MODELLING TRAFFIC FLOW ON INTERCHANGE

Master of Technology

In

Transportation Engineering

By

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIRMENTS FOR THE DEGREE OF

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CERTIFICATE

This is to certify that the thesis entitled "**MODELLING TRAFFIC FLOW ON INTERCHANGE"** submitted by **ARUMUGA SUBHASHINI N** in partial fulfilment of the requirements for the award of **Master of Technology in Civil Engineering** with specialization in "**Transportation Engineering"** during 2012-2014 session at the National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance. To the best of my knowledge, the results contained in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

Date**:**

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ARUMUGA SUBHASHINI N

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ABSTRACT

The rapid urbanization alters the life style in high scale and metropolitan cities adapt traffic diverting structures like interchanges and bridges to handle the ever increasing traffic growth. It is high time to effectively utilize these traffic systems, hence a traffic model explaining the effective travel pattern is obligatory. Fuzzy logic is an effective concept in interpreting and reciprocating performance similar to human reasoning and can describe complex systems in linguistic terms instead of numerical values. In this thesis, a system was established based on Fuzzy Inference System (FIS) with output data as Vehicular Speed (S) and input data as various highway geometric elements. The study was conducted on two steps as for up - ramp condition and down – ramp condition. Two Traffic models (TFup & TFdn) were developed with radius of curvature, super elevation, frictional coefficient and slope as governing factors. The inferences show that these models can be used to predict and understand the traffic flow along the interchanges with the effect of gravity and friction on the travelling vehicle. A correlation was established between the geometric elements and speed of the vehicle. A simulation study and real life data analysis were performed to demonstrate model fitting the performances of the proposed model.

Keywords: Traffic flow (TF), FIS, Interchange Flow, Fuzzy Model

CHAPTER 1

INTRODUCTION

1.1 Background

Traffic is the stream of vehicles moving on highway and congestion happens when this stream comprises of slow moving vehicles. The rapid urbanisation alters the life style in high scale and metropolitan cities adapt traffic diverting structures like interchanges and bridges to handle such congestion. For efficient utilization of these structures it is significant to know about the traffic flow, hence a model explaining the same is essential. Earlier studies on traffic flow define it evidently that the traffic flow is dependent on the structural property of the traffic facility and also on the driver behaviour. Various studies relate the driver's response to specific conditions to predict the behavioural pattern and to develop different numerical models. Though such elaborate studies were done, no particular model could depict the realistic scenario as the governing factors for each situation varies. In this thesis, an effort is made to develop a model for an interchange, as it plays an integral part in managing traffic without interruption.

There are different types of interchanges, which can be broadly classified under,

System interchanges which includes -

- Four-way interchanges
  1. Cloverleaf interchange
  2. Stack interchange
  3. Cloverstack interchange
  4. Turbine interchange
  5. Roundabout interchange
  6. Other/hybrid interchanges
- Three-way interchanges
  1. Trumpet interchange
  2. Directional T interchange (Full Y interchange)
  3. Semi-directional T interchange
  4. Other/hybrid interchanges
- Two-way interchanges

Service interchanges which includes -

- Diamond interchange
- Parclo interchange/folded diamond
- Diverging diamond interchange
- Single-point urban interchange
- Other/hybrid interchanges

1.2 Objective

For an intricate study, the case of **cloverleaf interchange**is chosen, situated at ***Kathipara junction*** in ***Chennai*** which includes NH-4, NH-45,and NH-205, the thesis is aimed

- To study the effect of gravitational force existing on the vehicle moving along the loop of the interchange
- To study the relation between speed and the slope involving gravity and friction
- To develop model for the interchange studying the driver behaviour.

The conventional models like Pipe's, Forbes's and General Motors models are conserved in this case as there will be more number of variables, consequently simulation model is to be adopted which is an effective tool for analysing wide variety of dynamical problems.

The thesis is divided into seven chapters of which this is the first. The second chapter presents a review of the past work done on modelling traffic flow in accordance with driver behaviour as well as the literature on car-following theory and expresses the motivation for this thesis.

