DEVELOPMENT OF A RATING SYSTEM TO RANK HAZARDOUS LOCATIONS ON NATIONAL HIGHWAYS

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Declaration of the Candidate and Supervisor

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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ABSTRACT

In highway safety plan, identification of hazardous locations on highways is one of the most important factors. In this study, the geometry of road is considered to identify the hazardous locations with the concern of design standards used in Sri Lanka.

Availability of accident data is a significant requirement in identifying hazardous location of roads. However, for roads with poor accident data sets or no accident records, a method is needed to find and rank road segments with respect to road geometry, independent of the accident records. In this study, ***Geometric Design Standards of Roads*** published by Road Development Authority on 1998 was considered as the design standards of National Highway in Sri Lanka. According to the design standards; hazardous locations or road stretches were initially identified. Then major parameters of road geometry such as horizontal alignment, vertical profile and road side activities and combination of these were considered as main influence elements. Thereafter essential factors of the each element were identified. After that the relative contribution of the elements to the safety of critical location or road sections was determined by using the Analytical Hierarchy Process (AHP) with a system of scores which were suggested by an expert panel subject to a consistency test of the expert responses. AHP determines the weight of the elements on which the horizontal radius was identified as the most critical parameter of the geometry element, which creates accident prone hazardous location followed by long straight section or series of curves with small straight section with added effect of site condition.

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LIST OF ABBREVIATIONS

AHP	- Analytic Hierarchy Process
DEA	- Data Envelopment Analysis
PCU	- Passenger Car Unit
F	- Flat
R	- Rolling
M	- Mountainous
R_{min}	- Minimum Radius
e_{max}	- Maximum Super – elevation
f_{max}	- Maximum values of Coefficient of Side Friction
RDA	- Road Development Authority
λmax	- Maximum Eigenvalue
CR	- Consistence Ratio
RI	- Random consistency Index
CI	- Consistency Index
MFNSV	- Multi Function Network Survey Vehicle
accels	- Accelerometers
gyros	- Gyroscopes
ADT	- Average Daily Traffic
APSs	- Accident-Prone Sections
LHS	- Left Hand Side
RHS	- Right Hand Side

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1 INTRODUCTION

1.1 General

Accidents cause the loss of life and money which affects country's economy. The extremely high costs associated with highway crashes that initiate highway safety improvements would be an important objective of transportation engineering. General safety measures such as speed limit regulation, increased law enforcement, and education, or more localized measures relating to local traffic control and geometry improvements can enhance highway safety. The more localized methods are used in individual road facilities such as intersections and along roadway segments.

The identification of accident-prone spots represents a list of spots being prioritized for further engineering studies which can distinguish accident patterns, potential resolution, and effective factors (Transportation Research Board, 2002). Moreover, in these processes cost-effective projects are often chosen to obtain the best results from limited resources (Montella, A, 2010; Transportation Research Board, 2005)

Every year, Government provides budgeted funds for safety improvements. Portions of these safety funds are used to improve specific roadway facilities, in order to reduce roadway accidents. However, the budgeted funds are constrained and limited. Therefore, the locations truly requiring improvement must be identified correctly to minimize future accidents and to receive the highest benefits.

The aim of this research is the representation of a method to identify and prioritize hazardous locations/ sections based upon efficiency concept to reduce accidents with regard to traffic, geometric and environmental circumstances of road. In addition to that interactions of accidents as well as their casual factors also can be considered in this study. A case study was done on a selected national road of Colombo – Kandy Road [A001], section from Nittambuwa to Nelundeniya, to demonstrate the approach. It showed that the frequency and severity of accidents would not only be considered as the main factors for identification of hazardous locations. There is a need of decision-making tool for identifying accident-prone sections and their prioritizations. Also, it could be used to prioritize intersections, roundabouts or the entire road stretch based on safety.

1.2 Problems and Research Objective

1.2.1 Problems Identified

Since accidents are on the increase significantly, the accident prone locations and / or section of road stretches need to be identified without allowing accidents to happen. This will help to take remedial action to reduce accidents and /or to reduce the severity of accident.

The question that prompted to do this research is “What are the most hazardous locations on road especially National Highways in Sri Lanka?

1.2.2 Objective of the Study

The objectives of this research are to;

- Find a systematic method to identify hazardous locations along National Highways.
    - This will help to identify accident prone locations and / or road stretch and indicate the specific factors which cause road crashes.
    - It will help to evaluate which factors contributes for accident and make remedial action to improve that in good manner.
- Develop the rating system to rank hazardous locations by using Analytic Hierarchy Process (AHP) with the help of expertise in road safety.

1.2.3 Scope

A case study was conducted in road section from Nitambuwa to Nelundeniya on Colombo – Kandy Road [A001] for this research. The horizontal radius, vertical profile and road side activities were considered as main elements and verified with accident data. In addition, survey was made within the selected experts in the field of road safety, to identify hazardous locations and develop a rating system to rank hazardous locations by using Analytic Hierarchy Process (AHP).

2 LITERATURE REVIEW

The evaluation and enhancement of transport safety has been a concern of road authorities for many years; hence considerable research have been carried out to study safety of road users and to improve the safety performance of roads. Several researchers in transport have utilized different analysis methods to conduct road safety evaluation to enhance road safety. Human, road, environment and vehicle characteristics are the main factors influencing the safety level of road networks (Science Serving Society, 2004; Avebury Technical, 1996)

The first group of researchers considered crash outcomes as the main parameter to evaluate road safety. Statistical modeling has been used to establish a relationship between road, environmental, and traffic characteristics and the number of crashes (Lord, Washngton, & al, 2005; Haung, Chin, & al, 2009; Lovegrove, Lim, & Sayed, 2010). Crash severity investigation has also been carried out using statistical analysis (Quddus, Wang, & al, 2010; Zhu, K.Dixon, & al, 2010).

The second group of researchers approached the problem from a micro-level analysis viewpoint (Habibian, Mesbah, & Sobhani, 2011). They have examined conflicts instead of crashes since conflicts occur more often than crashes (Gettman & Head, 2003; Archer, 2005).

To find and rank hazardous road segments independent of the crash records, an auditing based methodology is proposed to determine the hazardous locations by Meeghat Habibian, Mahmoud Mesbah, & Amir Sobhani. A rural road is investigated by decomposing it first into six elements such as straight segments, horizontal and vertical curves, bridges, tunnels, merges and intersections, and side road land use, then into safety factors corresponding to each element. The relative contribution of the elements to the safety of a road segment is determined using the Analytical Hierarchy Process (AHP) via a system of weights which are suggested by an expert panel (Habibian, Mesbah, & Sobhani, 2011)

The aim of the another research of a method to identify and prioritize accident-prone sections (APSs) based upon efficiency concept to emphasize accident with regard to traffic, geometric and environmental circumstances of road which can consider the interaction of accidents as well as their casual factors. This study incorporates the segmentation procedure into Data Envelopment Analysis (DEA) technique (Sadeghi, Ayati, & Neghab, 2013)

2.1 Research Gap

The earlier researchers considered the relative contribution of the elements to the safety of a road segment without concern of geometry data of existing road network and accident data. It was determined by using the Analytical Hierarchy Process (AHP) via a system of weights which were suggested by an expert panel.

The concern of the data which was lack in previous studies has been fulfilled in this study to identify the hazardous locations along National Highway in Sri Lanka. The existing geometry data of the road were collected from Multi Function Network Survey Vehicle [MFNSV] that belongs to Planning Division of Road Development Authority and accident data obtained from Department of Police.

The availability of road geometry data and accident data were used to validate the weights that suggested by an expert panel for this study.

2.2 Design Guidance

For designing purpose; different varieties of guidance are used all over the world for designing a suitable road network that fulfill the requisite safety of road users as well as enhance the transportation facilities to the nation. In Sri Lanka the Road Development Authority is in charge of the national roads and highways. The guidance “Geometric Design Standards of Roads” issued by Road Development Authority in 1998 is used for the purpose of design criteria of national roads & highways.

2.2.1 Design Speed

A speed fixed for design and correlation of geometric features of highways, such as curvature, super-elevation and sight distance. The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, design volume and the functional classification of the highway. Table 2.1

gives the relationship of the design speed related with road classification, terrain and design volume.

Table 2.1 : Relationship of the design speed related with road classification, terrain and design volume

Type of Road	Road class	Terrain	Design Volume PCU/Day	Design Speed (kmph)	
				Rural	Urban
R5	D, E	F R M	< 300	50 40 30	40 40 30
R4	C, D	F R M	300 - 18,000	60 50 40	50 50 40
R3	A, B	F R M	18,000 - 25,000	70 60 50	60 60 50
R2	A, B	F R M	25,000 - 40,000	80 70 60	70 70 60
R1	A	F R	40,000 - 72,000	80 70	70 60
R0	A	F	72,000 - 108,000	80	70

Source: Geometric Design Standard of Roads, RDA

The forecasted traffic volume in a particular design period is one of the major factors to choose design speed of a road stretch.

2.2.2 Crossfall

Cross fall is the geometrical feature of pavement surface, the transverse percentage slope with respect to the horizontal. It is a very important safety factor. The purpose of the crossfall is to direct the surface run-off towards the drainage system. Crossfall act as a drainage gradient. In horizontal curves the crossfall is pooled into super elevation, in order to reduce dangerous lateral forces. The recommended crossfalls on straight section of roads for different surface types are given in the Table 2.2.

Table 2.2 : Recommended cross falls on straights for different surface types

Type of Surface of Carriageway	Recommended Cross fall / (%)
Portland Cement Concrete	2.0
Asphalt Pavement	2.5
Surface Seals	3.0
Unsealed Gravel	4.0

Source: Geometric Design Standard of Roads, RDA

2.2.3 Super-Elevation

The super elevation of a road is the difference in elevation between two edges of its cross section. This is considered when the road section is curved, by raising the outer edge of the curve to provide the stability for the moving vehicle through force exerted due to super-elevation. The rate of super-elevation changes with curve radius as well as speed of the vehicle.

The super-elevation adopted is chosen primarily for safety, other factors being comfort and appearance. In fixing the minimum super-elevation, the main consideration is the stability of slow moving vehicles, which can slide or track down a curve with steep super-elevation. The super-elevation applied to a road should be based on the design speed on the curve, which is taken as the speed that the 85^{th} percentile driver is likely to choose. Also the stability of highly loaded commercial vehicles and the length available to develop the necessary supper elevation should be taken into consideration, while selecting the rate of super-elevation.

2.2.4 Minimum Curve Radius

A set of values for the minimum radius (R_{min}) of horizontal curves for a given design speed could be obtained from the Equation 2.1 by adopting the maximum value of super elevation and maximum values of coefficient of side friction from Table 2.4. (Geometric Design Standards of Roads, 1998).

$$R_{\min} = \frac{V^2}{127(e_{\max} + f_{\max})} \quad \textit{Equation 2.1}$$

2.2.5 Maximum Super-Elevation

The maximum super-elevation applied to a road should be taken into consideration:

- Vehicles moving below the design speed, can track into the inner lane of the road.
- Steeper super-elevation will tend to increase the filling quantity in a flat terrain and give a poor appearance as well.
- The upper range in the speeds at which some drivers select to travel along a curve for a given radius.

The most preferred maximum super elevation values are given in the Table 2.3.

