Crashes index (fatal crashes)

Parameter	Pearson Correlation	Sig. (1-tailed)	N	Rank
L Integration	-.722**	.000	1233	2
Connectivity	.603**	.000	1233	2
G Choice	.564**	.000	1233	3
G Integration	-.477**	.000	1233	3
L Choice	.212**	.000	1233	

**Correlation is significant at the 0.01 level (1-tailed)

Table 3 Correlation between configuration values and crashes index (fatal crashes)

L Integration parameter, Connectivity parameter and crashes index of road segments shows a highly significant coefficient of correlation in comparison to other parameters. L Integration Parameter shows the highest. For L Integration Parameter: $r= .722$, $p < .01$.Further the L Choice and G Integration reveal a lower significant coefficient of correlation with Crashes Index. For L Choice: $r= .212$, $p < .01$ and for the G Integration parameter: $r= .477$, $p < .01$. All parameters make proportionate relationship except Integration Parameter and it indicates that Configuration Parameters have 'Linear relationship' with Crashes Index.

Parameter	Rank (Accidents)	
	Total	Fatal
L Integration	1	2
Connectivity	2	2
G Choice	2	3
G Integration	2	3
L Choice	4	4

Table 4 Summary of the correlation values

As a conclusion all five parameters show the reasonable correlations. Only the L Choice Parameter shows the lower ranks. Other four parameters display high ranks indicating the high correlations with Crashes Indexes. In particular the L Integration, Connectivity Choice makes the highest correlation.

Multiple Regression Analysis

Forward linear regression is performed in this step. In forward entry method, variables in the block are added to the equation one at a time. At each step, the variable not in the equation with the smallest probability of F is entered if the value is smaller than probability of F-to-enter (The default value is 0.05). The response variable is the crashes Index (Total Crashes (CIT) and Fatal crashes (CIF)). The predictor variables are G Choice, Connectivity, G Integration, L Choice, L Integration.

Crashes index (total crashes)

For the first step Regression Analysis was done with the G Choice, Connectivity, G Integration, L Choice, L Integration and Crashes Index (total crashes). The Correlation results indicated that configuration values have liner relationship with Crashes Indexes. Model summary results (table) indicate that L Integration and Connectivity parameters made significant values for R-Sq Change.

L Choice and G Integration show the moderate level of R-Sq Change. After the 4 th run of forward regression is that R, R Square and Adjusted R Square values were saturated. Model four obtained more than 0.001 level of Sig. F Change and beta value of G Integration which is insignificant in comparison to other predictor variable. (Table 4.5) summarizes the linear regression model with confidence interval at 95% level, of forward regression. Three predictor variables: L Integration, Connectivity, G Choice, G Integration, together explains over 97% of the variance in *CIF*. Individually, however, *L Integration* explains nearly 61% of *CIF* variance and *Connectivity* explains only about 27% of the variance, and *G Choice* explains only about 10% of the variance, *G Integration* explains an even smaller portion (1%). Considering the above relationships, the model can be specified as follows. Therefore, Model four can be considered as the appropriate model to explain the relationship between Crashes Index (Total Crashes) and above parameters. Therefore, the model can be illustrated as follows.

$$\mathbf{CIT = -23.905 - 0.245\ L\ Integration + 2.252 Connectivity}$$
$$\mathbf{+\ 0.992 G\ Choice - 0.073\ G\ Integration}$$

Model Summary									
					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.944^a	.892	.892	.48412	.892	10868.519	1	1316	.000
2	.982^b	.965	.965	.27472	.073	2771.867	1	1315	.000
3	.986^c	.972	.972	.24585	.007	327.959	1	1314	.000
4	.986^d	.972	.972	.24499	.000	10.245	1	1313	.001

a. Predictors: (Constant), L Integration
b. Predictors: (Constant), L Integration, Connectivity
c. Predictors: (Constant), L Integration, Connectivity, G Choice
d. Predictors: (Constant), L Integration, Connectivity, G Choice , G Integration

Table 5 Regression model summary for (Total) Crashes index

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	2.820	.014		201.580	.000					
	LIntegration	-.409	.004	.944	104.252	.000	.944	.944	.944	1.000	1.000
2	(Constant)	-16.369	.365		-44.902	.000					
	LIntegration	-.268	.003	.618	76.751	.000	.944	.904	.395	.407	2.454
	Connectivity	3.019	.057	.424	52.649	.000	.900	.824	.271	.407	2.454
3	(Constant)	-23.604	.516		-45.762	.000					
	LIntegration	-.246	.003	.567	73.335	.000	.944	.896	.337	.354	2.827
	Connectivity	2.296	.065	.322	35.309	.000	.900	.698	.162	.254	3.940
	G Choice	1.001	.055	.167	18.110	.000	.878	.447	.083	.250	4.004
4	(Constant)	-23.905	.523		-45.749	.000					
	LIntegration	-.245	.003	.534	73.479	.000	.944	.897	.337	.354	2.829
	Connectivity	2.252	.066	.313	34.016	.000	.900	.684	.156	.243	4.114
	G Choice	.992	.055	.165	17.993	.000	.878	.445	.082	.249	4.014
	G Integration	-.073	.023	.015	3.201	.001	.457	.088	.015	.774	1.292

a. Dependent Variable: AIT

Table 6 Coefficients – Regression model for (Total) Crashes index

Crashes index (fatal crashes)

