ASSESSMENT OF OPERATING SPEEDS OF REHABILITATED RURAL ROADS WITH ASPHALT SURFACING

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Degree of Master of Engineering

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October, 2017

DECLARATION

I declare that this is my own work and this thesis 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 Sri Lanka, rural roads are not specifically designed on technical requirements. Most of the rural roads (C and D classes) have historical backgrounds as being tracks and trails coming even beyond the colonial times. Hence, most of the rural roads in Sri Lanka are almost following the same traces and not designed technically. Nowadays, rural roads are being rehabilitated. So far those rehabilitation projects underwent with merely construction improvements and proper geometrical improvements have not been adopted. It was found out that the actual speeds can be significantly greater after rehabilitation affecting the safety of road users. Aim of this study was to assess actual operating speeds, posted speed limits and to find design operating speeds that supposed to be after the rehabilitation. Finally it suggests rational speed limits to rural rehabilitated roads under purview. Most of the rural roads in Sri Lanka don't have posted speed limits specified according to the geometric, road environment and functionality level of the road. The speed limits of 70km/h and 50km/h are the usual speed limits enforced for traffic in arterial roads which are categorized as class A and B. Since the speed limits are not categorized according to the type of the road, above speed limits apply to the rural roads as well. It's hardly been seen that traffic speeds are controlled or monitored by law enforcement in rural roads. Hence the speed choice of the rural road drivers depends on variety of other factors. The 85^{th} percentile speed was taken as the operating speed. This speed was used as a basis for suggesting rational speed limit since most drivers behave in a safe and reasonable manner and do not want to get into crashes. Also it encourages drivers to travel at about the same speed. The researchers have studied number of rehabilitated roads in North Western province in Sri Lanka. Each road was divided into several sections; straight and curved. Operating speeds on straight sections were given priority in suggesting rational speed limits. As operating speeds in curves are considerably lower and enforcing lower posted speeds only based on operating speeds on curves for entire road, would not be practical since drivers tend to disrespect the speed limit. The suggested rational speed limit for all the roads under purview is 50 km/h and this speed limit will be overridden to a lesser speed limit at a curved section based on the operating and design speed. This speed limit should be notified using sign boards and shall be enforced only for the curve itself.

DEDICATION

To my beloved wife and parents

who always encouraged me towards success

ACKNOWLEDGEMENT

I would like to acknowledge all the senior Lecturers, supporting staff and friends in making this research a success. First, thank goes to my project supervisor Prof. W. K. Mampearachchi who instructed and guided me throughout the research.

Also I would like to be thankful to the lecture panel, including Prof. W.K. Mampearachchi, Prof. J.M.S.J. Bandara, Dr. H.R. Pasindu, Dr. Dimantha De Silva, Mr. Loshaka Perera and all the other lecturers for their valuable lectures, comments and guidance.

In addition, I would like to be thankful to the staff of Provincial Road Development Department, North Western Province who helped me specially in collecting speed data.

Last but not least, I would like to thank the staff of Transportation Engineering division of department of Civil Engineering of University of Moratuwa for their continuous support.

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LIST OFABBREVIATIONS

Abbreviation	Description
AADT	Average Annual Daily Traffic
ADT	Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
DBST	Double Bituminous Surface Treatment
GPS	Global Positioning System
NWP	North Western Province
NW	North Western
ROW	Right of Way
STD	Standard Deviation

1. INTRODUCTION

1.1 Problem Statement and Background

The road network in Sri Lanka consists of several types of roads classified on their function and management. Roads in Sri Lanka are categorized into several classes. Classes A, B, and E belong to major arterial roads connecting major city centres while provincial roads connecting cities and rural roads connecting villages comes under classes C, and D which also feed arterial roads by connecting with each other. This research mainly concerns on operating speeds in provincial roads in Sri Lanka. Most of the rural roads in Sri Lanka are not technically designed prior to construction. Most of them have historical backgrounds running beyond colonial times when roads were constructed mainly to transport agricultural products such as tea and coffee. Some of them had been created following manmade traces and trails which were used by people to transport commodities for a long period of time.

Nowadays rural roads are rehabilitated to enhance the living standards of people in rural town areas and villages as well as major cities in the country. However, it has been a common practice to rehabilitate most of the roads with merely construction improvements. A rehabilitated road usually follows the existing road with the same horizontal and vertical alignments. Geometrical features such as intersections, horizontal, vertical curves, approaches, often remain unchanged while road surface and road structures are improved or reconstructed in rehabilitation. Even though the road surface and other infrastructures are improved, most of these roads are not geometrically improved which leads to lower the design speeds. However, the actual speeds of these roads seem to be significantly greater.

1.2 Objectives of the Study

It was observed that vehicle crashes in rural roads have been increased with the completion of road rehabilitation. As mentioned early, operating speeds were observed to be significantly greater after rehabilitation relative to the actual design speeds of those roads. The objective of this research is to assess actual operating speeds, posted speed limits and design operating speeds of roads after rehabilitation. It also focuses on suggesting rational speed limits based on operating speeds (85^{th}

percentile speed) and the design speeds that will comply with the existing geometrical features in rehabilitated rural roads with asphalt surfacing.

Geometric solutions and recommendations for places with higher risk of road crashes and safely issues will be facilitated.

1.3 Scope of Work

The scope of this research was limited to North Western provincial and rural roads of Sri Lanka. Only the Rehabilitated roads with asphalt surfacing were considered in this study. Priority was given for the roads with higher Annual Daily Traffic (ADT).

2. LITERATURE REVIEW

2.1 Speed and Geometric Design

Geometric design of a road refers to the selection of roadway elements that include horizontal alignment, vertical alignment, cross section, and roadside of a particular road. Simply, good geometric design means providing the appropriate level of mobility and land use access for road users while maintaining a high degree of safety. The roadway design must also be sustainable and, cost effective in the current financially constrained economy. While balancing these design decisions, the designer needs to provide consistency along a roadway alignment to prevent abrupt changes in the alignment that do not match motorists' expectations. Speed is used both as a design criterion to promote this consistency and as a performance measure to evaluate highway and street designs. (Fitzpatrick, K., P. Carlson, M.A. Brewer, M.D. Wooldridge, and S.P. Miaou, 2003)

2.2 Design Speed and Operating Speed

The design Speed is a selected speed used to determine the various geometric design features of the roadway (AASHTO, 2001).

Operating Speed is the speed at which drivers operate their vehicles in free flow conditions. The 85th percentile of the distribution of observed speeds is considered as the most frequently used measure of the operating speed associated with a particular location or geometric feature. (AASHTO, 2001)

4.3 Speed Measurement Options

There were three main speed measures that were recorded during survey. They are speed limit, mean speed and 85th percentile speed. These measurements allow for more detailed interpretation and more reliable analysis of issues related to the speed in the speed assessments.

Definitions for speed limit, mean speed, and 85th percentile speed are given below.

- Speed limit: the sign-posted legal speed limit or, where no speed limit signs are posted, the speed limit that applies as a matter of law.

- Mean speed: The average speed of vehicles past a nominated point.
- 85th percentile speed: The speed at or below which 85% of all vehicles are observed to travel under free flowing conditions past a nominated point.

The 85th percentile speed is a key attribute used in the setting of speed limits. Measurement of actual speeds (particularly on higher risk lengths of the network) was considered an essential part of this study. This data can be used to calculate mean speeds, 85th percentile speed, and provide a valuable source of information to help guide any debate on speed management needs. (Eric Howard, Rob McInerney, 2010)

Use of the 85th percentile speed concept is based on the theory that;

- The large majority of drivers:
    - are reasonable and prudent
    - do not want to have a crash
    - desire to reach their destination in the shortest possible time
- A speed at or below which 85 percent of people drive at any given location under good weather and visibility conditions may be considered as the maximum safe speed for that location.

(Rational Speed Limits and the 85th Percentile Speed: Frequently Asked questions, 2010)

2.3 Speed and Safety

The relationship between higher traffic speeds and crash involvement has been investigated by most researches and has been provided with many evidences. (Baruya, 1998). The risk of crash and the probability of serious injury increases with the increased speed of the traffic. Hence the speed is considered as one of the basic factors in traffic crash injuries. The distance travelled during driver's reaction time increases with respect to the speed. With increased speed, the driver's attention to outside objects is reduced and this may lead to vehicle handling errors. Furthermore, speeding of the vehicle decreases the vision of surrounding limiting the ability to handle oncoming hazards timely.

The probability of injury, and the severity of injuries that occur in a crash increases, not linearly, but exponentially varying with vehicle speed by a factor of four for fatalities, three for serious injuries, and two for casualty crashes. Even small increase in travel and impact speed results in a great increase in the forces experienced by vehicle occupants and other road users (Elvik, Christensen, 2004).