Table 2.3 : Maximum Super-Elevation Values

Terrain Type	e_{max} [%]	
	Open	Build-up
Flat	6	6
Rolling	8	6
Mountainous	10	6

Source: Geometric Design Standards of Roads, RDA, 1998

Apart from very critical locations, 4% is considered as maximum in normal practice to provide smooth and comfortable ride.

The Table 2.5 represents the tabulation form of calculated values of the minimum radii for different super-elevations.

2.2.6 Maximum Side Friction Factor

The values of the coefficient of lateral friction depend upon number of factors such as vehicle speed, type and condition of roadway surfaces and the condition of the tire. The side friction factor basically relates to the riding comfort on horizontal curves. However, the maximum design values use should allow vehicles to maintain their lateral position within a traffic lane and to change lanes as the need comes up. The Table 2.4 shows the maximum design value of coefficient of side friction for various design speeds.

Table 2.4 : Maximum Values of Coefficient of Side Friction

Design Speed / [kmph]	Maximum Design values of Coefficient of Side Friction, f_{max}	
	Bituminous Roads	Gravel Roads
30	0.210	0.14
40	0.190	0.13
50	0.170	0.12
60	0.160	0.11
70	0.150	0.10
80	0.140	0.09
90	0.130	-
100	0.128	-

Source: Geometric Design Standards of Roads, RDA, 1998

Minimum curve radii can be calculated for different super elevations and speeds, from the Equation 2.1 and by substituting values for e_{max} and f_{max} from Table 2.3 and Table 2.4 respectively. The following Table 2.5 represents the tabulation form of calculated values of minimum radii for different super-elevation.

Table 2.5 : Minimum Radii for Different Super-Elevation

Design Speed (km.p.h)	Super-elevation [%]								
	2.5	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
30	35	30	30	30	30	30	25	25	25
40	60	60	55	55	55	50	50	45	45
50	105	100	95	90	90	85	80	80	75
60	155	150	145	135	130	125	120	115	110
70	225	215	205	195	185	180	170	165	155
80	310	300	280	270	255	240	230	220	210
90	415	400	380	355	340	320	305	290	280
100	515	500	470	445	420	400	380	365	350

Source: Geometric Design Standards of Roads, RDA, 1998

2.2.7 Gradient

Gradient or slope is calculated as a ratio of “rise over run” in which rise is the vertical distance and run is the horizontal distance. In traffic engineering various road designs are rated for their ability to ascend terrain. Grades will allow a design vehicle in top gear to maintain the design speed whilst climbing or descending without breaking. Such grades are usually too steep for heavy trucks and make difficulties for low power cars to ascend in top gear.

2.2.8 General Maximum Gradient

Maximum gradient vary with the class of road, speed and topography. On high speed roads, grades close to 3% provide a very satisfactory level of service. The general maximum gradient for a design speed is the grade that majority of cars can travel without loss of speed uphill and without increase downhill. The maximum gradient based on type of terrain and road class is given in the Table 2.6 below.

Table 2.6 : Maximum Gradient Based on Type of Terrain and Road Class

Class of Road	**A**			**B**			**C**			**D**			**E**		
Terrain type	F	R	M	F	R	M	F	R	M	F	R	M	F	R	M
Maximum gradient	4	6	8	5	7	9	7	9	10	9	10	10	9	10	10

Geometric Design Standards of Roads, RDA, 1998

2.2.9 Minimum Gradient

In a flat terrain, a certain minimum gradient is necessary for efficient drainage. However in flat terrain it may be difficult to provide required minimum gradient. In that case a level gradient may be used; it is preferable to limit the length of level gradient to be as small as possible. In urban areas where pavements are kerbed, the longitudinal gradients of kerb and channel should not be flatter than 0.3%. In rural areas a minimum gradient of 0.5% should be maintained.

2.3 Method of Analysis

The Analytic Hierarchy Process (AHP) is a general theory of measurement; Thomas Saaty developed the AHP in 1971- 1975 which is pair wise comparison. A scale of absolute judgments of experts is used for comparisons, which represent how much more; one element dominates another with respect to a given attribute. The scale might be taken from actual measurements or from a fundamental scale that reflects the relative strength of the preferences and feelings (R. W. Saaty, 1987).

The methodology of AHP compares criteria or alternatives in pair wise mode with respect to the importance of each criterion. The AHP is a decision support tool which can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. The relevant data are derived by using a set of pair wise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion (Pogarcic, Francic, & Davidovic, 2008)

AHP dealt with consistency of the pair wise comparison matrix. A consistent matrix mean that, if an expert says a criterion ***x*** is equal important to another criterion ***y*** (so the comparison matrix will contain value of a_{xy} = 1= a_{yx}), and the criterion ***y*** is absolutely more important as an criterion ***w*** (a_{yw} = 9; a_{wy} = 1/9); then the criterion ***x*** should also be absolutely more important than the criterion ***w*** (a_{xw} = 9; a_{wx} = 1/9). Unfortunately, the decision maker is often not able to express consistent preferences in case of several criteria. Then, the Saaty's method measures the inconsistency of the pair wise comparison matrix and set a consistency threshold which should not be exceeded.

In ideal case the comparison matrix (*A*) is fully consistent, the rank (*A*) = 1 and $\boldsymbol{\lambda} = n$ (n = number of criteria). In this case, the following equation is valid: $A \cdot x = n \cdot x$ (where *x* is the *eigenvector* of *A*) the vector *x* represent the weights we are looking for.

In the non-consistent case (which is more common) the comparison matrix ***A*** may be considered as a perturbation of the previous consistent case. When the entries a_{ij} changes only slightly, then the eigenvalues change in a similar fashion. Moreover, the maximum eigenvalue ($\boldsymbol{\lambda}_{max}$) is closely grater to n while the remaining (possible) eigenvalues are close to zero. Thus is order to find weights we are looking for the *eigenvector* which corresponds to the maximum eigenvalue ($\boldsymbol{\lambda}_{max}$).

In order to obtain weights from calculated eigenvector the values have to be normalized by Equation 2.2 (The weights have to sum up to 1.)

$$w_j = \frac{\tilde{w}}{\sum_{i=1}^{n} \tilde{w}} \qquad \text{Equation 2.2}$$

The Consistency Index (CI) is calculated as following Equation 2.3.

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad \text{Equation 2.3}$$

Then, the Consistence Ratio (CR) is calculated as the ratio of consistency index and Random consistency Index (RI) as shown in the Equation 2.4. The RI is the random index representing the consistency of a randomly generated pair wise comparison matrix. It is derived as average random consistency index Table 2.8 calculated from a sample of 500 of randomly generated matrices based on the Preference Index – Relative Importance of criteria (Saaty & Wong, 1983) [Table 2.7].

$$CR(A) = \frac{CI(A)}{RI(n)} \qquad \text{Equation 2.4}$$

If CR(A) ≤ 0.1, the pair wise comparison matrix is considered to be consistent enough. In the case CR(A) > 0.1, the comparison matrix should be improved. The value of RI depends on the number of criteria being compared.

Table 2.7 : Preference Index - Relative Importance of criteria (Saaty & Wong, 1983)

Relative Importance	**Qualitative Scale**	**Comments**
1	Equal	
3	Moderate importance	
5	Strong importance	
7	Demonstrated importance	
9	Absolute importance	
2, 4, 6, 8	Values between the levels above	Used only when a compromise in comparisons is necessary
Reciprocal	If importance of item x to item y is ai,j then the importance of item y to item x is aj,i =1/ai,j.	

Table 2.8 : Random Index (RI) for different dimensions of RWM (Saaty & Wong, 1983)

n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

3 METHODOLOGY

By literature review, the previous researches have been overviewed to select a systematic method for developing a system for rating of hazardous locations to national roads.

Based on the literature review the following factors are identified as those contributing to accidents on roads, locations or stretch of roads where frequent accidents happen are known as hazardous locations.

Major factors that could contribute to accidents

- **Existing geometry of the road**
  - Sharp bends / curvatures on horizontal alignment
  - Steeper gradient in vertical profile
  - Improper super elevation
  - Poor surface Condition
- **Land use activities**
  - Township area
  - Intersection
  - Interchange
  - Urban area
  - Rural area
- **Visibility in day and night**
  - Inadequate stopping sight distance.
  - Passing sight distance
  - In night time street light facility
  - Commercial area
- **Level of service of the particular road**
  - Traffic compositions
  - Capacity of road
  - No of lanes and width of lanes
  - Pedestrian facilities
  - Proper channelization

- **Volumes of pedestrian and cyclist**
  - Walkway facility and condition to cater pedestrian demand
  - Safety precaution taken for pedestrian and cyclist
- **Weather Condition**
- **Road users**
- **Condition of the vehicle**

3.1 Overview

The geometry of the roads can be rectified with the help of road organizations. Thus geometric parameters such as horizontal radius, super elevation and vertical grade, road side activities and combination of these were considered in this study as main influential elements and identified the venerable factors of the each element.

The Figure 3.1 : Flow Chart; illustrates the steps of the research.

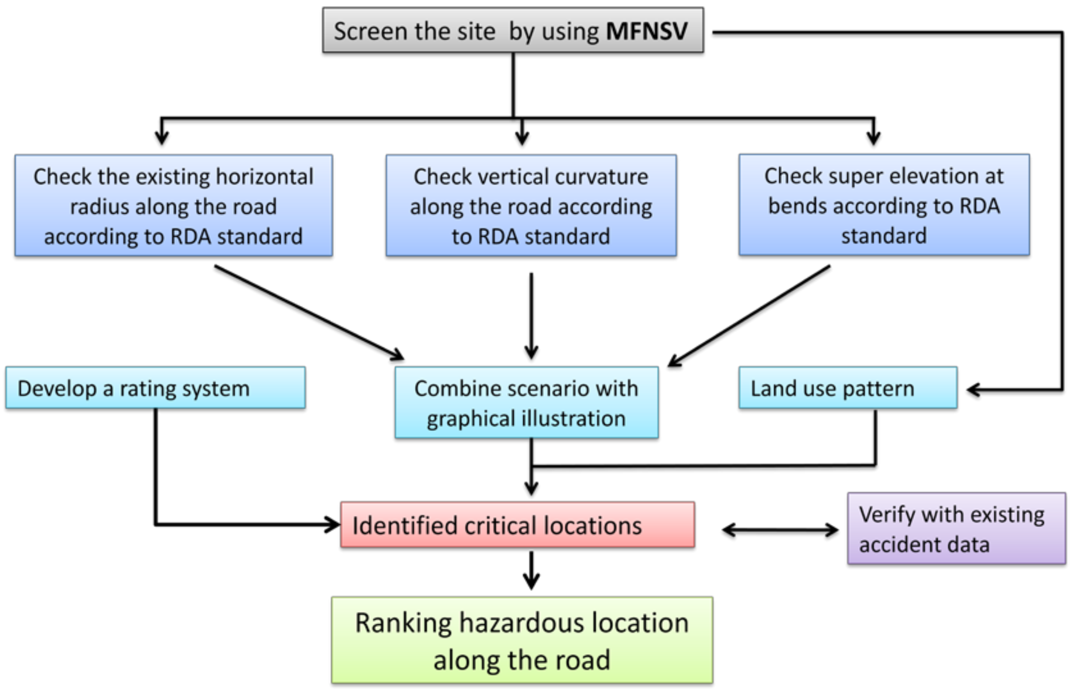


Figure 3.1 : Flow Chart

The selected road section was screened by Multi Function Network Survey Vehicle. The collected geometry data were analyzed. Initially horizontal radius along the road was checked with RDA Standards incorporate with super elevation and design speed.