In Chapter 3, the data collected for this thesis work are described. The structural and traffic data of the study area are consolidated by appropriate survey by NHAI (National Highway Authority of India). The governing factors for the vehicle and their limitations are prescribed

In Chapter 4 the empirical studies to determine the traffic flow on interchanges is described in detail.

The chapter 5 defines proposed model and also the effect of the governing factors on the vehicle motion to streamline the model and presents the results obtained from the proposed model. These results are used to validate the model

Chapter 6 validates the analysis by summarizing results obtained from comparison of observed and simulated values. Chapter 7 concludes the thesis.

CHAPTER 2

LITERATURE REVIEW

This chapter provides an overview of literature related to traffic modelling and the factors that contribute to it. The study aims to develop an efficient traffic model for an interchange by analysing the impact of gravity and highway geometric elements on deciding the speed of the vehicle.

2.1 Vehicular flow models

Partha Chakroborty et al. (2004) studied the driver behaviour in uninterrupted traffic flow to develop a microscopic model which aims to predict the driver behaviour in diverse driving circumstances and the response of driver including both steering and speed control were analysed.

Y. Hassan et al. (2003) studied on effect of vertical alignment on driver perception of horizontal curves and found that perception of the driver of the road features ahead is an important human factor and should be addressed in road design. An erroneous perception of the road can lead to actions that may compromise traffic safety and the poor coordination of horizontal and vertical alignments is believed to cause such wrong perceptions. Through statistical analysis they suggested that the horizontal curvature looked consistently sharper when it overlapped with a crest curve and consistently flatter when it overlaps with a sag curve.

Pattharin Sarutipand et al. (2003) redefined the conventional car-following model as the response depends both on the stimulus and sensitivity. As stimulus is a function of relative speed and sensitivity is a function of speed and headway.

Johan Janson Olstam, Andreas Tapani (2004) compared and described the car-following models used in the four traffic micro-simulation software packages AIMSUN, MITSIM, VISSIM, and the Fritzsche car-following model. It resulted in similarity between the behaviour of the models even though the car following approaches was different.

Richard W. Rothery studied the analysis of local and asymptotic stability in a line of vehicles and provided a mathematical driving model with scientific foundation. It provided a steady state description of single lane traffic flow with regard to safety and traffic characteristics of to develop advance automatic vehicle control systems.

Elmar Brockfeld et al. (2004) studied that whenever a microscopic model is developed an error of 15.1% to 16.2% is observed. The error is due to the negligence of prime factors which governs the vehicle characteristics. It is obligatory to understand the impact of each of these factors and their importance in deciding the vehicle characteristics when a model tries to depict the realistic situation.

2.2 Traffic models – case studies

Ruili Wang et al. studied driver behaviour and its effects on traffic flow at three-lane roundabouts and developed Multi-stream Minimum Acceptable Space (MMAS) Cellular Automata (CA) models to simulate heterogeneity and inconsistency of driver behaviour and subsequent interactions were analysed.

Chao Wang and Benjamin Coifman (2013) studied the vehicular traffic for multi-lane and developed two models. The models when compared by fundamental traffic parameters resulted in variation because the model considered lane changes but in reality such changeover will cause platoons reducing the traffic flow.

H. J. Ruskin and R. Wang (2002) studied traffic flow at urban un-signalised intersection using cellular automata by simulating the heterogeneity and inconsistency of driver behaviour. The study exposed the driver distribution having a noticeable impact on capacity of major and minor traffic streams.

Scott Henry Chacon (2009) studied the effect of driver behaviour on freeway traffic flow. A model was developed by simulating the driver behaviour in recreated segment of freeway by incorporating real data. The result obtained evidently proves that there is an optimal following distance which improves traffic flow.

Roger V. Lindgren and Sutti Tantiyanugulchai studied traffic flow at a suburban interchange by simulating two traffic models (Paramics and VISSIM) for a diamond interchange and results showed irregular arrival patterns along the ramp terminals hence modelling traffic along the adjacent intersections became necessary. The results also prompted to determine the required number of model runs as results differed with every random data due to its stochastic nature.