The kinetic energy to be absorbed in a crash equals to one half of mass multiplied by the square of velocity illustrating that the effect of velocity is greatly enhanced as velocity increases. The level of damage to the body will depend on the shape and rigidity of the colliding surface or object, but velocity usually plays the most critical role (Tom Christoffel, Susan Gallagher, 2006).

Compared to others, road users like pedestrians, cyclists, moped riders, and motorcyclists have a higher vulnerability of severe or fatal injury when they collide with motor vehicles. This is because they are often completely unprotected or, in the case of a motorcyclist, have very limited protection. The probability of a pedestrian to be killed by a motor vehicle crash increases dramatically with the speed.

In Figure-1, the probability of a fatal injury for a pedestrian colliding with a vehicle is illustrated. It indicates that most of the vulnerable (unprotected) road users can survive only if the colliding vehicle is travelling at a speed lesser than30 km/h, the majority can be killed if hit by a car travelling at 50 km/h or more (OECD Annual Report, 2006)

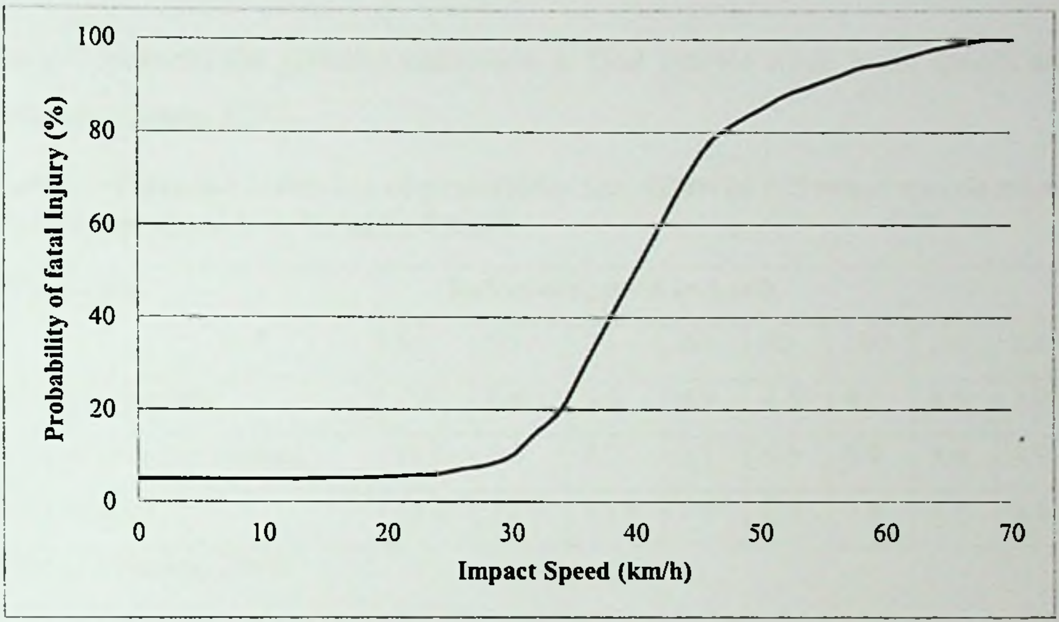

Figure 1: Probability of fatal injury for a pedestrian colliding with a vehicle

(C. Tingvall, N Hawarth, 1999)

It can be clearly identified that fatalities are significantly increased with small increase of the speed.

Figure-2 indicates the increase in crashes for varying severity levels with a small increase in travel speed.

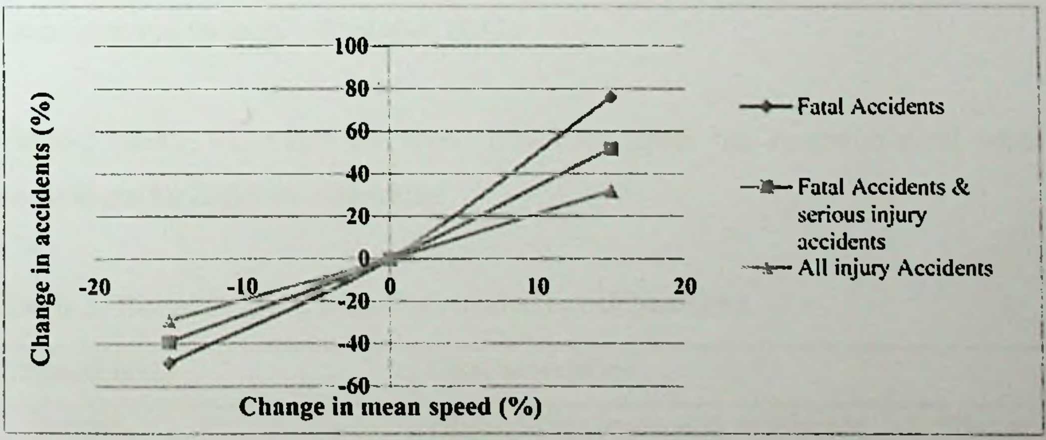

Figure 2: The relationship between percentage changes in accidents with percentage change in mean speed.

(Nilsson, 2004)

It can be clearly identified that relatively small mean speed reductions lead to major fatal (and to a lesser extent, other injury) crash reductions.

Table-1 indicates the potential reductions in fatal crashes when mean speeds are reduced (Nilsson, 2004).

Table 1: Potential reduction of probability for different reference speeds when the average speed is reduced by 2 km/h

Crash type	Reference speed in km/h							
	50	60	70	80	90	100	110	120
All injury crashes	7.8	6.6	5.6	4.9	4.4	4.0	3.6	3.0
Fatal and serious crashes	11.5	9.7	8.3	7.3	6.5	5.9	5.4	4.9
Fatal crashes	15.1	12.7	10.9	9.6	8.6	7.8	7.1	6.5

Source: *(Nilsson, 2004)*

2.4 Rural Speed Management

Implementing Speed limits in rural roads should be considered as only one part of rural safety management, while the assessment framework given in 'Setting Local Speed Limits' provides local flexibility of choice within an overall consistent procedure. This also consider factors like traffic and road user mix, geometry, general characteristics of the road, and its surroundings, potential safety and environmental impacts. (Scotland, 2012)

Table-2 below, illustrates the speed limits for upper tier routes in rural areas as encouraged by highway authorities.

Table 2: Suitable speed limits in rural areas of Scotland

Speed limit	Characteristics
60 mph	High quality roads with few bends, junctions or accesses
50 mph	Lower quality strategic roads which may have a

	relatively high number or bends, junctions or accesses
40 mph	Where there are high number of bends junctions or accesses, substantial development, where there is a strong landscape reason, or where the road is used by considerable numbers of vulnerable road users
30 mph	Should be the norm in villages where appropriate

2.5The influence of the road and roadside features for the speed

The features of the road and its direct environment also have a significant effect on speed choice. Anyone can give examples for roads that have a completely different speed limit than what you would have expected; roads that almost provoke driving too fast. Features of the road and its surroundings that have an effect on the speed choice are cross section, alignment, and direct road environment. In general, the relationship of speed with the above features can be shown as follows:

(SWOV, 2009)

Cross section

- Number of lanes: more lanes → higher speed
- Road width: wider → higher speed
- Width of the obstacle-free zone: wider → higher speed
- Presence/Absence of emergency lane: present → higher speed
- Presence/Absence of cycle track or service road: present → higher speed
- Presence/Absence of road marking: present → higher speed

Alignment

- Bendiness of the road (sight length): fewer bends → higher speed
- Sort and state of road surface: level road surface → higher speed

Road environment

- Buildings alongside the road fewer buildings → higher speed
- Vegetation alongside the road less vegetation → higher speed

2.6 Speed and Horizontal Curves

This research is associated with the vehicle speeds moving along horizontal curves. Hence it is important to discuss about the influence of speed of a moving vehicle along a horizontal curve. The relationship of travelling speed of a vehicle moving along a horizontal curve can be derived by analysing the forces acting on the vehicle that moves on a horizontal curve.

Assuming the radius of the curve to be constant, it can be expressed in following terms;

$$\frac{0.01e + f}{1 - 0.01ef} = \frac{v^2}{gR}$$

Where;

e = Rate of roadway superelevation

Super elevation is tilting of the roadway to offset centripetal forces developed as the vehicle travels on a horizontal curve. Along with friction, super elevation is helpful in keeping vehicle tyres in touch with road and protecting the vehicle going off the road due to speed.

f = Side-friction factor

v = Vehicle speed, (ft/s, m/s)

g = Gravitational constant, (32.2ft/s^2, 9.81 m/s^2)

R = Curve radius, (ft, m)

The value of ef (in the equation denominator) is relatively small, so the term, (1 – 0.01ef) is approximately equal to 1.0. As such, a simplified curve formula can be derived for highway design, and this equation can be further developed to accommodate common speed units as follows.