The sharp curves which did not satisfy the RDA standards were identified. Then vertical profile was checked with standards. The road stretches where the standards deviate were identified.

Then found out the road stretches where combination of horizontal curve and vertical curve were in the same place. Then the list of the critical locations was cross checked with accident data as well as land use activities. Thereafter the list of hazardous locations were verified by an expert panel and analyzed using the Analytical Hierarchy Process (AHP) with a system of scores which were suggested by the expert panel. These scores were used to obtain weights of importance of each elements and factors subject to a consistency test of the expert responses.

3.2 Data Collection

Required data for study were road traffic accident data, road geometry data and land use activity data. Accident data were collected from Sri Lanka Police and geometry data and land use activities were collected from Multi Function Network Survey Vehicle [MFNSV]. Furthermore ideas were taken from experts in road safety to develop the rating method to identify hazardous locations.

3.2.1 Accident Data

Accident data were collected from Sri Lanka Police Traffic Headquarters. These data tabulated with Microsoft Access. It consists with details about accident damage and location according to their coordinate system. These accident data sheets consist with many details as shown in Appendix B that gives a clear image of accident.

3.2.2 Geometry Data

Geometry data related to the study were collected from Multi Function Network Survey vehicle [MFNSV]. All major systems of MFNSV; laser profiler, digital imaging, geometry and GPS are connected together and integrated into a single system, single software operation.

A package knows as GIPSI TRAC Geometry consist accelerometers and gyroscopes to measure road geometry. The Figure 3.2 shows the Multi Function Network Survey vehicle [MFNSV] what was used to collect geometry data and land use activities.

All measurements are independent of driver behavior, acceleration, braking and turning. The combination of accelerometers (accels) and gyroscopes (gyros) permit to remove all effects of the vehicle suspensions. From which, grade, cross slope and horizontal curvatures were collected for this study.

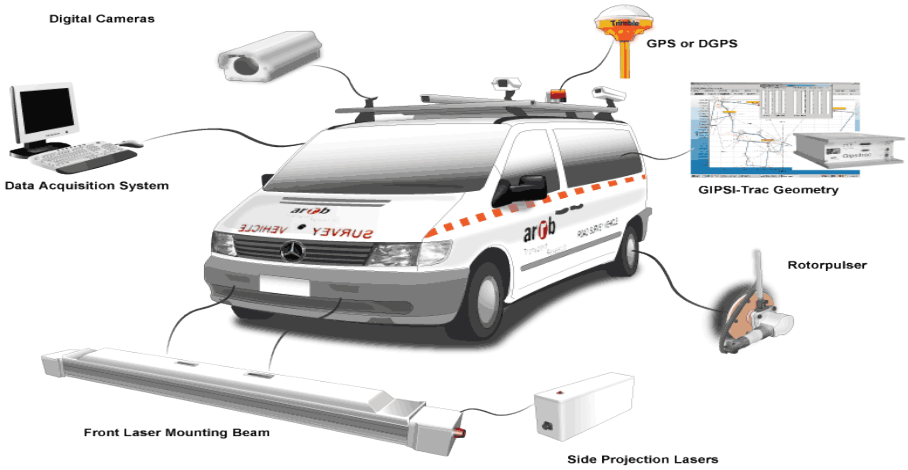


Figure 3.2 : Multi Function Network Survey vehicle

Horizontal curvature and combination of horizontal and vertical curve at one point are more critical parameters than others in road geometry. Based on the availability of the data and to reduce complexity in analysis and interpretation the critical parameter was considered as main influence factor to this study. In addition, vertical grade and cross slope, land use activity and accident data have also been taken in to account.

Table 3.1 : Sample Sheet of Geometry Data Collected from MFNSV

From	To	Grade (%)	Change of grade (%)	Cross Slope (%)	Horizontal Curvature (deg/10m)
40.225	40.235	-1.71		-0.23	0.1604
40.235	40.245	-1.4	0.31	-0.66	0.0229
40.245	40.255	-1.03	0.37	-1.12	0.0286
40.255	40.265	-0.45	0.58	-1.53	0.1031
40.265	40.275	0.41	0.86	-1.81	0.1547
40.275	40.285	1.37	0.96	-2.03	0.149
40.285	40.295	2.19	0.82	-2.22	0.1146
40.295	40.305	2.74	0.55	-2.4	0.0917
40.305	40.315	2.96	0.22	-2.48	0.0917
40.315	40.325	2.83	-0.13	-2.42	0.1031
40.325	40.335	2.59	-0.24	-2.31	0.1203
40.335	40.345	2.49	-0.1	-2.21	0.1261
40.345	40.355	2.64	0.15	-2.14	0.1203
40.355	40.365	2.94	0.3	-2.1	0.0802
40.365	40.375	3.08	0.14	-2.1	0.0286
40.375	40.385	3.01	-0.07	-2.13	-0.0172
40.385	40.395	2.9	-0.11	-2.16	-0.0401
40.395	40.405	2.8	-0.1	-2.17	-0.0573
40.405	40.415	2.61	-0.19	-2.21	-0.0745
40.415	40.425	2.31	-0.3	-2.3	-0.1031
40.425	40.435	2.04	-0.27	-2.44	-0.149
40.435	40.445	1.87	-0.17	-2.55	-0.1948
40.445	40.455	1.69	-0.18	-2.6	-0.2292

4 DATA ANALYSIS AND DISCUSSION

The data analysis was based on standards that are adopted by Road Development Authority. The standards are guided by “Geometric Design Standards of Roads” published by Road Development Authority on 1998. The geometric data of the road section from Nittambuwa to Nelundeniya on Colombo – Kandy Road [A001] was gathered by Multi Function Network Survey vehicle [MFNSV]. Analysis was done according to the geometric data collected using MFNSV and other related data obtained from Planning Division, RDA and accident data from Department of Police.

Assumptions

Geometric Design Standards of Roads **published by Road Development Authority on 1998 is suitable for Sri Lankan National road and highways.**

4.1 Standards Adopted

The following parameters are considered as per RDA standards,

4.1.1 Design Speed

The range of design volume of the road stretch is 25,000 – 40,000 PCU/Day and the design speed of National roads is 70 kmph (Gazette, 1987); 70 kmph was selected as design speed for this road stretch. (ADT in year 2013 was 25,006 PCU/Day as per the record of traffic data in Planning Division – 1, RDA). As per the manual design speed can vary from 60 km/h to 80 km/h.

4.1.2 Cross fall

Since the road pavement is asphalt surfacing, the cross fall was considered as 2.5 % to this study.

4.1.3 Minimum Radius and Super-Elevation

Since the design speed was considered at the range of 60 – 80 km/h, the Table 4.1 gives the minimum radii for different super-elevation.

Table 4.1 : Minimum Radii for Different Super-Elevation for the Speed Range of 60 km/h - 80 km/h

Design Speed (km.p.h)	Super-elevation [%]								
	2.5	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
60	155	150	145	135	130	125	120	115	110
70	225	215	205	195	185	180	170	165	155
80	310	300	280	270	255	240	230	220	210

4.1.4 General Maximum Gradient

For an “A” class road in a rolling terrain with design speed of 70 kmph, the maximum grade should be kept below 6% as shown in the Table 2.6.

4.1.5 Minimum Gradient

In urban areas where pavements are kerbed, the longitudinal gradients of kerb and channel should not be flatter than 0.3%. In rural areas a minimum gradient of 0.5% should be kept.

4.2 Graphical Illustration

The considered geometric parameters of this study were horizontal radius of the road alignment in meter (m), change of grade in percentage (%) to check vertical profile and cross fall in percentage (%) of the road surface. In addition road side activities also were considered. The accident data were used for the purpose of verification to check whether any accidents did happen.

The comparison between geometric parameters were analyzed and verified with RDA standards and accidents data.

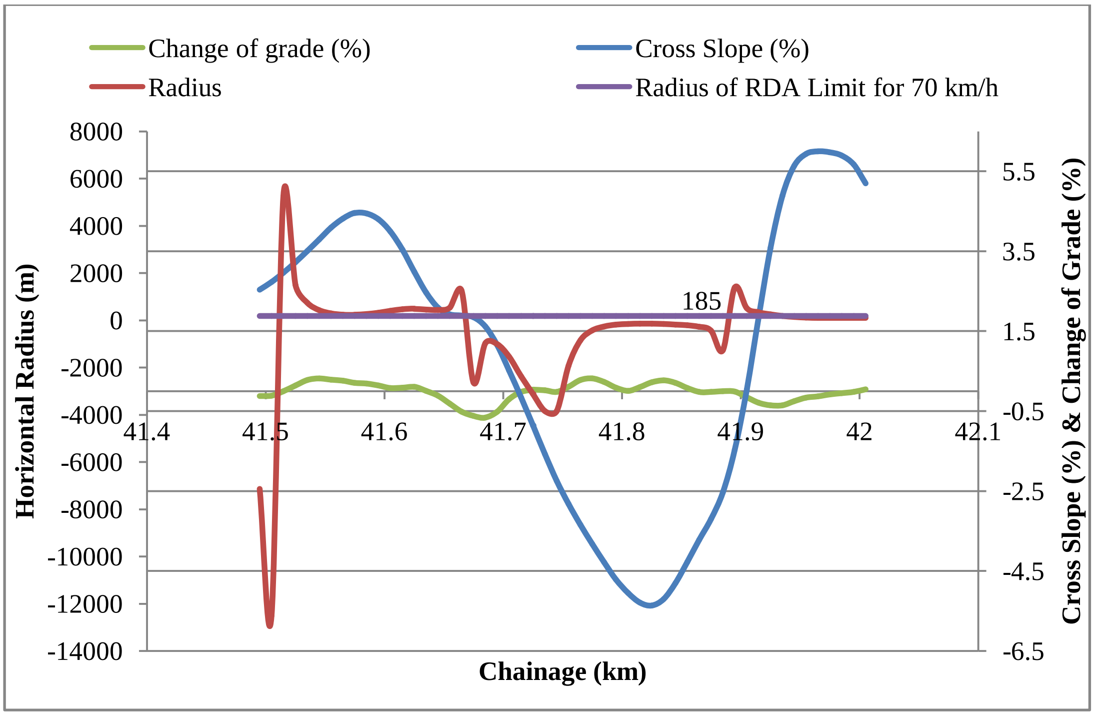


Figure 4.1 : Comparison between changes of Grade, cross slope and Horizontal Radius along the road section of 41+400 to 42+100 km

A horizontal alignment of a road is normally a series of straights and curvatures that indicating the path of the road in plan. In case of curvatures there could be left and right side bends. To differentiate these left and right sides; sign factor has been introduced. Positive (+) sign given to left hand side (LHS) bend and negative (-) sign given to right hand side (RHS) bend along the road. The negative value of radius in the Figure 4.1 and Figure 4.5 denote curve radius of right hand side bends.