2.3 Summary of the Literature Review

The primary interest in researching traffic models was to investigate a common commuting phenomenon and as interchange has become vital in all major cities to handle congestion, a model personalised to such condition seemed essential. Even though the cloverleaf interchange has disadvantages, the interchange allows uninterrupted traffic flow which is essential for speed analysis.

CHAPTER 3

EMPRICAL OBSERVATIONS

3.1 Background

For this study, the cloverleaf interchange situated at kathipara junction, Chennai was selected. Various field data such as Traffic characteristics, Directional distribution and Speed analysis data were collected for the roads. Careful collection of such data was acquired from National Highway Authority of India (NHAI), Chennai.

Kathipara intersection is the gateway to Chennai from the airport. The intersection consists of four roads meeting at a roundabout. The four roads are Anna Salai leading to Guindy, NH-45 leading to airport, Poonamallee road and the Inner Ring Road (IRR). The IRR and NH-45 carry substantial heavy traffic as this section acts as a thoroughfare and bypass for Chennai city. Anna Salai leads to Guindy and is an important corridor in the road network of the city.

Fig 3.1: Kathipara junction – Before

The NHAI along with TNRDC did advanced action to develop the intersection to a standard. With various investigations about topography, traffic, structural conditions and utility services, the design options and their evaluation had been carried out. The most efficient option was modified **Cloverleaf interchange**.

The Airport – IRR link will have three lanes in each direction and Anna Salai Road – Poonamallee corridor was raised to give headroom clearance. There are four cloverleaf loops to handle right turning traffic and the left turning traffic will be undertaken at ground level.

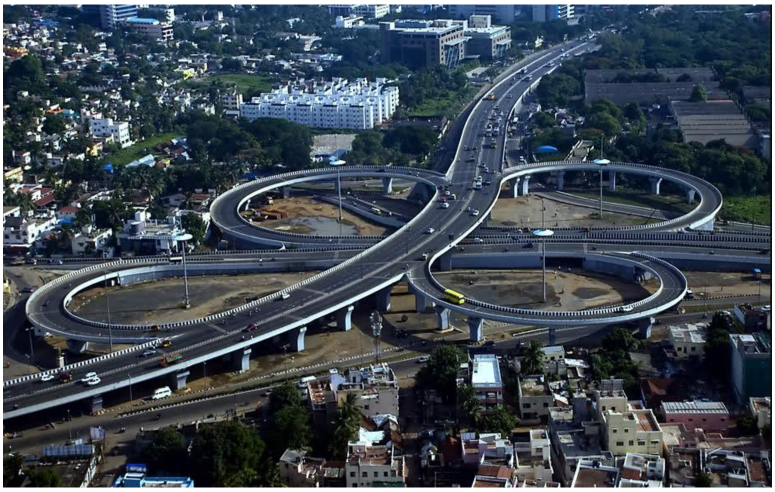

Fig 3.2: Kathipara junction – After

3.2 Details of the Interchange

Table 3.1: Geometric design Standards of the Interchange

Particulars	For NH and Airport road		For Loop ramps	
	MINIMUM	**DESIRABLE**	**MINIMUM**	**DESIRABLE**
Ramp design speed (kmph)	50	65	30	40
Radius of curvature (m)	90	155	30	60

1. Maximum super-elevation-7% ; considered – 4%
2. Grades on ramp : 1 in 40 for up-ramps ; 1 in 25 for down-ramps
3. Codes followed:
   a. IRC 92-1985
   b. IRC 38-1988
   c. IRC 6-2000

DETAILS OF THE ROADWAYS

1. Airport-Poonamalle
2. Airport-Inner Ring Road
3. Airport-Guindy
4. Poonamalle-Airport
5. Inner Ring Road-Airport
6. Guindy-Airport
7. Inner Ring Road-Airport
8. Inner Ring Road-Poonamalle
9. Inner Ring Road-Guindy
10. Guindy-Airport
11. Guindy-Poonamalle
12. Guindy-Inner Ring Road

CHAPTER 4

ANALYSIS OF EMPRICAL DATA AND RESULTS

4.1 Background

Speed analysis has been carried out to determine the effects of different alignment elements of the highway on the speed of the vehicle along the loops of the interchange. These alignment elements are radius of curvature, super elevation, friction factor and slope of the ramp. Finally, these geometric elements are statistically analysed and considered for model development which are statistically significant.