U.S. Customary Units

$$0.01e + f = \frac{V^2}{15R}$$

Where; V = Velocity, (mph)

Metric Units

$$0.01e + f = \frac{V^2}{127R}$$

Where; V = Velocity, (km/h)

(Paul H Wright, Karen Dixon , 2004)

Research and experience have established limiting values for e and f. Use of the maximum e and safe value in the formula permits determination of minimum curve radii for various design speeds.

The limiting value of the side friction factor (*f*) at which the tires begin to skid, may be as high as 0.6 or higher. In design, engineers use only a portion of the side friction a driver begins to feel uncomfortable and react instinctively to avoid higher speed. Empirical studies have determined that f-values may vary from 0.17 at 20mph (30km/h) to 0.08 at 80 mph (130 km/h). (Paul H Wright, Karen Dixon , 2004)

3. SELECTION OF RURAL ROADS FOR THE STUDY

3.1 Characteristics of Provincial or Rural Roads (C and D Classes) in North Western Province (NWP), Sri Lanka.

Most of the rural roads in Sri Lanka do not have posted speeds specified according to the variations of the geometry and the road use along the road. The top speed limits of 70km/h and 50km/h in city areas are usual speed limits for ordinary traffic enforced in arterial roads which are Class A and B (Except Expressways, i.e. Class E). Since the speed limits are not categorized according to the type of the road, aforesaid speed limits can be applied to rural roads as well. It can be hardly been seen that traffic speeds are controlled by law enforcement in rural roads. Hence the speed choice of the rural road drivers depends on variety of other factors but not law enforcement. Some of those factors will be discussed later.

North Western Provincial Road Network mainly consists of a mix of asphalt, macadam, double bitumen surface treatment (DBST), concrete and gravel roads. 66% of entire road length has become unworthy and unsuitable to accommodate increasing transportation needs of road users. Most of road bases had been designed decades ago and are weak hence not suitable for current traffic demand. These roads usually have higher roughness index having uneven roads surfaces, and it is difficult to acquire higher speeds in these kinds of roads. Also these roads have common types of distresses such as potholes, raveling/weathering edge cracking, block cracking, and etc. Due to above reasons, local drivers are aware of the places at which they should increase or decrease the speed regardless of any posted speed.

Most of the roads are having higher number of curves per kilometer with respect to A and B class roads in the province. This leads drivers to go for a lesser speed choice. Also the speed choice depends on the sight distance along these curves. Better the sight distance, higher speed can be selected, provided the road surface condition is better.

Some of the rural roads in north western province were rehabilitated in recent past. Road Rehabilitation involves with geometric design improvements, restoration of original slopes, and natural drainage. However almost every road that rehabilitated went on with merely construction improvements involved with road surface such as scarifying and removal of existing damaged road surface, removal of unsuitable soil, and base correction with suitable filling material, asphalt overlaying, drainage improvements, and etc. Rehabilitated roads usually follow the existing road having same horizontal and vertical alignments. Geometrical features such as intersections, horizontal and vertical curves, approaches, and etc. are more often remain unchanged while road surface, sometimes road structures are improved or reconstructed in rehabilitation.

Following are some of the basic characteristics of NWP rural roads in general.

- Paved or unpaved carriage way
- Have low Average Daily Traffic
- Carriageway width ranges from 3.2m - 4.2m
- Shoulder width 0 -1m
- Intensive pedestrian activity in some sections occurring locally
- Higher number of Horizontal curves per unit length
- Poor traffic control and the lesser enforcement over traffic speed
- Absence of sufficient walkways for pedestrians
- Higher accessibility, and land use activities
- Higher roughness
- Majority of road users are local to the area

3.2 Selection Norms of Roads for the speed assessment

North western provincial road network comprises of 2752km of road length as per the NW Provincial Road Development Department sources. There are two districts in the North Western Province (NWP) which are Kurunegala and Puttalam. The two districts have road lengths of 1738km and 1014km consecutively. For this study, only the roads with comparatively higher Annual Daily Traffic (ADT) were concerned. Roads with higher crash rates, specially recently rehabilitated were considered for the study as well.

Since the available resources for this research were limited, it was difficult to assess precise sample of roads that could represent entire North western province. Also there had been an indirect involvement in selection criteria with the ability to visit a road by the research team. By considering all the aforesaid factors and practical concerns, seven roads from Kurunegala district were selected for data collection.

Table-3 shows the provincial roads selected for the speed assessment that covers nearly 50 kilometers of total road length.

Table 3: Selected NW Provincial roads for the speed assessment

No.	District Secretariat	Name of Road	Total Length (km)
1	Kuranagala	Rangama - Gonagama	10.25
2		Kawdawaththa - Alakoladeniya	6.30
3		Lakeround - Kudagalgamuwa	8.80
4	Mallawapitiya	Thorayaya - Kudakowana	3.46
5		Mallawapitiya - Katupitiya	8.40
6	Maspotha	Hanhamuna - Dampitiya	6.10
7		Pallandeniya - Dikwehera	7.60
Total Length			50.91

4. METHODOLOGY

4.1 Identification of Road Segments

A road was subdivided into number of segments in order to easily collect speed data. Initially each road was divided into segments using two simple basic types. They were straight segments, and curved segments. The grade of the road was not considered since the terrain was almost flat. Following road features were also considered in categorizing segments of the road under purview.

- Roads having wide verges, good overtaking opportunities, large radii bends, good visibility, appropriate lane widths, and etc.
- Roads which may include some bends and undulations, and average quality verges.
- Roads which have sharp bends, narrow verges, and undulating roads with low forward visibility.
- Higher local activity and ingresses.

Figure-3 shows a road (Thorayaya – Kudakowana in Mallawapitiya divisional secretariat) which was sub divided into number of straight, and curved sections. Segments 25, 28, 29, and 30 were identified as the most significant horizontal curved sections while segments 26 and 27 were recognized as straight segments.

Then an accurate sketch of the site including all the reference points, GPS coordinates, and type of the section was documented. Satellite maps were used for this purpose. Furthermore, it could also be used to verify the collected data from sites. The curvature of the curved sections could also be captured, and central angle was estimated using an AutoCAD plot generated on satellite maps (See Figure-4).

Figure 3: Example Segments as in Thorayaya – Kudakowana road

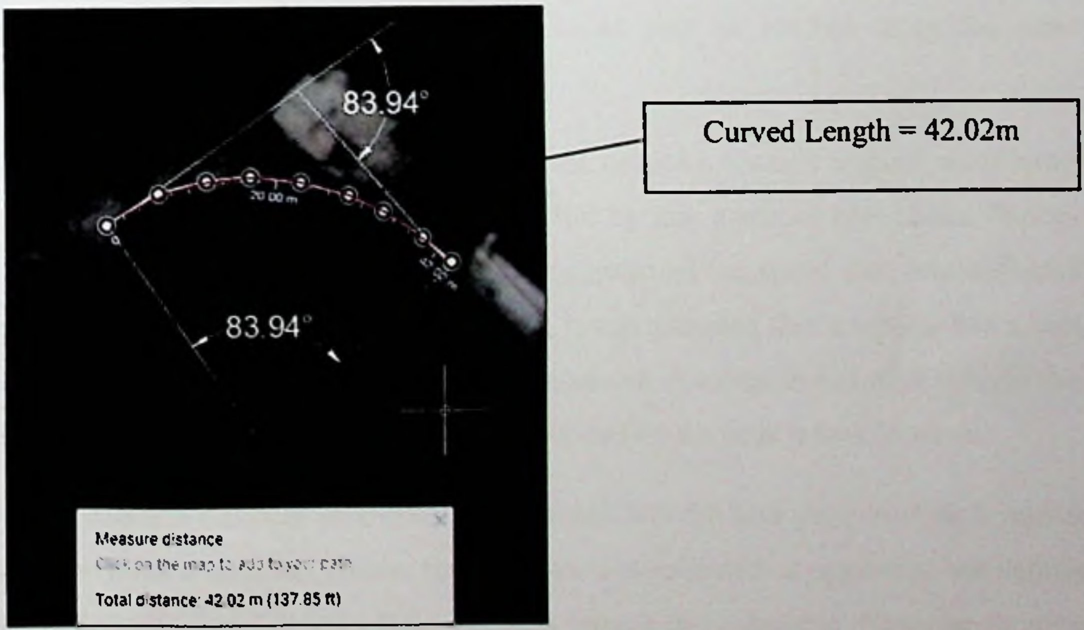

Figure 4: Included angle as measured using CAD file (station 25)

4.2 Data Collection

Each selected road was inspected throughout its length and crucial sections that were required to be assessed were identified. GPS coordinates were taken, and the entire road was mapped using satellite maps so that all the identified sections could be marked and clearly visualized.