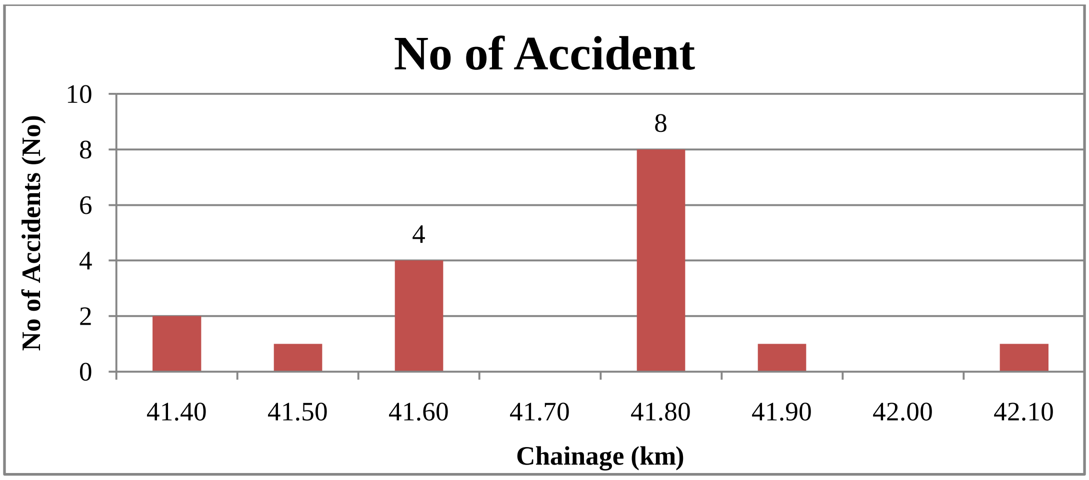


Figure 4.2 : Accidents along road section of 41+400 to 42+100 km

The Figure 4.1 illustrates how horizontal radius, change of grade and cross fall, were changing along the road stretch from 41+400 to 42+100 km. This particular section all parameters considered for this study such as horizontal radius, vertical grade and cross fall satisfied RDA standards except chainage at 41+800 km. With the concern of accident data as shown in the Figure 4.2 there were 4 and 8 accidents that happened at the locations 41+600 km and 41+800 km respectively.

Table 4.2 : Values of variables at accident happened locations at 41+600 km and 41+800 km

Chainage (km)	Horizontal Radius (m)	Grade (%)	Cross Slope (%)
41+600	400	2.42	4
41+800	138	0.87	5.29

The above Table 4.2 listed down the variables where accidents happened at the chainage of 41+600 km and 41+800 km. Figure 4.3 and Figure 4.4 given below provide clear picture of land use pattern at locations 41+600th km and 41+800th km respectively.

Figure 4.3 : Site Condition at Chainage 41+600 km

Figure 4.3 above shows that four lanes road narrow down to two lanes as well as hard shoulder of the merging area is used as parking area; due to these uncommon circumstance; there were four (4) accidents that occurred as shown in Figure 4.2.

Figure 4.4 : Site Condition at Chainage 41+800 km

Figure 4.4 shows pedestrian crossing just after the bend and it is located in front of Police Station. In addition the horizontal curve radius is less than the required minimum radius. Due to these reasons make this location considered a hazardous location. Figure 4.2 clearly indicates; 8 number of accidents occurred at this location.

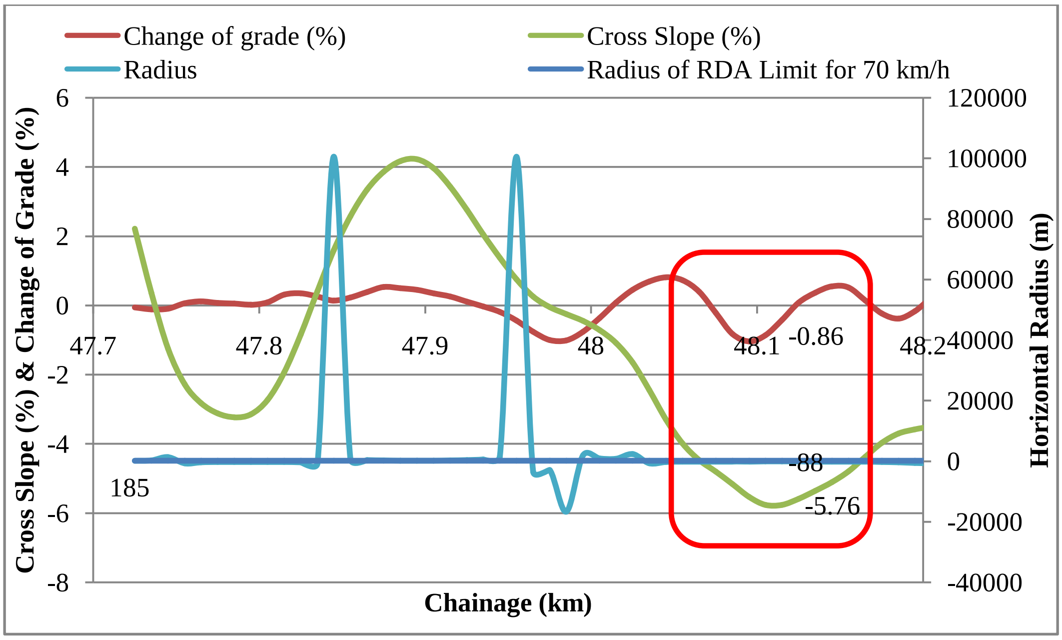


Figure 4.5 : Comparison between changes of Grade, cross slope and Horizontal Radius along the road section of 47+700 – 48+200 km

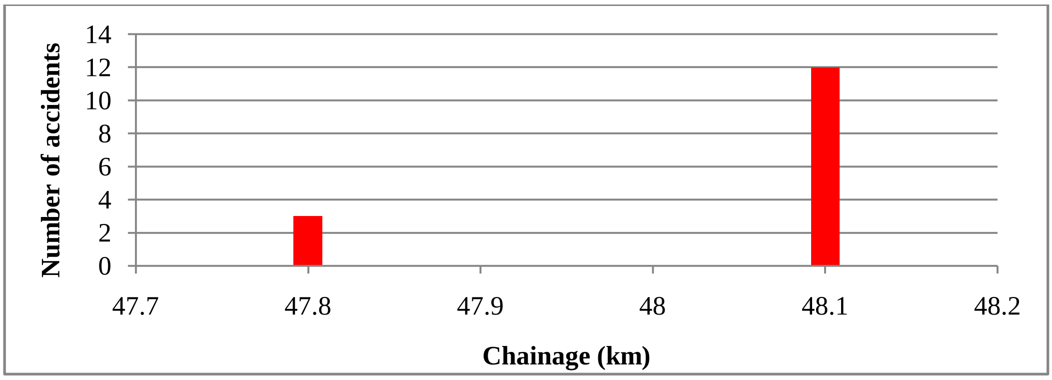


Figure 4.6 : Accidents along road section of 47+700 – 48+200 km

Table 4.3 : Values of variables at accident happened locations (47+700 – 48+200 km)

Chainage (km)	Horizontal Radius (m)	Grade (%)	Cross Slope (%)
47+800	115	-0.44	5
48+100	88	-0.83	5.76

Three (3) and twelve (12) accidents have happened at the chainages of 47+800 km and 48+100 km respectively. It is shown in the Figure 4.6. To verify the reasons why these accidents happened at this section, geometric parameters were analyzed. The Figure 4.5 illustrates comparison between changes of Grade, cross slope and Horizontal Radius along the road section of 47+700 – 48+200 km. Table 4.3 list down the geometric parameters where accidents occurred. Figure 4.7 below provides clear picture of site at 47+800th km.

Figure 4.7 : Site Condition at Chainage 47+800 km

There is a horizontal radius of 115 m radius along with 5% of super elevation which does not satisfy the RDA standard for the speed of 70 km/h. It is considered as a critical location. In addition pedestrian crossing is located very close to the bend. Due to these reasons it is considered as a hazardous location.

Figure 4.8 : Site Condition at Chainage 48+100 km

The Figure 4.8 illustrates the site condition at chainage 48+100 km. the radius of this curve is 88 m which is considered as very sharp bend with the concern of design speed 70 kmph. In addition to this vertical curve coincide with this shape horizontal curve. Combination of both horizontal and vertical curves in same road stretch courses road accidents at this location. Figure 4.6 indicates twelve (12) numbers of accidents were occurred at this particular location.

4.2.1 Calculation

The Figure 4.9 provides clear idea about this research. Five criteria were analyzes with the concern of three main influence elements of horizontal radius, vertical profile and road site activities. Each element has different factors that influence the characteristic of the element. Here, radius, super-elevation, shoulder width and warning signs & road marking were considered as factors which influence the element of horizontal radius.

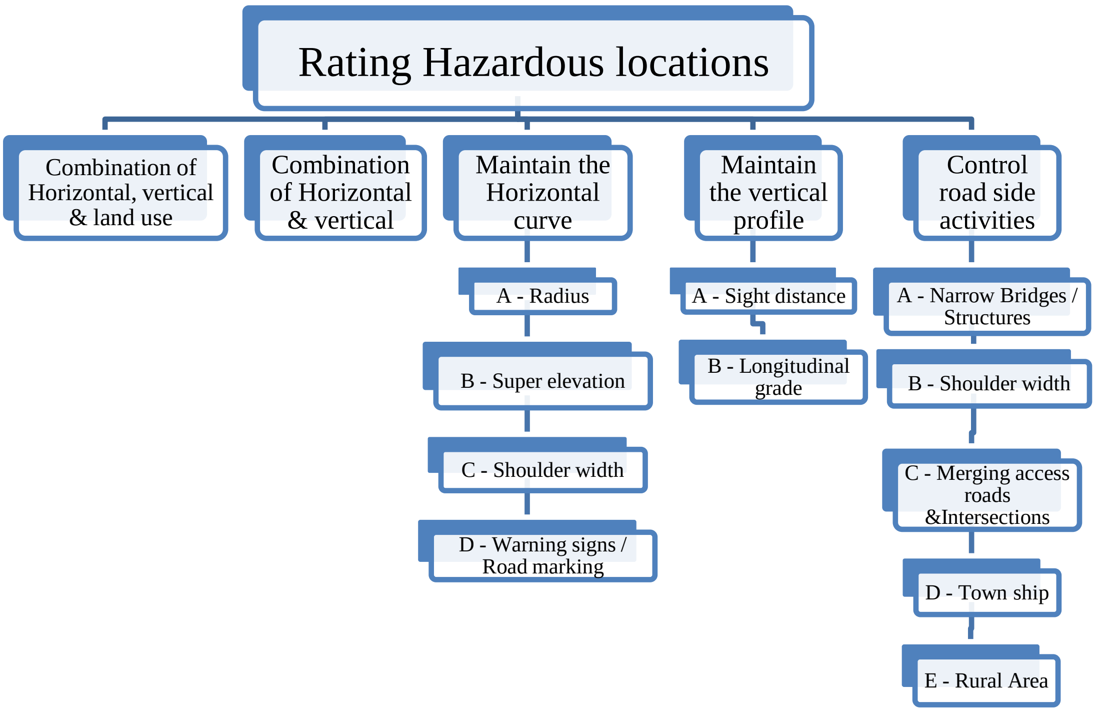


Figure 4.9 : Hierarchy Structure

An expert panel was selected and scores were collected for Analytical Hierarchy Process (AHP). Radius of horizontal alignment, vertical profile and land use activities were considered as main elements which are most venerable parameters for road accidents. Consistency Ratios (CR) of each element as well as each factor were calculated to find rate of hazardous location along road by the experts' response.