4.2 Speed Analysis

The speed of the vehicle is the resultant of the geometric design of the interchange and driver's interaction with the environment. The prime governing factors of speed of the vehicle are radius of curvature, friction factor, super elevation and direction. It is generally expressed as kilometre per hour.

Speed is calculated by

- Friction factor and radius of curvature

$$\text{Speed} = (F \times g \times R)^{(1/2)}$$

- Radius of curvature and super elevation

$$\text{Speed} = (e \times g \times R)^{(1/2)}$$

- Friction factor , radius of curvature and super elevation

$$\text{Speed} = [127 \times R\,(e + F)]^{(1/2)}$$

Where,

F – Friction factor

g – Gravitational force (9.81 m/s)

R – Radius of curvature

e – Super elevation

4.3 Analysis of geometric variables

The alignment elements of the interchange has been analysed with speed of the vehicles.

4.3.1 Analysis of speed with Radius of curvature

Speed of the vehicle has been calculated for every 5m interval of radius of curvature and the same has been plotted in Figure 4.1.

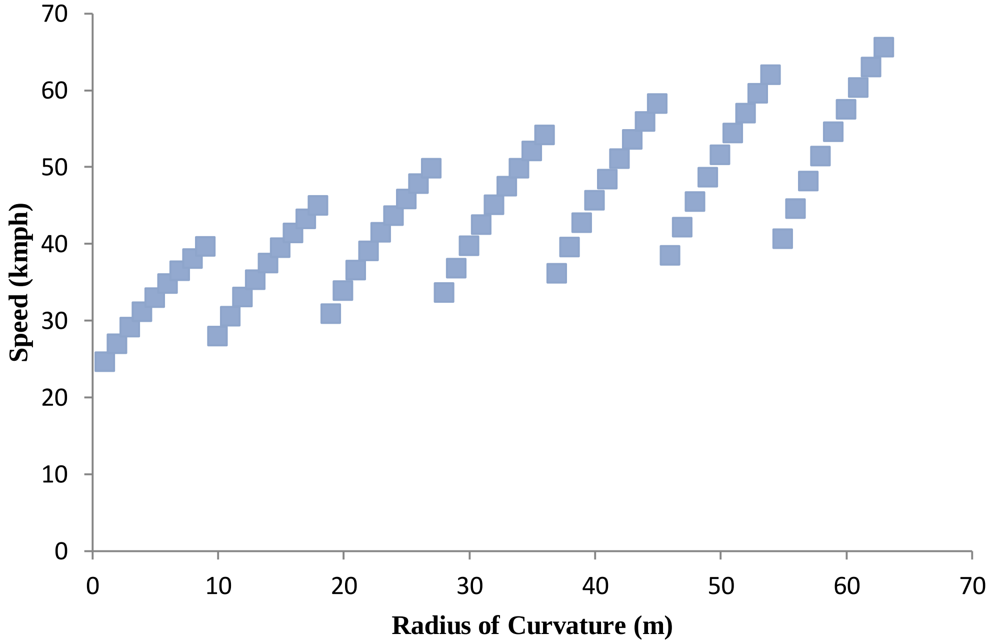

Fig 4.1: Speed versus Radius of curvature

4.3.2 Analysis of speed versus Super elevation

Speed of the vehicle has been calculated for every 0.5% interval of super elevation and the same has been plotted in Figure 4.2.