After identifying the sections, and numbering them accordingly for a particular road, following data was collected for each section at site.

- Geometrical Data;
  - Section length or curved length (Arc length) depending on the section type.
  - Angle of change of direction in curved sections (The angle between the tangents of the curve. This angle is equal to the central angle of the curvature by geometry).
  - Superelevation.
- Speed data.

The angle of change of direction or the central angle of a curved section was measured using a compass. Then this measured angle was verified using satellite maps. Section length or the arc length could also be verified using the same procedure. See Figure-4.

Speed data was recorded for both ways of the sections. Usually a speed radar meter is used to find instantaneous speed of traffic by law agencies (Sri Lanka Police). However, as it was a very limited resource, most of the speed data was collected manually. In manual speed data collection, it was assumed that a vehicle has a very low speed variation within the section concerned. Average speed of a vehicle that travels the section, was the section length divided by the time it took to travel.

Video cameras mounted on tripods were used to find the time periods of each vehicle that travelled a constant section length. Data was recorded as oppose to the vehicle type. Speeds were then calculated for each vehicle and tabulated. However in some curved sections, where the sight distances were comparatively lesser, maximum applicable segment that could be covered plus adjacent road section were considered in measuring speed data.

Maximum superelevations of curved sections were measured using a level instrument. Technically, the maximum superelevation is attained at the middle of the curve. Average value was calculated by taking several readings at that point.

Figure-5 shows a screen print of a spread sheet that used to work out speeds. A sample speed data collection worksheet is represented Table-4 as well (Note that this data sheet is only a part data sheet and is for presentation purposes).

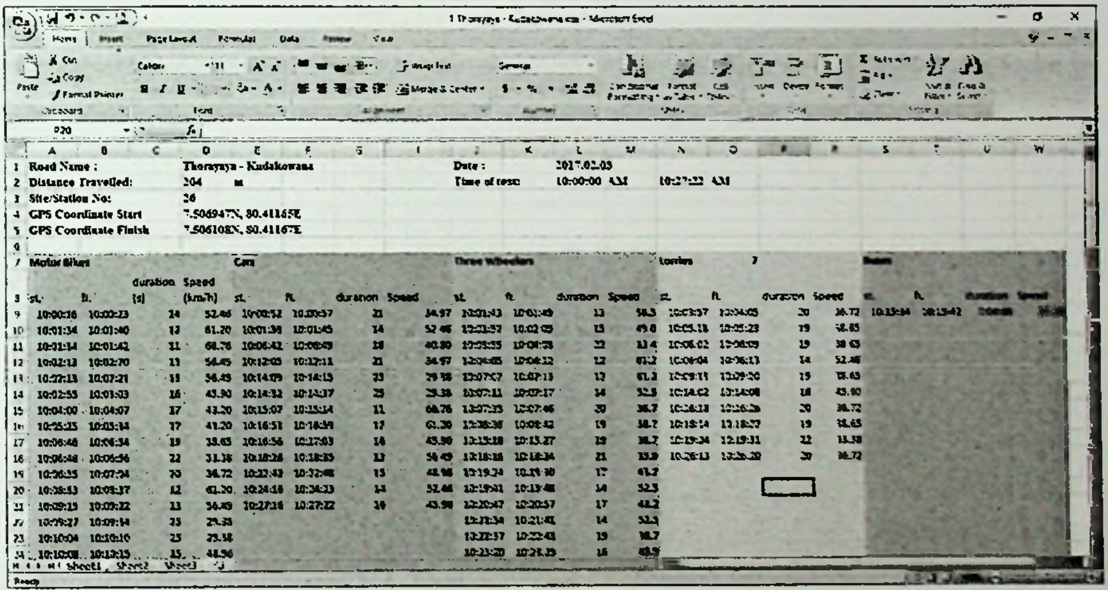

Figure 5: Screen print of Typical Data Collection spreadsheet

Table 4: Sample Speed Data Collection Spreadsheet

Road Name :		Thorayaya - Kudakowana	
Site/Station No:		26	
Secction Length (m):		204	
GPS Coordinate Start		7.506947N, 80.41165E	
GPS Coordinate Finish		7.506108N, 80.41167E	
Section Type (Straight/Curved):		Straight	
Date/Time :		2017.02.03 10.00AM to 10.30AM	
Motor Bikes			
t1	**t2**	**duration (sec)**	**Speed (km/h)**
10:00:16	10:00:23	14	52.46
10:01:34	10:01:40	12	61.20
10:01:34	10:01:42	11	66.76
10:02:13	10:02:20	13	56.49
10:02:13	10:02:21	13	56.49
10:02:55	10:03:03	16	45.90
Cars			
t1	**t2**	**duration (sec)**	**Speed (km/h)**
10:00:52	10:00:57	21	34.97
10:01:38	10:01:45	14	52.46
10:06:42	10:06:49	18	40.80
10:12:05	10:12:11	21	34.97
10:14:09	10:14:15	25	29.38
Three Wheelers			
t1	**t2**	**duration (sec)**	**Speed (km/h)**
10:01:43	10:01:49	13	56.5
10:01:57	10:02:05	15	49.0
10:03:55	10:04:03	22	33.4
10:04:05	10:04:12	12	61.2
10:07:07	10:07:13	12	61.2
10:07:11	10:07:17	14	52.5
10:07:39	10:07:46	20	36.7
Lorries			
t1	**t2**	**duration (sec)**	**Speed (km/h)**
10:03:57	10:04:05	20	36.72
10:05:18	10:05:23	19	38.65
10:06:02	10:06:09	19	38.65
Busses			
t1	**t2**	**duration (sec)**	**Speed (km/h)**
10:15:34	10:15:42	0:00:08	34.20

4.3 Analysis of Speed data

4.3.1 Calculation of 85th Percentile speed

Speed data for each section was separately considered in the analysis. For one road, there were several sections identified as speed data collection stations.

Steps followed to calculate 85th percentile speed.

- Re-order the speed data values in ascending order.
- If number of speed data points is n, the actual frequency of each data point is 1/n.
- Speed distribution curve was drawn by plotting actual frequency with speed data (Using MS Excel chart tool).

Figure-4 shows the cumulative speed distribution curve for station **26** at **Thorayaya – Kudakowana road.**

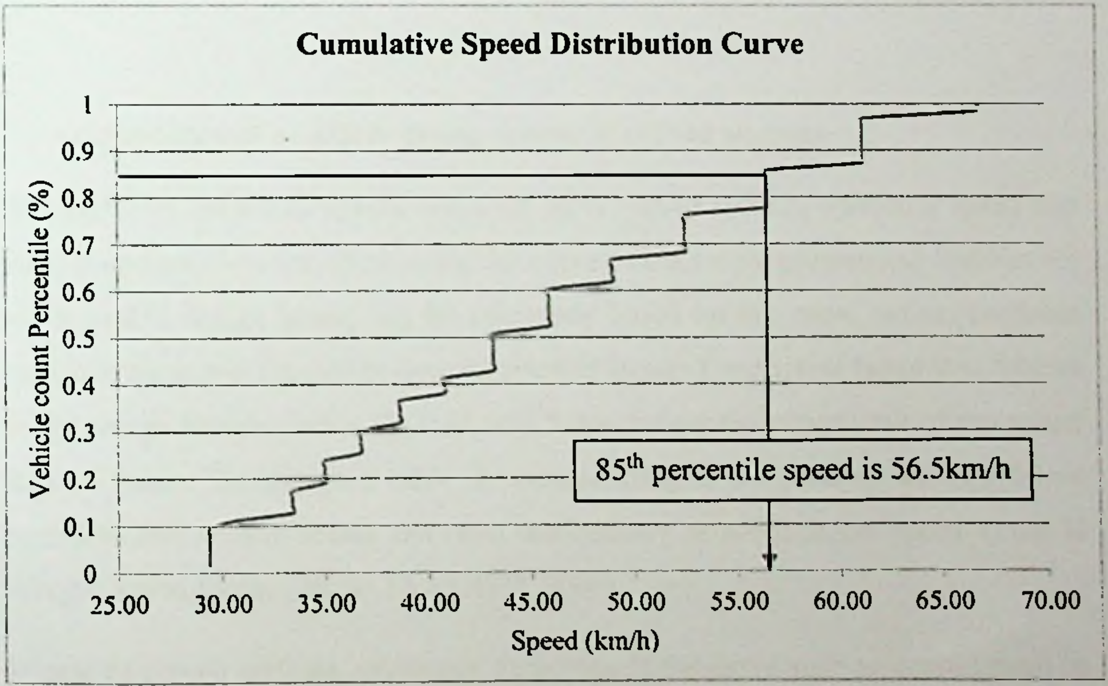

Figure 6: Cumulative Speed Distribution Curve for station 26

Using the speed distribution curve, 85th percentile value was found. For above example road section, the approximate value for 85th percentile speed of the section is 56.5 km/h, which means 85% drivers of the sample travelled at a speed of 56.5 km/h or below.