According to the scores from survey sheet that was given by each experts; were used for developing a pair wise comparison matrix for each criterion

Table 4.4 : The Relative Weight Matrix- Expert 1

	H, V & Land	H&V	Horizontal Curve	Vertical Profile	Land Use Activities
H, V & Land	1	4	4	4	7
H&V	1/4	1	3	2	5
Horizontal Curve	1/4	1/3	1	8	3
Vertical Profile	1/4	1/2	1/8	1	3
Land Use Activities	1/7	1/5	1/3	1/3	1
Total	1.893	6.033	8.458	15.333	19

Table 4.5 : The Relative Weight Matrix - Expert 2

	H, V & Land	H&V	Horizontal Curve	Vertical Profile	Land Use Activities
H, V & Land	1	3	2	7	5
H&V	1/3	1	3	5	6
Horizontal Curve	½	1/3	1	5	3
Vertical Profile	1/7	1/5	1/5	1	1/2
Land Use Activities	1/5	1/6	1/3	2	1
Total	2.176	4.7	6.533	20	15.5

Table 4.6: The Relative Weight Matrix - Expert 3

	H, V & Land	H&V	Horizontal Curve	Vertical Profile	Land Use Activities
H, V & Land	1	3	7	8	8
H&V	1/3	1	5	4	5
Horizontal Curve	1/7	1/5	1	2	4
Vertical Profile	1/8	1/4	1/2	1	2
Land Use Activities	1/8	1/5	1/4	1/2	1
Total	1.726	4.65	13.75	15.5	20

Table 4.7 : Relative Weight Matrix - Expert 4

	H, V & Land	H&V	Horizontal Curve	Vertical Profile	Land Use Activities
H, V & Land	1	5	7	7	8
H&V	1/5	1	4	2	3
Horizontal Curve	1/7	1/4	1	2	2
Vertical Profile	1/7	1/2	1/2	1	2
Land Use Activities	1/8	1/3	1/2	1/2	1
Total	1.611	7.083	13	12.5	16

Table 4.8 : The Relative Weight Matrix - Expert 5

	H, V & Land	H&V	Horizontal Curve	Vertical Profile	Land Use Activities
H, V & Land	1	3	3	4	9
H&V	1/3	1	3	4	7
Horizontal Curve	1/3	1/3	1	2	8
Vertical Profile	¼	1/4	1/2	1	5
Land Use Activities	1/9	1/7	1/8	1/5	1
Total	2.028	4.726	7.625	11.2	30

Then resulting matrixes of each expert were normalized and averaging the values in each row to get the corresponding rate' as shown in the tables 4.9 – table 4.13.

Table 4.9 : Weight of each element - Expert 1

	H, V & Land	H&V	Horizontal Curve	Vertical Profile	Land Use Activities	Total	w
H, V & Land	0.5283	0.6630	0.4729	0.2609	0.3684	2.2935	0.4587
H&V	0.1321	0.1658	0.3547	0.1304	0.2632	1.0462	0.2092
Horizontal Curve	0.1321	0.0552	0.1182	0.5218	0.1579	0.9852	0.1970
Vertical Profile	0.1321	0.0829	0.0148	0.0652	0.1579	0.4529	0.0906
Land Use Activities	0.0754	0.0331	0.0394	0.0217	0.0526	0.2222	0.0445
Total	1	1	1	1	1	5	1.0000

Consistency ratio (CR) was checked for each expert weights

λ_{max} = 6.031

CI = (λmax - n)/(n-1)

= (6.031 - 5)/(5-1)

= 0.258

CR = CI/RI

= 0.258/1.12 (Ref Table 2.8)

= 0.230357

> 10%

Since the Consistency Ratio (CR) is greater than 10% it is not accepted.

Table 4.10: Weight of each element - Expert 2

	H, V & Land	H&V	Horizontal Curve	Vertical Profile	Land Use Activities	Total	w
H, V & Land	0.4595	0.6383	0.3061	0.3500	0.3226	2.0765	0.4153
H&V	0.1532	0.2128	0.4592	0.2500	0.3871	1.4623	0.2924
Horizontal Curve	0.2298	0.0710	0.1531	0.2500	0.1935	0.8974	0.1795
Vertical Profile	0.0656	0.0425	0.0306	0.0500	0.0323	0.2210	0.0442
Land Use Activities	0.0919	0.0354	0.0510	0.1000	0.0645	0.3428	0.0686
Total	1	1	1	1	1	5	1

λ_{max}	=	5.398	CR	=	CI/RI
CI	=	(λmax - n)/(n-1)		=	0.099/1.12 (Ref Table 2.8)
	=	(5.398 - 5)/(5-1)		=	0.088393
	=	0.099		<	10%

Table 4.11 : Weight of each element - Expert 3

	H, V & Land	H&V	Horizontal Curve	Vertical Profile	Land Use Activities	Total	w
H, V & Land	0.5793	0.6452	0.5091	0.5161	0.4000	2.6497	0.5299
H&V	0.1931	0.2150	0.3636	0.2581	0.2500	1.2798	0.2560
Horizontal Curve	0.0828	0.0430	0.0727	0.1290	0.2000	0.5275	0.1055
Vertical Profile	0.0724	0.0538	0.0364	0.0645	0.1000	0.3271	0.0654
Land Use Activities	0.0724	0.0430	0.0182	0.0323	0.0500	0.2159	0.0432
	1	1	1	1	1	5	1

λ_{max}	=	5.433	CR	=	CI/RI
CI	=	(λmax - n)/(n-1)		=	0.108/1.12
	=	(5.433 - 5)/(5-1)		=	0.096429
	=	0.108		<	10%

Table 4.12 : Weight of each element - Expert 4

	H, V & Land	H&V	Horizontal Curve	Vertical Profile	Land Use Activities	Total	w
H, V & Land	0.6208	0.7059	0.5385	0.5600	0.5000	2.9252	0.5850
H&V	0.1242	0.1412	0.3077	0.1600	0.1875	0.9206	0.1841
Horizontal Curve	0.0887	0.0353	0.0769	0.1600	0.1250	0.4859	0.0972
Vertical Profile	0.0887	0.0706	0.0385	0.0800	0.1250	0.4028	0.0806
Land Use Activities	0.0776	0.0470	0.0384	0.0400	0.0625	0.2655	0.0531
	1	1	1	1	1	5	1

λ_{max} = 5.367

CI = (λmax - n)/(n-1)

= (5.367 - 5)/(5-1)

= 0.092

CR = CI/RI

= 0.092/1.12

= 0.082143

< 10%

Table 4.13 : Weight of Each Element - Expert 5

	H, V & Land	H&V	Horizontal Curve	Vertical Profile	Land Use Activities	Total	w
H, V & Land	0.4931	0.6348	0.3934	0.3571	0.3000	2.1784	0.4357
H&V	0.1644	0.2116	0.3934	0.3571	0.2333	1.3598	0.2720
Horizontal Curve	0.1644	0.0705	0.1312	0.1786	0.2667	0.8114	0.1623
Vertical Profile	0.1233	0.0529	0.0656	0.0893	0.1667	0.4978	0.0995
Land Use Activities	0.0548	0.0302	0.0164	0.0179	0.0333	0.1526	0.0305
	1	1	1	1	1	5	1

λ_{max} = 5.437

CI = (λmax - n)/(n-1)

= (5.437 - 5)/(5-1)

= 0.109

CR = CI/RI

= 0.109/1.12

= 0.097321

< 10%

While checking Consistency Ratio (CR); four CR values were satisfactory out of five. The satisfied weights were considered and got the average weights for each element.

Table 4.14 : Average Expert's Weights for Each Element

Element	**Combination of Horizontal, vertical & land use**	**Combination of Horizontal &vertical curve**	**Horizontal Curve**	**Vertical Profile**	**Road Side Activities**
Weight	**0.49**	**0.25**	**0.14**	**0.07**	**0.05**

Similarly the average weights were calculated for each factor.

Table 4.15: Average Expert's Weights for Each Factor

Element / Factor	Horizontal Curve	Vertical Profile	Road Side Activities
A (Refer Figure 4.9)	0.37	0.87	0.40
B (Refer Figure 4.9)	0.29	0.13	0.18
C (Refer Figure 4.9)	0.24	-	0.21
D (Refer Figure 4.9)	0.10	-	0.14
E (Refer Figure 4.9)	-	-	0.07

Finally the global weights were calculated. According to the results, the hazardous locations were ranked along the road. Figure 4.10 illustrates the global priority of the research. Refer to Figure 4.9 for descriptions of A, B, C, D and E.

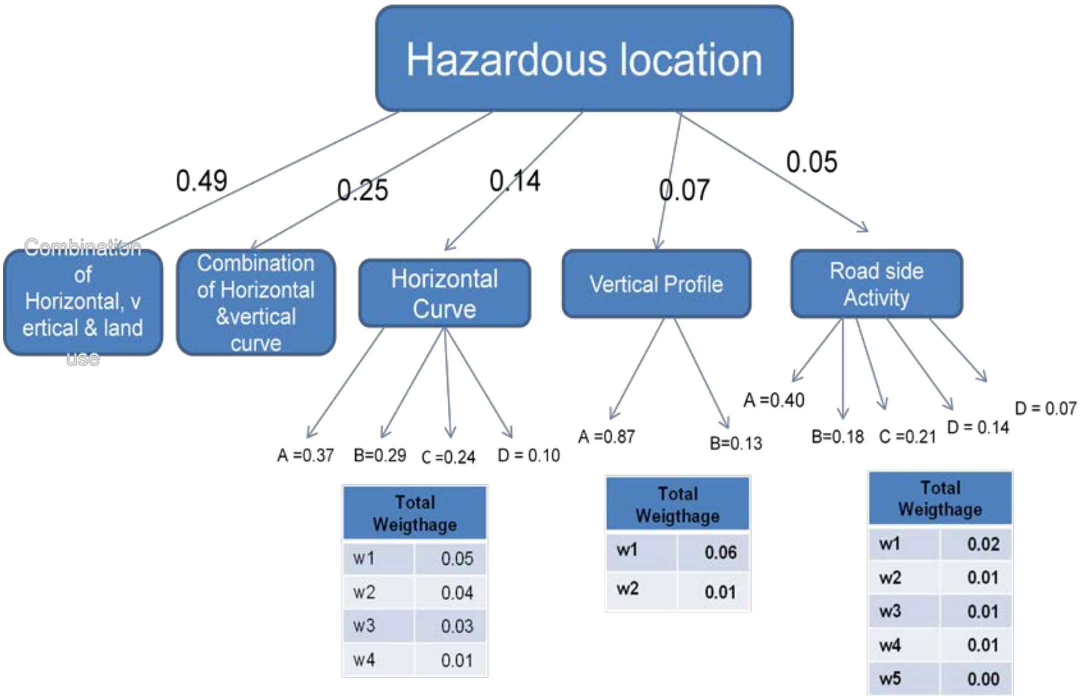


Figure 4.10 : Global Priority

The identified hazardous locations were tabulated in the Table 4.16. Those locations ranked according to the developed weightage of elements and factors. Numbers of accidents were considered to order priority hazardous location where the locations have same weightage.