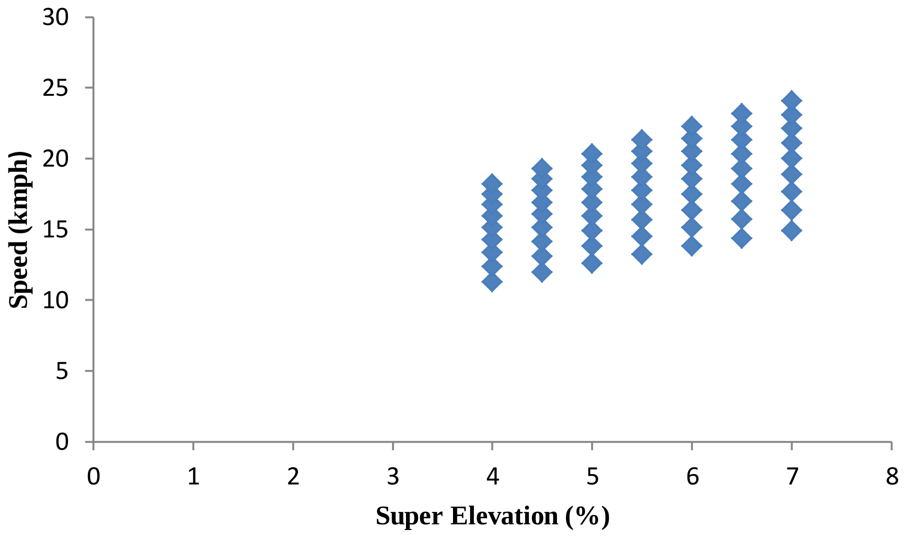

Fig 4.2: Speed versus Super elevation

4.3.3 Analysis of speed versus Frictional coefficient

Speed of the vehicle has been calculated for every 0.05 units of frictional coefficient and the same has been plotted in Figure 4.3.

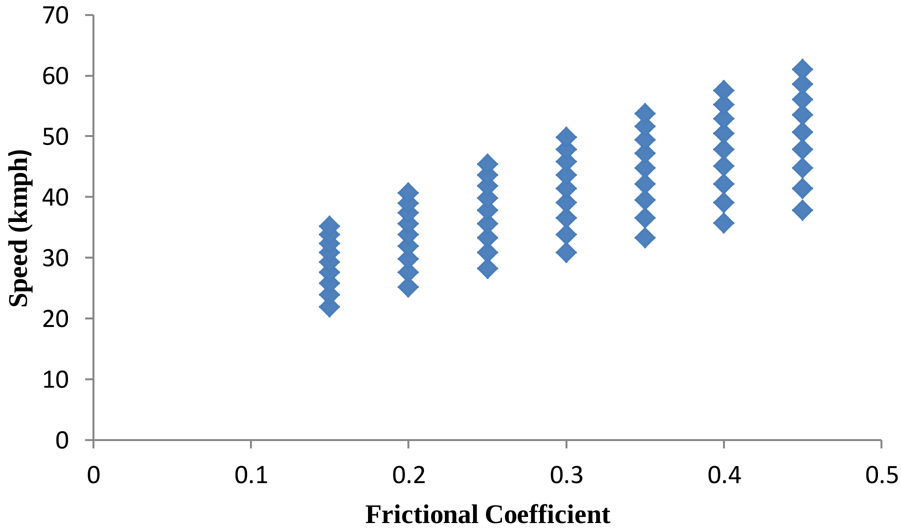

Fig 4.3: Speed versus Frictional Coefficient

4.4 Statistical Analysis of Variance

Analysis of variance (ANOVA) is a statistical process used to evaluate the differences between group means and their relation. In ANOVA setting, the significant impact of each variable on the response factor could be determined.

All geometric alignment elements has been analysed independently with speed of the vehicle of the interchange. Microsoft Office Excel has been used for the formulation of regression equation and analysis and the result of ANOVA has been furnished in Table 4.1 and Table 4.2

Table 4.1: Summary of Analysis of Variance of Up-Ramp

Variables	**Sum of square**	**Mean of square**	**F**
Radius of curvature	32.194	32.194	24.33
Super elevation	13.17	13.17	15.668
Friction coefficient	19.72	19.72	3.51

Table 4.2: Summary of Analysis of Variance of Down-Ramp

Variables	**Sum of square**	**Mean of square**	**F**
Radius of curvature	26.97	26.97	76.69
Super elevation	10.35	10.35	2.85
Friction coefficient	21.08	21.08	35.66

Above analysis shows that the highway geometric elements like, radius of curvature and super elevation are significant for determining speed of the vehicle in up-ramp condition and geometrics elements like, radius of curvature and frictional coefficient are significant for determining speed of the vehicle in down-ramp condition. The group effect of the geometric elements on speed of the vehicle has been calculated through regression model as below and same has been furnished in Figure 4.4 and Figure 4.5.