For the second step Regression Analysis were done with G Choice, Connectivity, G Integration, L Choice, L Integration and Crashes Index (fatal Crashes). The Correlation results indicated that values have linear relationship Crashes index. Model summary results (Table4.7) indicate that L Integration and Connectivity parameters made significant values for R-Sq Change. G Choice shows the moderate level of R-Sq Change. Up to the 4 rd run of forward regression is that R, R Square and Adjusted R Square values were saturated. (Table 4.7) summarizes the Linear Regression model with confidence interval at 95% level, of forward regression. Three predictor variables: L Integration, Connectivity, G Choice, G Integration, together explains over 98% of the variance in *CIF*. Individually, however, *L Integration* explains nearly 53% of *CIF* variance and *Connectivity* explains only about 31% of the variance. and *G Choice* explains only about 16% of the variance , *G Integration* explains an even smaller portion (10%). Considering the above relationships, the model can be specified as follows.

$$\mathbf{CIF = -24.005 - 1.245\ L\ Integration + 0.252 Connectivity + 0.992 G\ Choice - 0.003\ G\ Integration}$$

Model Summary									
					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.948ᵃ	.899	.899	.48412	[redacted]	10868.519	1	1316	.000
2	.986ᵇ	.972	.972	.27472	[redacted]	2771.867	1	1315	.000
3	.990ᶜ	.980	.980	.24585	.008	327.959	1	1314	.000
4	.990ᵈ	.980	.980	.24499	.000	10.245	1	1313	.001

a. Predictors: (Constant), L Integration
b. Predictors: (Constant), L Integration, Connectivity
c. Predictors: (Constant), L Integration, Connectivity, G Choice
d. Predictors: (Constant), L Integration. Connectivity, G Choice . G Integration

Table 7 Regression model summary for (fatal) Crashes index

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	2.820	.014		201.580	.000					
	LIntegration	-.409	.004	.944	104.252	.000	.944	.944	.944	1.000	1.000
2	(Constant)	-16.369	.365		-44.902	.000					
	LIntegration	-.268	.003	.618	76.751	.000	.944	.904	.395	.407	2.454
	Connectivity	3.019	.057	.424	52.649	.000	.900	.824	.271	.407	2.454
3	(Constant)	-23.604	.516		-45.762	.000					
	LIntegration	-.246	.003	.567	73.335	.000	.944	.896	.337	.354	2.827
	Connectivity	2.296	.065	.322	35.309	.000	.900	.698	.162	.254	3.940
	G Choice	1.001	.055	.167	18.110	.000	.878	.447	.083	.250	4.004
4	(Constant)	-24.05	.523		-45.749	.000					
	LIntegration	-1.245	.003	.610	73.479	.000	.944	.897	.337	.354	2.829
	Connectivity	0.252	.066	.270	34.016	.000	.900	.684	.156	.243	4.114
	G Choice	.992	.055	.101	17.993	.000	.878	.445	.082	.249	4.014
	G Integration	-.003	.023	.019	3.201	.001	.457	.088	.015	.774	1.292

a. Dependent Variable: AIF

Table 8 Coefficients – Regression model for (fatal) Crashes index

Two linear regression models were created, tested, and analyzed in this stage with confidence interval at 95% level. Following table illustrates the summary of results.

Steps	Model	R square
Crashes Index(Total)	**CIT = -23.905 – 0.245 L Integration + 2.252Connectivity + 0.992G Choice - 0.073 G Integration**	0.972
Crashes Index(Fatal)	**CIT = -24.005 – 1.245 L Integration + 0.252Connectivity + 0.992G Choice - 0.003 G Integration**	0.980

Table 9 Summary of regression model results

Results indicate that all two models obtained high R square values. Configuration values having significant correlation with Crashes Index (total) G Choice, Connectivity, L Integration. Further, in analysis with Crashes Index (fatal) also displays significant correlation specially G Choice, Connectivity, L Integration. Accordingly, those models are capable enough to explain the relationship in between Road Network Configuration and Vehicular Crashes.

6. Conclusion

This research is placed in a milieu where there are very limited research attempts to figure out the road configuration related reasons for vehicular crashes studies in Sri Lanka and the current practices are hampered by methodological, technical, financial and information availability issues. This research reveals the relationship between roads network configuration and vehicular crashes.

Road Configuration values which are calculated based on three different configuration parameters shows a significant correlation between transit demand values. Thus, argument (configuration measures are capable to explain the level of vulnerability of vehicular crashes in road segments) put forward in study is well recognized and valid. Yet, the level of coefficient of correlation is different by configuration parameters and considered scale. Local integration values which capture the idea that a visibility level change in road segment obtained the strongest correlation (> 0.8 at 1% Significance level) with both indexes(CIT and CIF)and scored the highest rank of correlation results among three configuration parameters. Connectivity (which captures the level of complexity of the road segment by considering the number of connections) and Global Choice (which captures degree of vehicular flow) configuration parameters also obtained strong positive correlations with both Crashes Indexes. Though the correlation coefficient is highly significant (R>0.7 at 1% Significance level).Global Integration values recorded a moderate level correlation (< 0.6 at 1% Significance level) with accident indexes but Local Choice revealed a lower correlation (> 0.4 at 1% Significance level l). Regression models developed in the study which having more than 80% accuracy, are applicable in measuring the level of vulnerability for Vehicular Crashes in road segments based on Configuration Parameters. To conclude, measures of Road Configuration reveal strong relationship with the Road Crashes. Thus the level of variation in Road Configuration values is a major cause for road Crashes. Sudden Visibility Change (Local Integration) is the key factor for accidents. And Complexity (Connectivity) is revealed as a secondary impact factor. Further any location having these two factors with higher choice for drivers (vehicular flow) will further increase the Crashes. The models developed in the study are capable to identify the locations which are vulnerable for Road Crashes in existing networks and the adjustments in Configuration Parameters may reduce the vulnerability. Road Configuration Assessment is a sophisticated tool for urban and transport planning process: mostly applicable in Sri Lankan context. Therefore, it can be used as a planning tool to identify the level of vulnerability for road crashes in existing roads and to identify the impact from proposed land use plans with new road networks.

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