Table 4.16 : List of Hazardous Location from Nittambuwa to Nelundeniya on A001 Road

No	Deviation from Standard			No of Accident	Weightage	Location of Accident	Rank of Hazardous location
	Horizontal Curve	Vertical Curve	Land Use Activity				
1	Yes	Yes	Yes	20	0.49	45+100 to 45+700	1
2	Yes	Yes	Yes	16	0.49	57+300 to 57+700	2
3	Yes	Yes	Yes	15	0.49	47+800 to 48+200	3
4	Yes	No	Yes	13	0.49	56+600 to 56+700	4
5	Yes	Yes	Yes	10	0.49	45+800	5
6	Yes	Yes	Yes	10	0.49	49+800 to 50+200	6
7	Yes	Yes	Yes	9	0.49	54+100	7
8	Yes	Yes	Yes	9	0.49	57+900 to 58+200	8
9	Yes	Yes	Yes	9	0.49	59+300 to 59+700	9
10	Yes	Yes	Yes	8	0.49	43+200 to 43+300	10
11	Yes	No	Yes	8	0.49	56+200 to 56+500	11
12	Yes	Yes	Yes	5	0.49	53+800	12
13	Yes	Yes	Yes	5	0.49	58+800 to 59+200	13
14	Yes	Yes	Yes	4	0.49	46+400 to 46+700	14
15	Yes	Yes	Yes	4	0.49	50+300 to 50+500	15
16	Yes	Yes	Yes	3	0.49	50+800	16
17	Yes	Yes	Yes	3	0.49	58+400 to 58+700	17
18	Yes	Yes	Yes	2	0.49	48+800 to 49+000	18
19	Yes	Yes	Yes	2	0.49	52+300 to 52+700	19
20	Yes	Yes	Yes	1	0.49	48+300 to 48+500	20
21	Yes	Yes	Yes	1	0.49	49+200 to 49+600	21
22	Yes	Yes	No	15	0.25	47+100 to 47+700	22
23	Yes	Yes	No	9	0.25	55+200 to 55+500	23

No	Deviation from Standard			No of Accident	Weightage	Location of Accident	Rank of Hazardous location
	Horizontal Curve	Vertical Curve	Land Use Activity				
24	Yes	Yes	No	3	0.25	54+400 to 54+700	24
25	Yes	Yes	No	0	0.25	51+800 to 51+900	25
26	Yes	No	Yes	19	0.14	40+800	26
27	Yes	No	Yes	13	0.14	40+600	27
28	Yes	No	Yes	2	0.06	55+000 to 55+100	28
29	Yes	No	No	2	0.05	41+900 to 42+100	29
30	Yes	No	No	2	0.05	44+200 to 44+300	30
31	No	No	Yes	14	0.02	56+800 to 57+200	31
32	No	No	Yes	8	0.02	41+800	32
33	No	No	Yes	4	0.02	41+600	33
34	No	No	Yes	9	0.01	43+800	34
35	No	No	Yes	8	0.01	42+800	35
36	No	No	Yes	8	0.01	55+800 to 55+900	36
37	No	No	Yes	7	0.01	59+800 to 60+100	37
38	No	No	Yes	4	0.01	56+000 to 56+200	38
39	No	No	Yes	3	0.01	40+300	39
40	No	No	Yes	3	0.01	40+900	40
41	No	No	Yes	3	0.01	54+800	41

5 Conclusion and Recommendation

The intention of this research is to find a systematic method to identify hazardous locations along National Highways and to develop the rating system to rank hazardous locations by using Analytic Hierarchy Process (AHP) with the help of expertise in road safety.

The major parameters of road geometry such as horizontal alignment, vertical profile and road side activities and combination of these were considered as main influence elements that create hazardous location and or road section. Also essential factors of the each element were considered. Based on the “Geometric Design Standards of Roads” published by Road Development Authority on 1998, critical locations and or road stretch were identified. Then the list of the critical locations was cross checked with accident data as well as land use activities. Thereafter; the list of hazardous locations were verified by an expert panel and analyzed using the Analytical Hierarchy Process (AHP) with a system of scores which were suggested by the expert panel in the road safety area. These scores were used to obtain weights for importance of each elements and consistency ratio was checked for the expert responses.

According to this study the following findings were obtained;

- Combined scenario of horizontal alignment, vertical profile and land use activities was the most critical criterion to cause accidents.
- The second rank was given to (as shown in the Figure 4.10) the location / road stretch where horizontal curve and vertical profile coincided together.
- Vertical and horizontal curves are the most critical parameters thus those to be improved for reducing road accidents. Furthermore; sharp curves influenced with sight distance are the Hazardous location compared to other geometric factors of the road.

Accident data has been used for the purpose of verification of the hazardous location or road stretch in the study. It can be recommended that the hazardous locations can be rectified in the early stages of planning and designing works by using the data, collected by Planning Division of Road Development Authority with the aid of Multi Function Network Survey Vehicle [MFNSV]. Accident data will not be sufficient to identify the hazardous location and / road section, thus; no need to wait for accident data to rectify the hazardous location. It facilitates to reduce accidents during design, planning and construction stages.

Furthermore, availability of warning signs and road markings was not considered as a critical factor in this study. However, warning signs and road markings has to be considered as a main safety feature in the non-availability of land for road widening and or curve improvements. The signs and markings alert drivers, where road geometry deviate the standards. Subject experts has not considered the availability of road sign and marking as important factors influence for road accidents. It is recommended to use availability of sign boards and marking as factor which will be very important in the land acquisition is difficult in improvements.

Reference List

1. Archer, J. (2005). *Indicators for traffic safety assessment and prediction and their application n micro-simulation modelling: astudy of urban and suburban intersections.* Doctoral Dessertation, Royal Institute of Technology, Department of Infrastructure, Division for Transport and Logistic (TOL), Stockholm, Sweden.

2. Avebury Technical;. (1996). Safer Roads : A guide to road safety engineering. In K. W. Ogden, *Safer Roads.* Aldershot, Hampshire, England: Avebury. Retrieved 2012

3. Gazette, G. o. (1987, March 13). Goverment Notification. *Gazette 444/18*. Colombo, Western, Sri Lanka.

4. *Geometric Design Standards of Roads.* (1998). Sri Lanka: Road Development Authority.

5. Gettman, D., & Head, L. (2003). Surrogate Safety Measures From Traffic Simulation Models. Mclean Virginia, U.S, Tanque Verde #170, Tucson: Department of Transportation. Retrieved from citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.473.4748&rep=rep1

6. Habibian, M., Mesbah, M., & Sobhani, A. (2011, September 28 - 30). *Ranking of Hazardous Road Locations in Two-Lane Two-Way Rural Roads with No Crash Record.* Retrieved from http://www.patrec.org/atrf.aspx: http://www.patrec.org/atrf.aspx

7. Haung, H. L., Chin, H. C., & al, e. (2009). Hotspot identification. In *Transportation and Traffic Theory 2009.* New York, Springer: S. C. Wong and H. K.Lo.

8. Lord, D., Washngton, S. P., & al, e. (2005). Poisson, poisson-gamma and zero inflated regression models of motor vwhicle crashes. *Accident Analysis & Prevention*, 35-46. Retrieved from http://scholar.google.com/citations?view_op=view_citation&hl=en&user=yka86dQAAAAJ&citation_for_view=yka86dQAAAAJ:u-x6o8ySG0sC

9. Lovegrove, G., Lim, C., & Sayed, T. (2010). Community-Based, Macrolevel Collision Prediction Model Use with a Regional Transportation Plan. *Journal of Transportation Engineering*, 120-128.

10. Montella, A. (2010). A comparative analysis of hotspot identification methods. In *Accident Analysis & Prevention* (Vol. 42, pp. 571-581).

11. Pogarcic, I., Francic, M., & Davidovic, V. (2008, September). APPLICATION OF AHP METHOD IN TRAFFIC PLANNING. Trpimirova 2/V, Rijeka, Croatia.

12. Quddus, M. A., Wang, C., & al, e. (2010). Road Traffic Congestion and Crash Severity. *Journal of Transportation Engineering*, *136*, 424-435.

13. R. W. Saaty. (1987). THE ANALYTIC HIERARCHY PROCESS-WHAT IT IS AND HOW IT IS USED. *Vol. 9*. 4922 Ellsworth Avenue, Pittsburg, PA 15213, U.S.A: Great Britain. Retrieved 2014

14. Saaty, T., & Wong, M. (1983). Projective averagefamily size in rural india by the analytic. *Journal of Mathematical Sociology*, *9*, 181-209.

15. SADEGHI, A., AYATI, E., & NEGHAB, M. P. (2013). IDENTIFICATION AND PRIORITIZATION OF HAZARDOUS ROAD LOCATIONS BY SEGMENTATION AND DATA ENVELOPMENT ANALYSIS APPROACH. In *Promet – Traffic&Transportation* (Vol. 25, pp. 127-136).

16. Science Serving Society;. (2004). Traffic safety. In L. Evans. Bloomfield Hills,, MI 48304-3153, United States of America: Science serving Society. Retrieved 2012, from http/www.scienceservingsociety.com/ts/text.htm

17. Transportation Research Board;. (2002). Screening the Road Network for Sites with Promise. In E. Hauer, J. Kononov, B. Allery, & M. S. Griffith, *Transportation Research Record* (Vol. 1784, pp. 27-32). Washington, United States: Transportation Research Board. doi:http://dx.doi.org/10.3141/1784-04

18. Transportation Research Board;. (2005). Safety reviews of existing roads. In A. Montella, *Transportation Research Record* (Vol. 1922, pp. 62-72). doi:http://dx.doi.org/10.3141/1922-09

19. Zhu, H., K.Dixon, K., & al, e. (2010). Single-vehicle fatal crash prediction for two lane rural highways in the Southeastern United States. *89th Transportation Research Board Annual Meeting.* Washington, USA.

Appendices

Appendix A : Survey Sheet among Expertise Panel

Horizontal alignment, vertical profile and road side activities are considered as main elements of this study. In cooperation of these elements, the following five criteria are selected to identify hazardous location / road section. The five criteria are;

1. combination of horizontal alignment, vertical profile and road side activities
2. combination of horizontal alignment and vertical profile
3. horizontal alignment
4. vertical profile
5. road side activities

Pair wise comparison need to be made between each pair criteria with the provision of scale according to the Saaty's preference index to determine the consistency.

Preference Index - Relative Importance of Criteria (Saaty & Wong, 1983)

Relative Importance	Qualitative Scale	Comments
1	Equal	
3	Moderate importance	
5	Strong importance	
7	Demonstrated importance	
9	Absolute importance	
2, 4, 6, 8	Values between the levels above	Used only when a compromise in comparisons is necessary
Reciprocal	If importance of item x to item y is ai,j then the importance of item y to item x is aj,i =1/ai,j.	