Speed (Up-Ramp) = 1.210(RC) + 155.126(SE) – 1.504

Speed (Down-Ramp) = 0.510(RC) + 82.29(FC) – 3.193

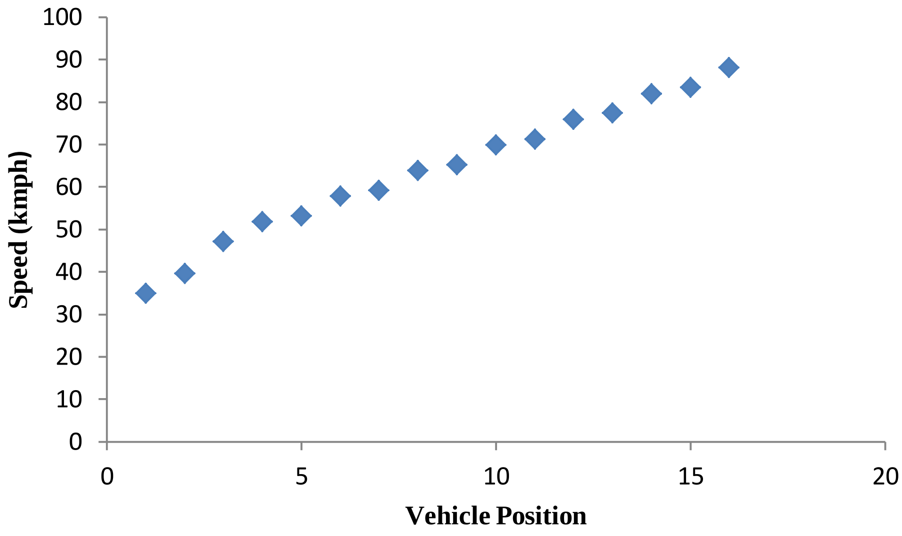

Fig 4.4: Speed Analysis – Up ramp

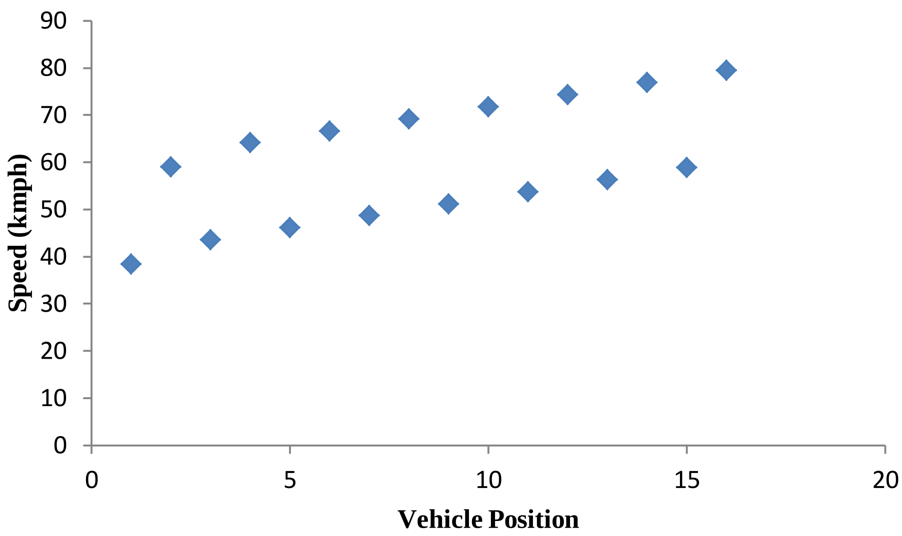

Fig 4.5: Speed Analysis – Down ramp

4.5 Results and Discussion

From the statistical analysis, it has been perceived that certain variables are very extensive in determining vehicle speed. The geometric elements like, radius of curvature, super elevation play a very significant role in deciding the speed of vehicles during up-ramp condition. However, radius of curvature and frictional coefficient determines vehicular speed during down-ramp condition.