4.3.2 Median, Mean, and Standard deviation

The mean speed of the above sample is 45.24km/h, and the standard deviation is 10.7km/h which means that if the speed data sample follows a normal distribution within one standard deviation of the mean, or in other words in the range of10.7 km/h to the left (i.e. 34.54 km/h), and 10.7 km/h to the right (i.e. 55.94 km/h), almost 70% of travelling speeds exist. Generally speaking, almost 70% of drivers travelling this section had the speed choice between 34.54km/h and 55.94km/h.

As described above, speed data was analysed and for each section of a particular road, and following results were calculated.

- 85^{th} percentile speed
- Mean speed
- Standard deviation

4.3.3 Calculation of available design speeds of curved sections

As oppose to the actual speeds collected for a curved section, operating speed that were supposed to be travelled along the curve based on its geometrical features (or the available design speed) can be calculated based on the curve radius, available superelevation, and the design limiting friction factor. The friction factor was limited to the design friction factor (f), 0.15 which was below the upper limit of the actual friction factor. The design f value is corresponding to the point at which a driver begins to feel uncomfortable and react instinctively to avoid higher speed. (Paul H Wright, Karen Dixon , 2004), (AASHTO, 2001)

In case of curved sections, geometric properties of the curve such as curve length or arc length, superelevation, and the angle of change of direction were also measured in addition to the collection of speed data. Curve radius was calculated using the curved section length, and the angle of change of direction which was equal to the central angle of the curve. (See Figure-4) Included angle was measured using CAD file (station 25).

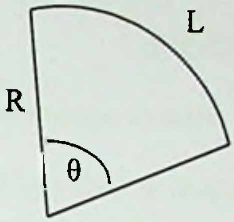

Figure 7: Basic properties of a simple circular curve

$$R = \frac{L}{\theta}$$

Where; R = curve radii

L = curve length

θ = central angle in radians

Safe operating travelling speed along the curve could be calculated by following equation. (See chapter 2, section 2.4, Speed and Horizontal curves)

$$0.01e + f = \frac{V^2}{127R}$$

In which $v = \sqrt{127R(0.01e + f)}$ *where* v = velocity in km/h

For station 25 in Thorayaya – Kudakowana road (See Figure 2);

L = 42.02 m

θ = 84 degrees = 1.466 radians

R = 42.02/1.466 = 28.66 m

e = 2%

f = 0.15

$$v = \sqrt{127 \times 28.66(0.01 \times 2.5 + 0.15)} = 24.23 \text{ km/h}$$

Hence the safe design speed of the above curved section under measured geometric properties was approximately 25 km/h. However, by analysing observed speed data, the Mean speed was found to be approximately30 km/h, and 85th percentile speed was36.2km/h approximately (represents 85% of drivers were travelling equal or below this speed) which were more than the safe operating speed (i.e. 25 km/h) of the curve.

5. RESULTS AND DISCUSSION

5.1 Speed assessment results

As discussed in previous chapters, speed data was analysed for each identified road sections. For each road, there were several sections or speed data collection stations that could be either a straight section or a curved section. Figure-8 illustrates this process up to the results of the data analysis.

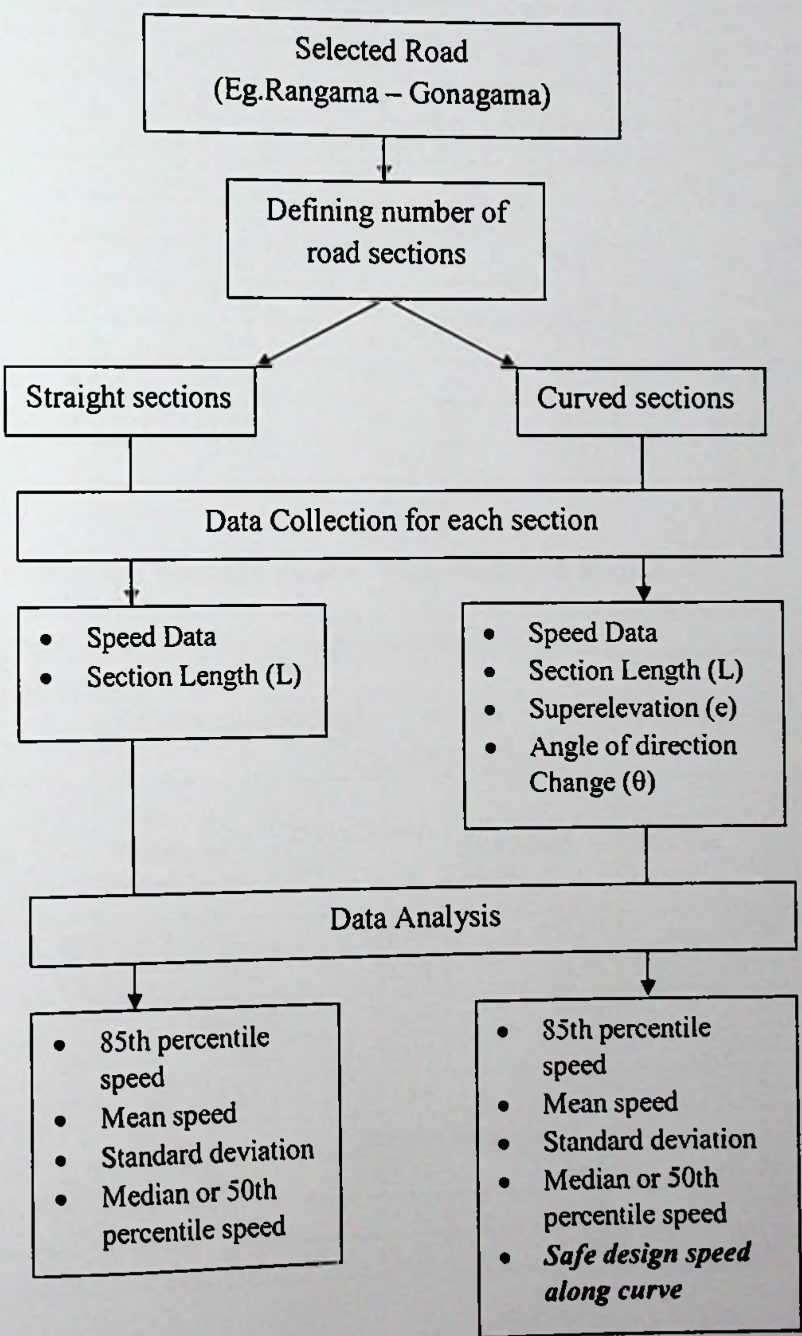

Figure 8: Research Flow simplified

Table 5: Results: Rangama – Gonagama Road.

Road Name	Rangama–Gonagama (10.25 km)				
GPS Coordinates					
Start :	7.630720, 80.305458	End :	7.572177, 80.365202		
Curved Sections					
Station	85th Percentile Speed km/h	Mean Speed km/h	Std. Deviation km/h	Mediankm/h	Safe design speed km/h
5	47.2	40.71	7.56	39.35	40.25
2	45.8	38.49	6.40	38.72	42.00
4	49.5	40.34	7.30	39.08	42.00
7	39.4	33.82	6.06	32.68	35.20
10	47.2	39.67	7.35	39.15	44.00
Straight Sections					
1	60.12	51.85	9.62	50.12	N/A
3	55.5	46.64	8.88	46.92	N/A
4	58.6	49.25	9.13	49.54	N/A
8	62.45	53.61	9.61	51.79	N/A
9	53.84	45.25	8.39	44.65	N/A
11	59.33	49.86	9.24	50.15	N/A

Table 6: Results: Kawdawaththa - Alakoladeniya Road.

Road Name	Kawdawaththa - Alakoladeniya(6.3km)				
GPS Coordinates					
Start :	7.5075884, 80.3422381	End :	7.479529, 80.349410		
Curved Sections					
Station	85th Percentile Speed km/h	Mean Speed km/h	Std. Deviation km/h	Median	Safe design speed km/h
13	32.5	28.03	5.20	27.10	25.23
14	39.4	33.11	6.31	33.31	42.10
17	41.81	35.14	6.51	35.34	35.47
18	35.45	30.43	5.46	29.40	21.50
19	33.25	27.94	5.18	27.58	20.12
Straight Sections					
12	50.45	43.51	8.08	42.06	N/A
15	49.2	41.35	7.88	41.59	N/A
16	53.8	45.21	8.38	45.48	N/A

Table 7: Results: Lakeround – Kudagalgamuwa Road.