	H, V & Land	H&V	Horizontal Curve	Vertical Profile	Land Use Activities
H, V & Land	1	a_{12}	a_{13}	a_{14}	a_{15}
H&V	$a_{21}=1/a_{12}$	1	a_{23}	a_{24}	a_{25}
Horizontal Curve	$1/ a_{13}$	$1/ a_{23}$	1	a_{34}	a_{35}
Vertical Profile	$1/ a_{14}$	$1/ a_{24}$	$1/ a_{34}$	1	a_{45}
Land Use Activities	$1/ a_{15}$	$1/ a_{25}$	$1/ a_{35}$	$1/ a_{45}$	1

The four factors such as Radius, Super-elevation Shoulder width and Warning signs / Road marking are considered under horizontal alignment. These factors also to be compared pair wise between each other, as shown in the matrix below,

Horizontal Alignment

	Radius	Super-elevation	Shoulder width	Warning signs / Road marking
Radius	1			
Super-elevation		1		
Shoulder width			1	
Warning signs / Road marking				1

Similarly pair wise comparison to be made between each factor of vertical profile and road side activities.

Vertical Profile

	Sight Distance	Longitudinal Grade
Sight Distance	1	
Longitudinal Grade		1

Road Side Activities

	Narrow Bridges / Structures	Shoulder width	Merging access roads & Intersections	Town ship	Rural Area
Narrow Bridges / Structures	1				
Shoulder width		1			
Merging access roads & Intersections			1		
Town ship				1	
Rural area					1

Appendix B : Sample Accident Data on Colombo – Kandy Road

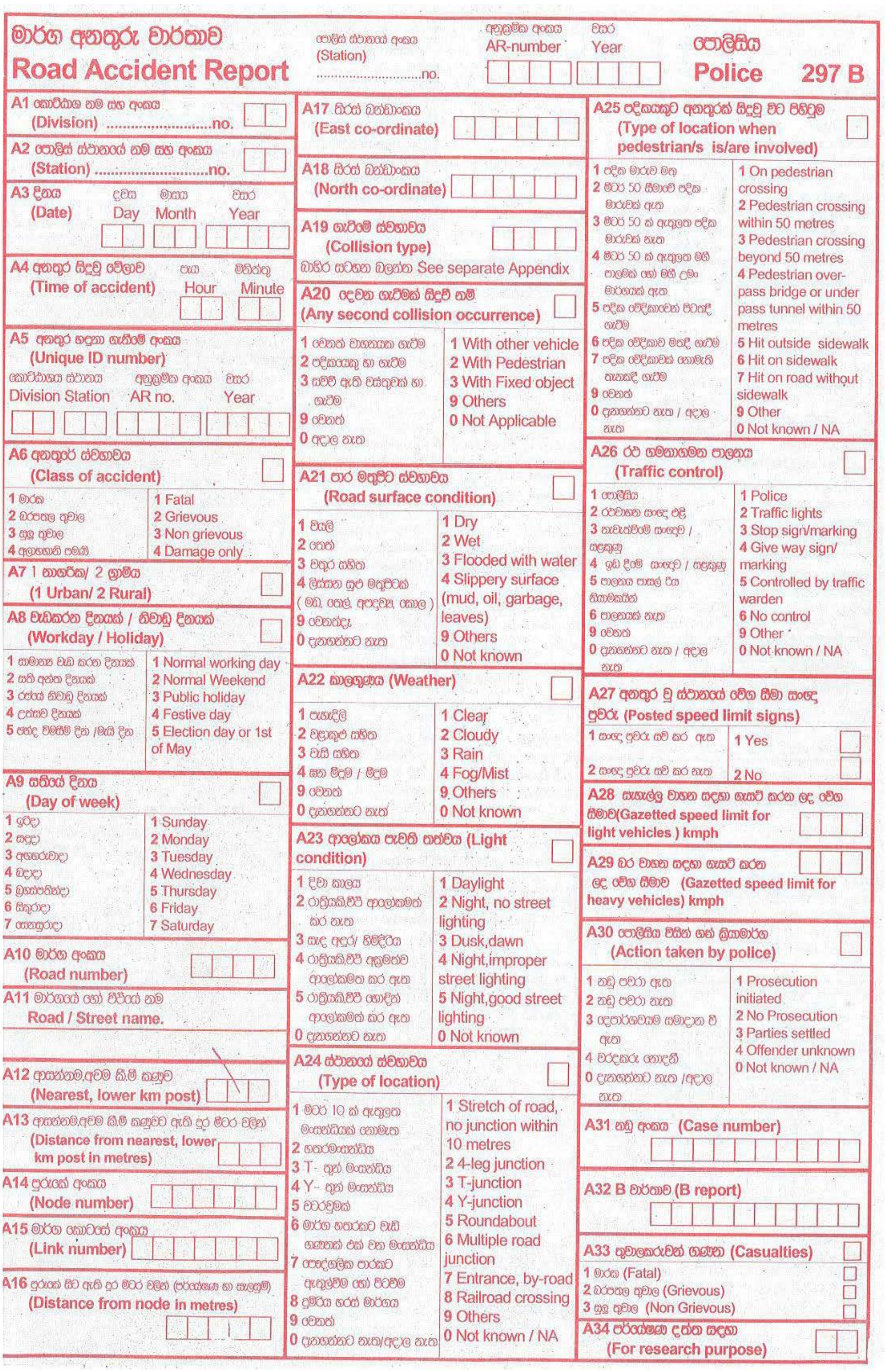
Attendant Circumstances										
Accident Key	**Number of Vehicles**	**Number of Casualties**	**DS Division**	**Station No**	**Date**	**Time**	**Serial No**	**Highest Severity**	**Urban Rural**	**Work Day/Holiday**
1229	2	0	21	2111	1/3/2012	16:25	211100012012	4	2	1
1230	2	0	21	2111	1/5/2012	17:05	211100022012	4	2	1
1233	2	0	21	2111	1/11/2012	14:15	211100052012	4	1	1
1234	2	1	21	2111	1/11/2012	18:45	211100062012	2	1	1
1235	2	1	21	2111	1/11/2012	19:40	211100072012	2	2	1
1236	2	1	21	2111	1/12/2012	7:40	211100082012	2	1	1
1237	2	3	21	2111	1/13/2012	20:50	211100092012	2	2	1
1238	2	3	21	2111	1/14/2012	22:30	211100102012	3	2	2
1240	2	1	21	2111	1/17/2012	14:30	211100122012	2	2	1
1242	3	1	21	2111	1/20/2012	15:00	211100142012	3	1	1
1244	2	0	21	2111	1/22/2012	4:50	211100162102	4	2	2
1246	1	0	21	2111	1/24/2012	3:00	211100182012	4	2	1
1248	2	1	21	2111	1/27/2012	5:50	211100202012	2	2	1

Attendant Circumstances										
Accident Key	Day of Week	Road Number	Road Street Name	Nearest Lower Km Post	Distance Lower Km Post	Node Number	Link Number	Distance From Node	East coordinate	North coordinate
1229	3	A001	COLOMBO-KANDY ROAD	79	150	533902	A001400	0	153759	228071
1230	5	A001	COLOMBO-KANDY ROAD	78	10	533902	A001400	0	152618	227919
1233	4	A001	COLOMBO-KANDY ROAD	78	350	533902	A001400	0	152711	227930
1234	4	A001	COLOMBO-KANDY ROAD	77	100	533901	A001390	0	151546	227689
1235	4	A001	COLOMBO-KANDY ROAD	77	50	533901	A001390	0	151538	227686
1236	5	A001	COLOMBO-KANDY ROAD	78	50	533902	A001400	0	152605	227909
1237	6	A001	COLOMBO-KANDY ROAD	75	200	533801	A001381	0	150221	227114
1238	7	A001	COLOMBO-KANDY ROAD	78	450	533902	A001400	0	152968	227963
1240	3	A001	COLOMBO-KANDY ROAD	70	150	533801	A001380	0	146809	226058
1242	1	A001	COLOMBO-KANDY ROAD	74	150	533801	A001380	0	150139	226360
1244	3	A001	COLOMBO-KANDY ROAD	85	900	534001	A001410	0	160020	228137
1246	6	A001	COLOMBO-KANDY ROAD	76	600	533901	A001381	0	150914	227689
1248	1	A001	COLOMBO-KANDY ROAD	78	50	533902	A001390	0	152626	227914

Attendant Circumstances									
Accident Key	Collision type	Second Collision	Road Surface	Weather	Light Condition	Location Type	Pedestrian Location	Traffic Control	Speed Limit Posted
1229	0411	0	1	1	1	1	0	1	2
1230	0799	0	1	1	1	1	0	1	1
1233	0922	0	1	1	4	1	3	1	2
1234	0925	0	1	1	4	1	3	1	2
1235	0960	0	1	1	1	1	7	1	1
1236	0120	0	1	1	2	4	1	6	1
1237	0310	0	1	1	5	1	0	1	1
1238	0799	0	1	1	1	1	0	1	2
1240	0310	2	1	1	1	1	1	1	1
1242	0110	0	1	1	2	1	0	1	2
1244	0811	3	1	1	4	1	0	1	1
1246	0922	0	1	1	2	1	3	1	2
1248	0941	0	1	1	4	1	3	1	2

	Attendant Circumstances							
Accident Key	**Speed Limit Light Veh**	**Speed Limit Heavy Veh**	**Police Action**	**Case Number**	**B Report**	**Description of Crash**	**Research Purpose**	**Export Status**
1229	72	56	3	0	0	0	0	0
1230	56	32	1	11861/12	0	0	0	0
1233	56	32	1	11971/12	0	0	0	0
1234	72	56	1	12658/12	0	0	0	0
1235	56	32	1	11972/12	0	0	0	0
1236	72	56	1	12087/12	0	0	0	0
1237	72	56	1	11973/12	00	0	0	0
1238	72	56	1	12086/12	0	0	0	0
1240	56	32	1	12077/12	0	0	0	0
1242	72	56	1	12079/12	0	0	0	0
1244	72	56	1	12088/12	0	0	0	0
1246	72	56	1	12510/12	0	0	0	0
1248	56	32	1	12351/12	0	0	0	0

Form for Road Accident Report Use by Department of Police



Road Accident Report (Station) ....no. AR-number Year **Police 297 B**

A1 (Division) ....no.

A2 (Station) ....no.

A3 (Date) Day Month Year

A4 (Time of accident) Hour Minute

A5 (Unique ID number) Division Station AR no. Year

A6 (Class of accident)
1 Fatal
2 Grievous
3 Non grievous
4 Damage only

A7 1 / 2 (1 Urban/ 2 Rural)

A8 (Workday / Holiday)
1 Normal working day
2 Normal Weekend
3 Public holiday
4 Festive day
5 Election day or 1st of May

A9 (Day of week)
1 Sunday
2 Monday
3 Tuesday
4 Wednesday
5 Thursday
6 Friday
7 Saturday

A10 (Road number)

A11 Road / Street name.