As the relation between the governing parameters induce convolution, fuzzy models have been proposed which provide the vehicular speed for the ramp of the interchange. The cause variables are radius of curvature, super elevation and slope for up-ramp condition and radius of curvature, frictional coefficient and slope for down-ramp condition.

CHAPTER 5

PROPOSED MODEL

5.1 Background

In the former studies, commonly the traffic flow models were developed as statistical prediction model with limited parameters. From the analysis it is preferred to use fuzzy logic, as decision making is a human quality and no precise inference could be attained by other logical means.

This chapter explains the proposed fuzzy logic model, where an attempt has been made to predict the Speed (S) with respect to the various highway geometric elements.

Fuzzy logic is a mathematical tool for modelling that explains any natural phenomenon for decision making in the absence of complete and precise information. Their role is significant as it can express any natural phenomenon especially related to human decision making using linguistic variables, which is not possible using any mathematical expression.

5.2 Basics of Fuzzy Sets

A fuzzy set is defined as the sets whose elements have degrees of membership(Zadeh and Klaua, 1965). A fuzzy set theory permits the gradual valuation of the membership of the elements in the set. When the elements fit into the group completely, the set is called a classical or crisp set.

A crisp set *A* can be defined as $A = \{x \mid x \in X\}$

Where, *x* is an element of the set and *X* is the common property of the set.

A fuzzy set is such kind of set, where belonging to that group may be partial. In a fuzzy set an element can belong to any group either completely or partially and can also belong to any other group partially. The dissimilarity between a crisp set and a fuzzy set is defined by their boundary. In a crisp set, the boundary is crisp, i.e., well defined. But, in a fuzzy set, the boundary is a vague region. The degree of belonging to a set is defined by membership value, which is obtained using some membership function. For a crisp set, if an element belongs to it, the membership value is 1 and if does not it is 0. For a fuzzy set, it is any value between 0 to1.

So, a fuzzy set $\tilde{A}$ can be defined as $\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) \mid x \in X\}$

Where, $\mu_{\tilde{A}}$ is called the membership function of x in set $\tilde{A}$, value of $\mu_{\tilde{A}}$ is in between 0 to 1.

Fuzzy analysis deals with linguistic variables through approximate reasoning. While variables in mathematics usually take numerical values, in fuzzy logic application, the non-numeric linguistic variables are often used to simplify the expression of rules and facts.

5.3 Basics of Fuzzy Membership Function

The membership function of a fuzzy set for the possible values consolidated between the boundaries. In fuzzy logic, it can be defined in number of ways as long as they follow the conditions of the set. The shape of the membership function is used to define the fuzzy set and hence the type to use is dependent on the purpose. The membership function choice is an independent aspect of the logic as it allows the desired values to be interpreted appropriately. However, in practical applications triangular and trapezoidal functions are preferred as simple linear functions.

For any set X, a membership function on X is any function from X to the real unit interval [0,1].

Membership functions on X represent fuzzy subsets of X. The membership function which represents a fuzzy set $\tilde{A}$ is usually denoted by μ_A. For an element x of X, the value $\mu_A(x)$ is called the *membership degree* of x in the fuzzy set $\tilde{A}$.

The membership degree $\mu_A(x)$ quantifies the grade of membership of the element x to the fuzzy set ***A***. The value 0 means that x is not a member of the fuzzy set; the value 1 means that x is fully a member of the fuzzy set. The values between 0 and 1 characterize fuzzy members, which belong to the fuzzy set only partially.