Road Name	Lakeround - Kudagalgamuwa(8.8km)				
GPS Coordinates					
Start :	7.498206, 80.365366	End :	7.558642, 80.341030		
Curved Sections					
Station	85th Percentile Speed km/h	Mean Speed km/h	Std. Deviation km/h	Median	Safe design speed km/h
22	30.42	26.24	4.87	25.36	22.1
24	31.4	26.39	5.03	26.54	20.5
22a	37.5	31.51	5.84	31.70	23.6
Straight Sections					
20	61.2	52.79	9.80	51.02	N/A
21	54.8	46.05	8.77	46.33	N/A
23	50.4	42.36	7.85	42.61	N/A
24a	53.2	45.67	8.19	44.12	N/A
24b	48.32	40.59	7.52	40.06	N/A

Table 8: Results: Thorayaya – Kudakowana Road.

Road Name	Thorayaya - Kudakowana(3.46 km)				
GPS Coordinates					
Start :	7.509238, 80.407497	End :	7.483503, 80.410611		
Curved Sections					
Station	85th Percentile Speed km/h	Mean Speed km/h	Std. Deviation km/h	Median	Safe design speed km/h
25	36.2	30.00	4.23	29.85	24.23
28	33.4	28.07	5.35	28.23	23.5
29	35	29.41	5.45	29.59	30.2
30	36.5	31.33	5.62	30.27	37.4
Straight Sections					
26	56.5	45.24	10.7	43.20	N/A
27	48.6	40.84	7.78	41.08	N/A
31	52.3	43.95	8.15	44.21	N/A

Table 9: Results: Mallawapitiya - Katupitiya Road.

Road Name	Mallawapitiya - Katupitiya(8.4 km)				
GPS Coordinates					
Start :	7.475688, 80.387081	End :	7.408298, 80.387186		
Curved Sections					
Station	85th Percentile Speed km/h	Mean Speed km/h	Std. Deviation km/h	Median	Safe design speed km/h
34	42.3	36.48	6.77	35.27	35.4
35	38.6	32.44	6.18	32.63	35.2
Straight Sections					
32	52.3	43.95	8.15	44.21	N/A
33	57.2	49.10	8.80	47.44	N/A
36	60.1	50.51	9.36	49.84	N/A
37	55	47.44	8.80	45.85	N/A

Table 10: Results: Pallandeniya - Dikwehera Road.

Road Name	Pallandeniya - Dikwehera(7.6 km)				
GPS Coordinates					
Start :	7.522560, 80.329473	End :	7.534629, 80.284249		
Curved Sections					
Station	85th Percentile Speed km/h	Mean Speed km/h	Std. Deviation km/h	Median	Safe design speed km/h
39	38	32.78	6.08	31.68	28.4
40	40.1	33.70	6.42	33.90	32.7
Straight Sections					
38	58	48.74	9.29	49.03	N/A
41	55.5	46.64	8.65	46.92	N/A

Table 11: Results: Hanhamuna – Dampitiya Road.

Road Name	Hanhamuna - Dampitiya(6.1 km)				
GPS Coordinates					
Start :	7.551756, 80.302197		End :	7.534918, 80.263984	
Curved Sections					
Station	85th Percentile Speed km/h	Mean Speed km/h	Std. Deviation km/h	Median	Safe design speed km/h
42	38	32.78	6.08	31.68	37.4
45	40.7	34.20	6.52	34.41	40.00
Straight Sections					
43	55.21	45.44	8.7	46.05	N/A
44	45.4	40.34	7.31	39.1	N/A

5.2 Comparison of results

5.2.1 Curved Sections

As discussed in previous chapters, almost every rural road in North Western Province (NWP) has higher density of bends/curves with respect to an average major A or B class roads. Hence travel speeds are highly dependent on this factor. In this study, not only speed data analysis was done, but also safe design speed of a vehicle that travels along the curve was calculated using actual geometrical properties of the curve. Hence this gives a clear image of actual behaviour of traffic with the design speeds of curves. Speed comparison of curved sections of Rangama – Gonagama road is shown in Figure-9.

5.2.1.1 Rangama – Gonagama, comparison of speeds

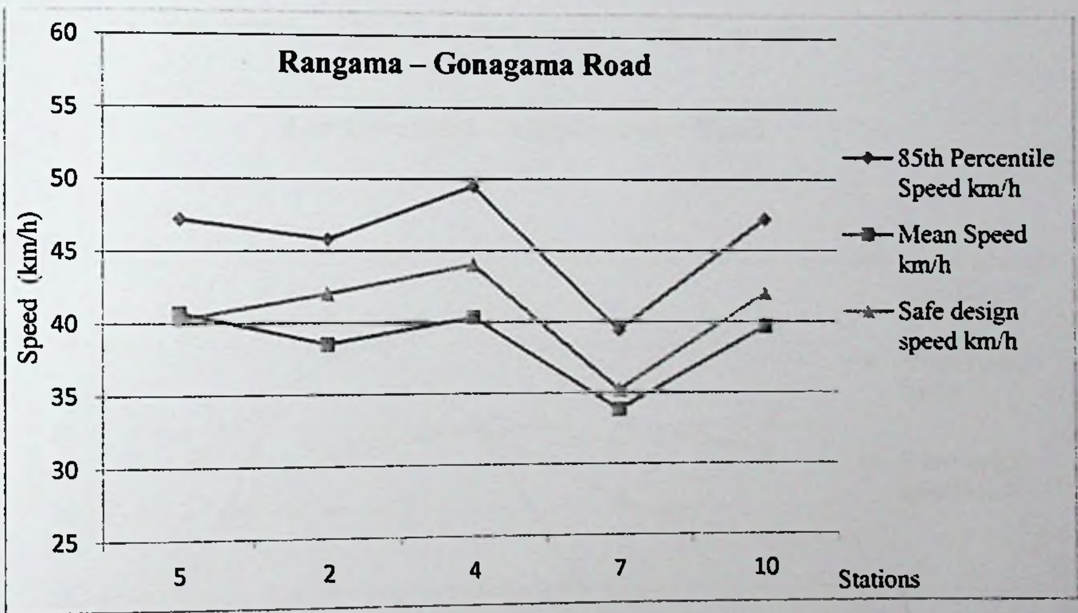

Figure 9: Rangama – Gonagama, comparison of speeds

There were five curved sections in this road (stations 5, 2, 4, 7, and 10. See Figure-6). The mean speed of stations 2, 4, and 10 are below the safe design speed of those corresponding curves. Following results can be explained by considering standard deviations of those sections (See Table-12).

In station 2, almost 70% of travelling speeds are in between the range 32.09 km/h and 44.89 km/h, in which the design speed of the road (42 km/h) lies within the same range. However, the 85th percentile value on this section is 46.0 km/h. This means that 85% of speeds in the sample are equal or below 46.0 km/h or 15% of the drivers speed more than 46.0 km/h which is not favourable with safe design speed. Same scenario can be explained with section 4 and 10 (See Table 12).

Table 12: Comparison of design speed with statistical results.

Station	Mean Speed km/h	Std. Deviation km/h	Mean - STD	Mean + STD	Safe design speed km/h	85th Percentile Speed km/h
2	38.49	6.4	32.09	44.89	42	46.0
4	40.34	7.3	33.04	47.64	44	49.5
10	39.67	7.35	39.15	42	42	47.2