A12 (Nearest, lower km post)

A13 (Distance from nearest, lower km post in metres)

A14 (Node number)

A15 (Link number)

A16 (Distance from node in metres)

A17 (East co-ordinate)

A18 (North co-ordinate)

A19 (Collision type) See separate Appendix

A20 (Any second collision occurrence)
1 With other vehicle
2 With Pedestrian
3 With Fixed object
9 Others
0 Not Applicable

A21 (Road surface condition)
1 Dry
2 Wet
3 Flooded with water
4 Slippery surface (mud, oil, garbage, leaves)
9 Others
0 Not known

A22 (Weather)
1 Clear
2 Cloudy
3 Rain
4 Fog/Mist
9 Others
0 Not known

A23 (Light condition)
1 Daylight
2 Night, no street lighting
3 Dusk,dawn
4 Night,improper street lighting
5 Night,good street lighting
0 Not known

A24 (Type of location)
1 Stretch of road, no junction within 10 metres
2 4-leg junction
3 T-junction
4 Y-junction
5 Roundabout
6 Multiple road junction
7 Entrance, by-road
8 Railroad crossing
9 Others
0 Not known / NA

A25 (Type of location when pedestrian/s is/are involved)
1 On pedestrian crossing
2 Pedestrian crossing within 50 metres
3 Pedestrian crossing beyond 50 metres
4 Pedestrian over-pass bridge or under pass tunnel within 50 metres
5 Hit outside sidewalk
6 Hit on sidewalk
7 Hit on road without sidewalk
9 Other
0 Not known / NA

A26 (Traffic control)
1 Police
2 Traffic lights
3 Stop sign/marking
4 Give way sign/ marking
5 Controlled by traffic warden
6 No control
9 Other
0 Not known / NA

A27 (Posted speed limit signs)
1 Yes
2 No

A28 (Gazetted speed limit for light vehicles) kmph

A29 (Gazetted speed limit for heavy vehicles) kmph

A30 (Action taken by police)
1 Prosecution initiated
2 No Prosecution
3 Parties settled
4 Offender unknown
0 Not known / NA

A31 (Case number)

A32 B (B report)

A33 (Casualties)
1 (Fatal)
2 (Grievous)
3 (Non Grievous)

A34 (For research purpose)

E1 අනතුරට භාජනය වූ දෑ (Element type)

01 Car
02 Dual purpose vehicle
03 Lorry
04 Cycle
05 Motor cycle, Moped
06 Three wheeler
07 Articulated vehicle, prime mover
08 SLTB bus
09 Private bus
10 Intercity bus
11 Land vehicle/ Tractor
12 Animal drawn vehicle or rider on animal
13 Pedestrian
19 Others
00 Not known

E5 වාහනයේ අයිතිය (Vehicle ownership)

1 Private vehicle
2 Private company own vehicle
3 Government vehicle
4 Semi Government vehicle
5 Service vehicle
6 Police vehicle
0 Not Known

E7 රියදුරුගේ/ පැදිකරුගේ/ පදිකයාගේ ස්ත්‍රී පුරුෂ භාවය (Driver / Rider / Pedestrian Sex)

1 Male
2 Female
0 Not known

E10 රියදුරු බලපත්‍රයේ වලංගුභාවය (Validity of driving license)

1 Valid license for the vehicle
2 Without valid license for the vehicle
3 Learner permit
4 Probation license
5 International license
0 Not known / NA

E13,E14 අනතුර සිදුවීමට රියදුරාගෙන් බලපෑ මූලික හේතු (Human pre crash factors contributing to accident)

01 Speeding
02 Aggressive / negligent driving
03 Error of judgment
04 Influenced by alcohol / drugs
05 Fatigue / fall asleep
06 Distracted/ inattentiveness (handling radio, mobile phone, mental stress etc.)
07 Poor eye sight
08 Sudden illness
09 Blinded by another vehicle / sun
19 Others
00 Not known / NA

E15 අනතුර සිදුවීමට පදිකයාගෙන් බලපෑ හේතුව (Pedestrian pre crash factor contributing to accident)

1 Unexpected pedestrian movement
2 Disobey designated crossing
3 Influenced by alcohol / drugs
4 Poor visibility (clothing)
9 Other
0 Not known / NA

E16 අනතුර සිදුවීමට මාර්ගයෙන් බලපෑ හේතුව (Road pre crash factor contributing to accident)

1 Defective road surface, slippery road, pot holes, water puddles, large cracks, high or low sewer covers etc.
2 Defective, absent or badly maintained road markings or signs
3 Road works without adequate traffic control devices
4 Weather conditions
5 Poor street lighting
9 Other
0 Not known / NA

E17 අනතුර සිදුවීමට වාහනයෙන් බලපෑ හේතුව (Vehicle pre crash factor defects contributing to accident)

1 Brakes
2 Tyres, wheels
3 Steering
4 Lights, lamps
5 Poor mechanical condition
6 Overloaded or wrongly loaded vehicle
9 Other
0 Not known / NA

E18 අනතුරේ බරපතලකමට හේතුවූ කරුණු (Crash factor contributing to accident severity)

1 Hitting tree
2 Hitting pole / post
3 Hitting stone or boulder
4 Hitting road island, curb etc.
5 Hitting barrier or guard rail
6 Hitting other fixed object
7 Rolled over
0 Not known / NA

E19 වෙනත් හේතු (Other factors)

1 Avoiding maneuver
2 Hit and run
3 Road works
4 Post crash violence
5 Stolen vehicle
0 Not known / NA

E20 මධ්‍යසාර පරීක්ෂාව (Alcohol test)

1 No alcohol or below legal limit
2 Over legal limit
3 Not tested

E21 රියදුරු/පැදිකරු/පදිකයා අනතුරට වගකිවයුතු (Driver/ Rider/ Pedestrian at fault)

1 Yes
2 No
0 Not known / NA

තුවාලකරු පිළිබඳ විස්තර (CASUALTY DETAILS)

C1 අනතුරට භාජනය වූ දෑහි අංකය (Traffic element number)

If a driver or passenger casualty indicate the vehicle's element number in which the casualty traveled.

If a pedestrian casualty indicate the element number for the pedestrian

C2 දණ්ඩ නීති සංග්‍රහයට අනුව තුවාලකරුගේ තත්වය (Severity according to penal code)

1 Fatal
2 Grievous
3 Non grievous

C3 වර්ගය (Category)

1 Driver / Rider
2 Pedestrian
3 Passenger / pillion rider
4 Passenger/pillion rider falling off vehicle
5 Passenger entering or leaving bus
0 Not known

C4 ස්ත්‍රී පුරුෂ භාවය (Sex)

1 Male
2 Female
0 Not known

C6 ආරක්ෂාව (Protection)

1 Safety belt, worn
2 Safety belt, not worn
3 Helmet, worn
4 Helmet, not worn
5 Child restrain seat used
0 Not known / NA

C7 රෝහල් ගත කිරීම (Hospitalized)

1 Injured and admitted to hospital at least 1 day
2 Injured but not admitted to hospital or admitted less than 1 day

අනතුරට භාජනය වූ වාහනයේ අංකය (TRAFFIC ELEMENT)	අංකය Traffic Element No.	අංකය Traffic Element No.	අංකය Traffic Element No.
E1 අනතුරට භාජනය වූ දෑ (Element type)			
E2 වාහනයේ ලියාපදිංචි අංකය (Vehicle Registration number)			
E3 වාහනය නිපදවූ වර්ෂය (Vehicle year of manufacture)			
E4 වාහනය කොපමණ පැරණිද යන වග (Age of vehicle)			
E5 වාහනයේ අයිතිය (Vehicle ownership)			
E6 ගමන් කරන දිශාව (Direction of movement)			
E7 රියදුරුගේ / පැදිකරුගේ / පදිකයාගේ ස්ත්‍රී පුරුෂ භාවය (Driver / Rider / Pedestrian sex)			
E8 රියදුරුගේ / පැදිකරුගේ / පදිකයාගේ වයස (Driver / Rider / Pedestrian age)			
E9 රියදුරු බලපත්‍රයේ අංකය (Driving License number)			
E10 රියදුරු බලපත්‍රයේ වලංගු භාවය (Validity of Driving License)			
E11 රියදුරු බලපත්‍රය නිකුත් කල වර්ෂය (Year of issue of Driving License)			
E12 රියදුරු බලපත්‍රය නිකුත් කල අවස්ථාවේ සිට කාලය (අවුරුදු) (Number of years since first issue of driving license)			
E13 අනතුර සිදුවීමට රියදුරාගෙන් බලපෑ පලමු හේතුව (Human pre crash factor 1 contributing to accident)			
E14 අනතුර සිදුවීමට රියදුරාගෙන් බලපෑ දෙවන හේතුව (Human pre crash factor 2 contributing to accident)			
E15 අනතුර සිදුවීමට පදිකයාගෙන් බලපෑ හේතුව (Pedestrian pre crash factor contributing to accident)			
E16 අනතුර සිදුවීමට මාර්ගයෙන් බලපෑ හේතුව (Road pre crash factor contributing to accident)			
E17 අනතුර සිදුවීමට වාහනයෙන් බලපෑ හේතුව (Vehicle pre crash factor contributing to accident)			
E18 අනතුරේ බරපතලකමට හේතුවූ කරුණ (Crash factor contributing to accident severity)			
E19 වෙනත් හේතු (Other factors)			
E20 මධ්‍යසාර පරීක්ෂාව (Alcohol test)			
E21 රියදුරු / පැදිකරු /පදිකයා අනතුරට වගකිවයුතුද ? (Driver / Rider / Pedestrian at fault ?)			
E22 පර්යේෂණ දත්ත සඳහා (For research purpose)			

තුවාලකරු (CASUALTIES)	A	B	C	D	E	F	G
C1 අනතුරට භාජනය වූ වාහනයේ අංකය (Traffic element number)							
C2 දණ්ඩ නීති සංග්‍රහයට අනුව තුවාලකරුගේ ස්වභාවය (Severity according to penal code)							
C3 වර්ගය (Category)							
C4 ස්ත්‍රී පුරුෂ භාවය (Sex)							
C5 වයස (Age)							
C6 ආරක්ෂාව (Protection)							
C7 රෝහල් ගත කිරීම (Hospitalized)							

ගැටීමේ සටහන
(Collision Sketch)

උතුර
North

අතිරේක තොරතුරු හෝ අනතුර සිදුවූ ආකාරය පිළිබඳ ලුහුඬු සටහනක්
(Discription of accident & additional information)

....

....

....

....

විභාග කරන නිළධාරියා විසින් මෙම වාර්තාව සකස් කරන ලදී. නම / අත්සන:
This Report has been prepared by the investigating Officer. Name / Signature: ....

ස්ථානාධිපති (රථ වාහන) විසින් මෙම වාර්තාව නිවැරදි බව සහතික කරන ලදී. නම / අත්සන:
This Report is certified to be correct by OIC (traffic). Name / Signature: ....

සංකේත ලිපිකරු විසින් සටහන් හා සංකේත යෙදීම පරීක්ෂා කරන ලදී
Entring and Coding checked by coding clerk Name / Signature: ....

ස්ථානාධිපති (සංඛ්‍යාලේඛණ කොට්ඨාශය) විසින් සටහන් හා සංකේත යෙදීම පරීක්ෂා කරන ලදී
Entring and Coding checked by OIC (Statistics Division) Name / Signature: ....

H 036008 – 30,000 (2010/11) ශ්‍රී ලංකා රජයේ මුද්‍රණ දෙපාර්තමේන්තුව Swe/28.05.2k3

Appendix C : Video Clip of the Road Stretch and Soft Copy of Accident Data on Colombo – Kandy Road [A001]