5.2.1.2 Kawdawaththa - Alakoladeniya, comparison of speeds.

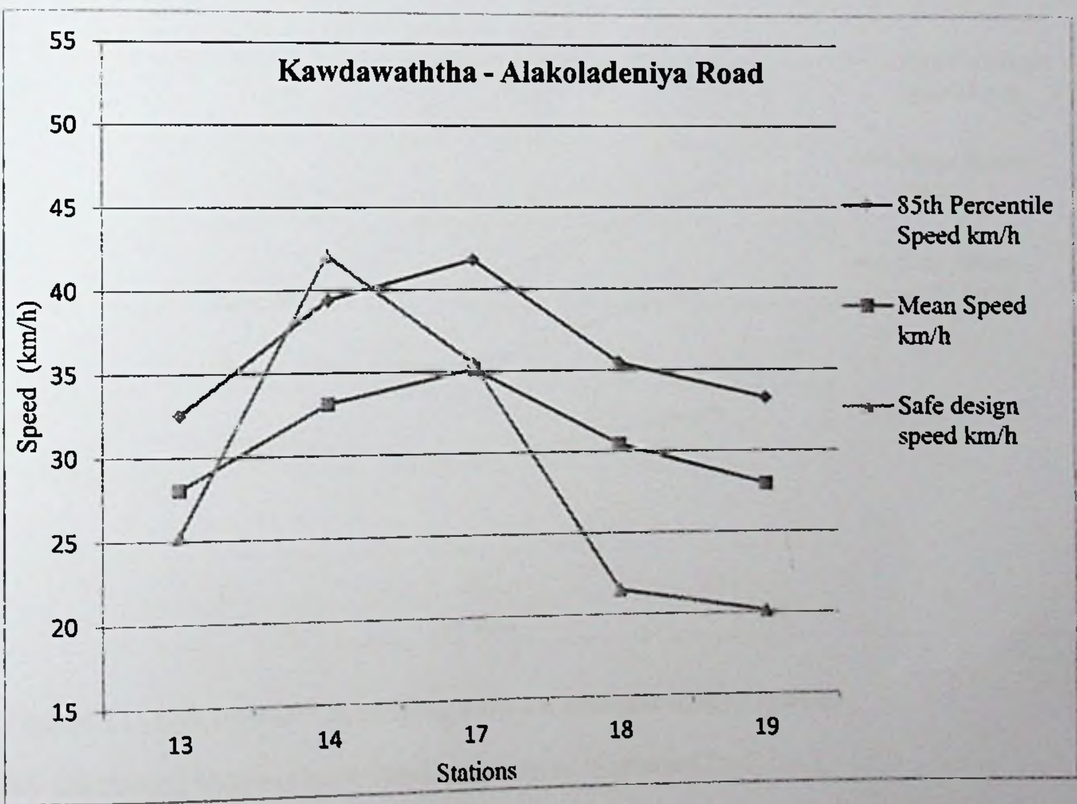

Figure 10: Kawdawaththa - Alakoladeniya, comparison of speeds

As the Figure-8 illustrates, station 14, and 17 curves seem to have safe passage of driving pattern. In case of station 14 curve, both 85th percentile speed, and the mean speed are below the design speed. This was because this section had poor line of sight due to vegetation, and the roadside constructions. Also the right of way was limited causing a narrow carriageway. Drivers had chosen lesser operating speed due to these reasons when passing this curve. However, it is crucial to investigate this kind of sections together with crash statistics, since drivers who don't have experience about the area can speed at these kind of curves, and may encounter with traffic conflicts unknowingly. Less driving experience or driving in night time can also increase the travelling speed. Hence the sight distance of the curve must be improved. Curved sections 13, 17, 18, and 19 are similar to the sections discussed in 5.2.1.1.

5.2.1.3 Lakeround - Kudagalgamuwa, comparison of speeds

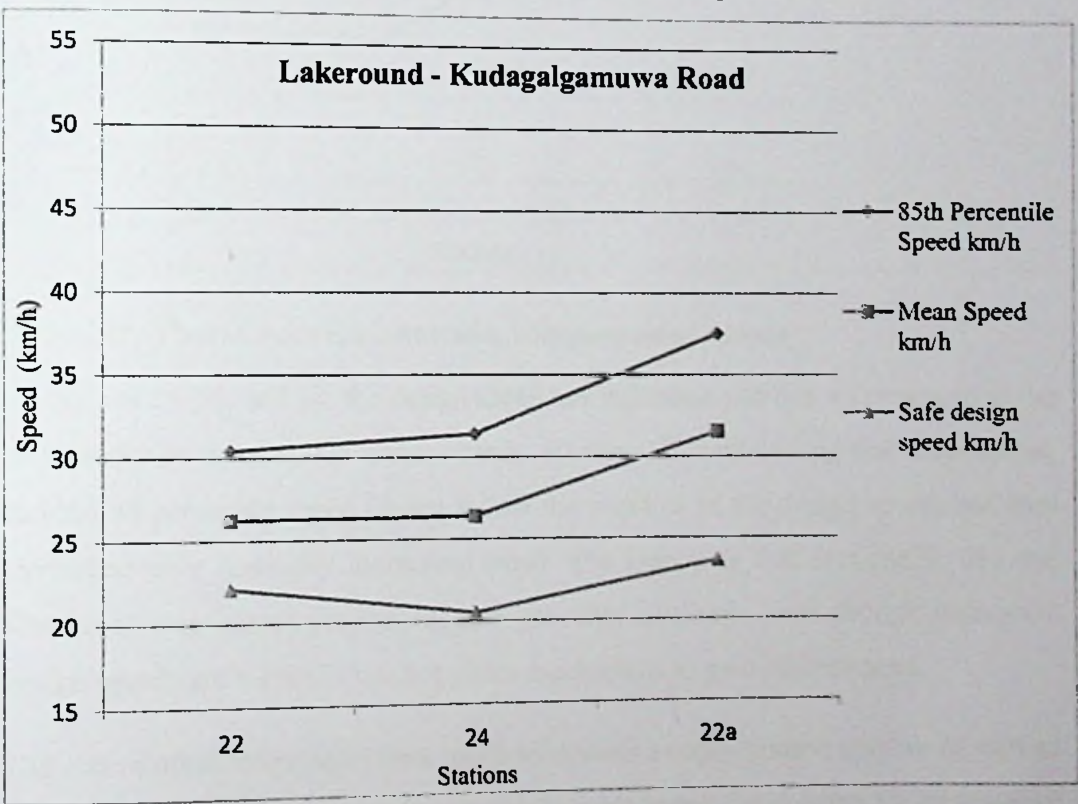

Figure 11: Lakeround - Kudagalgamuwa, comparison of speeds.

All the curved sections have similar pattern as discussed in 5.2.1.1.

5.2.1.4 Thorayaya - Kudakowana, comparison of speeds

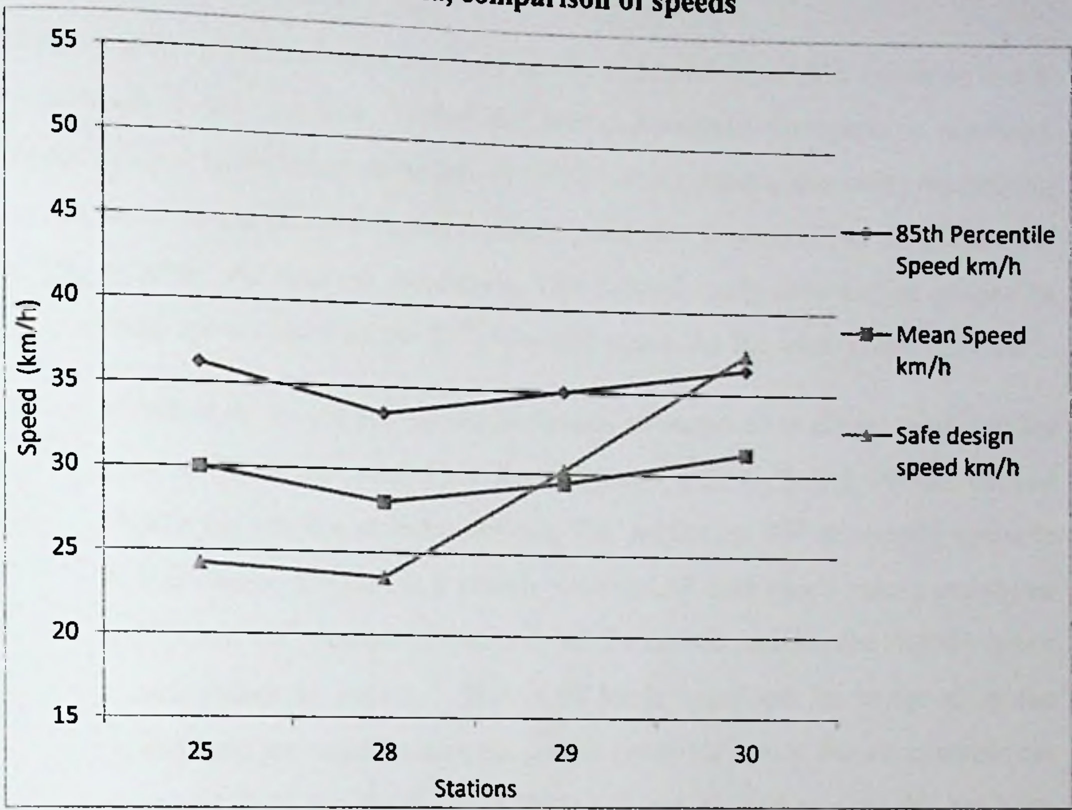

Figure 12: Thorayaya - Kudakowana, comparison of speeds

In sections 28, 29, and 30, the design speed has increased and this was because of the increase in the curve radius at those bends. However it is interesting that mean speed, and the 85 percentile speed do not follow the trend as of the design speed, but they have their own gradually increasing trend. The reason is that sections28, 29, and 30were reverse curves (curves located one after another). Even though individual design speeds are higher, it has not given much space to gain higher speed.

The rest of other roads don't have much to discuss as only limited number of curved sections (Two sections per road) were studied. However, these curved sections have similar pattern as discussed in 5.2.1.1.

5.2.2 Straight sections and curved sections

North western provincial rural roads do not have posted speed like major A and B class roads in the province. Neither the law enforcement for speed is practised. Hence rational speed limits come into discussion that promote the safety by helping drivers to choose a reasonable and prudent speed that is appropriate to the normal traffic, weather, and roadway conditions. This limited study concerns on proposing such rational speeds based on the 85th percentile speed, for the roads under purview.

Figure-13 below shows the 85th percentile speeds as measured in eleven road stations in Rangama – Gonagama road. First five stations (5, 2, 4, 7, and 10) are curved sections while the rest are straight sections. The maximum 85th percentile speed is 62.45 km/h in station 8 which is a straight section. All said speed values are above the speed 50 km/h. 85th percentile speeds of all the curved sections are slightly lesser than 50 km/h except in station 7. Hence 50 km/h speed can be assigned as the rational speed limit provided limiting the posted speed for bends. For an example the maximum speed limit for the bend at station 7 can be assigned as 40 km/h by considering the operating speed (i.e. 85th percentile speed), and the available design speed of that curve. This speed limit is imposed only for the curve itself so that the posted speed for the entire road is overridden at that section.

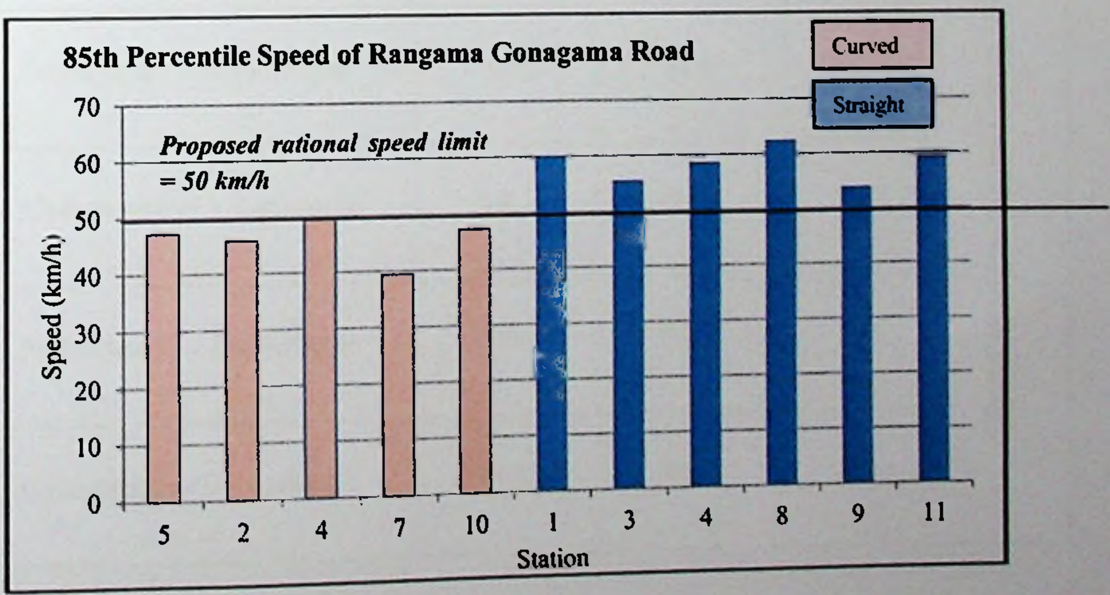

Figure 13: 85th Percentile Speed of Rangama - Gonagama Road.

Similarly, 85th percentile speed calculated for other roads were graphed and rational speed limits could be estimated graphically as above. Table-13 shows summary of results found and suggested speed limits for the roads studied.

Table 13: Rational Speed limits proposed.

Name of the road	Maximum 85th Percentile speed in straight sections km/h	Minimum 85th Percentile speed in straight sections km/h	Proposed rational speed limit km/h	Remarks
RangamaGonagama	62.45	53.8	50	Override to lesser speed limits at bends where necessary
Kawdawatta - Alakoladeniya	53.8	49.2	50	
Lakeround - Kudagalgamuwa	61.2	48.3	50	
Thorayaya - Kudakowana	55.7	48.6	50	
Mallawapitiya - Katupitiya	60.1	52.3	50	
Pallandeniya - Dikwehera	58.0	55.5	50	
Hanhamuna - Dampitiya	55.21	45.4	50	

6. DISCUSSION, CONCLUSION AND RECOMMENDATIONS

6.1 General findings

In previous chapters, it was discussed that the provincial or rural roads have higher density of curves per unit length. The safe design operating speeds of selected curved sections for each road was calculated and this speed is often lesser than the actual operating speeds of corresponding curves. The reason for this might be the available actual side friction factor (f) which is higher than that of the design value (f = 0.15) used for calculations in this study. As discussed in literature findings, side friction factor (f), can be as higher as 0.6, but in higher f values, the speed is higher and driver feels uncomfortable due to centripetal force acting. It seems that available side friction factor that a driver is willing to travel the curves was slightly higher than the design value.

This study focuses on speed assessment, based on current operating speeds of rehabilitated rural roads. It can be argued that the operating speed of a rehabilitated road suddenly increases just after the completion of rehabilitation. Anyway, with time, the operating speeds are stabilized as local drivers choose a reasonable, safe speed that associates with roadway conditions, nature of traffic, and the weather. This may more or less has been shown reduction of likelihood of crashes. However it was observed that when road improvement projects in major arterial roads (A & B) were undergone, most of road crashes happen in provincial roads (C & D). It can be obviously argued that this is because of the increased traffic which is diverted from major roads due to road construction bottlenecks. Anyway it is more likely that the above mentioned increased traffic is not local to the region. In other words, the drivers are not experienced about these road traces. Hence there is likelihood of involving crashes or at least encountering traffic conflicts. On contrary, local drivers know how to manage speed according to the road trace. They know when to increase speed, where road surface is fine, whether they have a good sight visibility, where straight sections are located, when to decrease speed, where are sharp bends, intersections, public places, places having higher pedestrian movement, and etc. Thus, speed is stabilized timely with local drivers after rehabilitation; A driver having a less experience about the road can still face traffic conflicts. This again reiterates the importance of enforcing rational speed limits, and providing road user safety measures than present.

6.2 Limitations

It is important to discuss about the limitations of this study. This study was based on the speed data of provincial rural roads of North western province of Sri Lanka. It has two districts, Kurunegala and Puttalam. Thus in sample selection, there should have been roads from both districts. However due to lack of resources, and time restrictions, only several roads from Kurunegala district were selected for assessment. The main activity of this process is speed data collection. An accurate study of operating speeds depends on unbiased sample of data set. However, vehicle speeds can vary throughout the day as a function of traffic conditions, volume, traffic flow, weather conditions, and other factors. At night time, vehicle speeds may be significantly higher than the speed limit than vehicle speeds in congested peak hour conditions. At night time, there is less traffic and there is no any enforcement for speed limits. For this study, only day time speed data was collected. Hence the study is limited to daytime traffic behaviour.

Another limitation of speed data is its accuracy. Resources to find accurate speed data were limited for this research. Most of the speed data were measured manually. Hence speed data collection methods with higher resolution are important in further implementation of this study.

6.3 Conclusion

Operating speeds on straight sections were given priority in suggesting rational speed limits. Because operating speeds in curves are considerably lower and enforcing lower posted speeds only based on operating speeds on curves for entire road, would not be practical since drivers tend to disobey the speed limit. This is where rational speed limits become important. Rational Speed Limits based on operating speeds, promote public safety by helping drivers to choose a reasonable, and prudent speed that is appropriate for normal traffic, and roadway conditions.

6.4 Recommendations

The suggested rational speed limit for all the roads under purview is 50 km/h (See Table-13) and this speed limit will be overridden to a lesser speed limit (or limits) at horizontally curved sections based on the design speed and, the 85th percentile speed of those curves where necessary. These speed limits are to be prior notified to the approaching traffic using traffic signs (See Figure-14) and are enforced only for the curve itself.

Figure 14: Traffic signs limiting the speeds on curves (Examples)

The 85th percentile speed is determined in the speed assessment. This speed was used as a basis for suggesting rational speed limit since most drivers behave in a safe and reasonable manner, do not drive at excessive speeds, and do not want to get into crashes. Also it encourages drivers to travel at the same speed. However this research has significant limitations, as it has not considered formal review of factors like traffic flow, roadway design, crash information, and local development activities,, and as it has only considered 85th percentile speed and the design speed as the basis of deciding rational speed limits. Considering above discussed reasons, it can be identified that there is a mandatory requirement for provincial or rural roads to implement speed limits associated with law enforcement for the assurance of public safety. Here in this study, rational speed limits based on 85% percentile speed, can be utilized as a good basis for the above requirement.

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