The membership functions, both linear and non-linear, and most commonly used in engineering can be classified into four types as follows:

The function S: $x \to [0,1]$ defined as

$$S(x;\alpha,\sigma,\beta)=\begin{cases} 0 & for \quad x \le \alpha \\ 2\left(\dfrac{x-\alpha}{\beta-\alpha}\right)^2 & for \quad \alpha < x \le \sigma \\ 1-2\left(\dfrac{x-\beta}{\beta-\alpha}\right)^2 & for \quad \sigma < x \le \beta \\ 1 & for \quad x > \beta \end{cases}$$

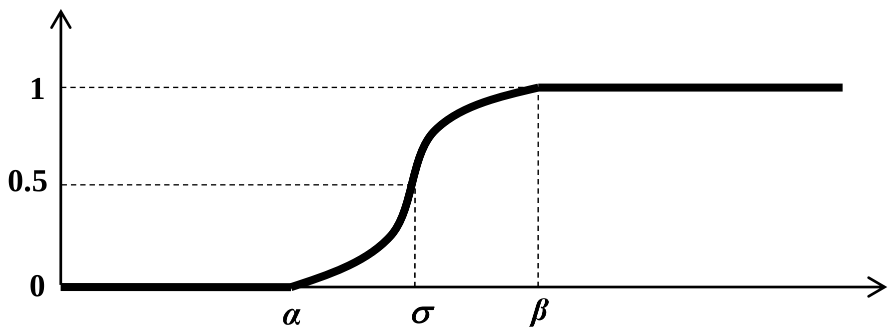

Figure 5.1: Representation of a S -function

The function Γ: $x \to [0,1]$ defined as

$$\Gamma(x;\alpha,\beta)=\begin{cases} 0 & for \quad x < \alpha \\ \dfrac{(x-\alpha)}{(\beta-\alpha)} & for \quad \alpha \le x \le \beta \\ 1 & for \quad x > \beta \end{cases}$$

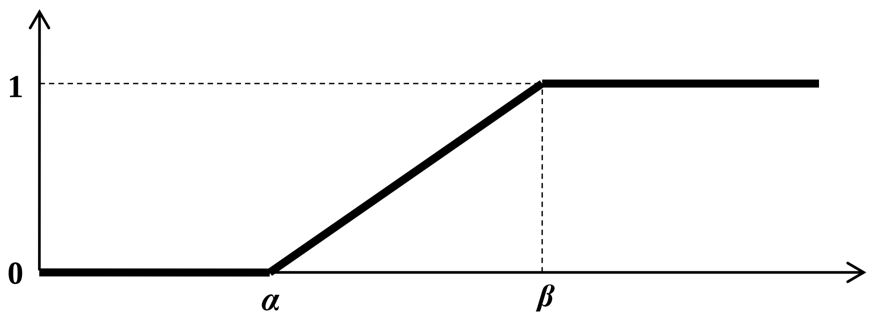

Figure 5.2: Representation of a Γ -function

The function L: $x \rightarrow [0,1]$ defined as

$$L(x;\alpha,\beta)=\begin{cases} 1 & for \quad x<\alpha \\ \dfrac{(\beta-x)}{(\beta-\alpha)} & for \quad \alpha\le x\le\beta \\ 0 & for \quad x>\beta \end{cases}$$

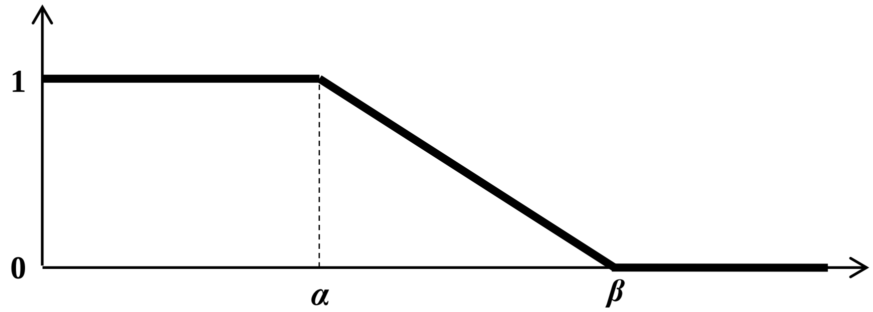

Figure 5.3: Representation of a L -function

The function A: $x \rightarrow [0,1]$ defined as

$$S(x;\alpha,\sigma,\beta)=\begin{cases} 0 & for \quad x<\alpha \\ \dfrac{(x-\alpha)}{(\sigma-\alpha)} & for \quad \alpha\le x\le\sigma \\ \dfrac{(\beta-x)}{(\beta-\sigma)} & for \quad \sigma\le x\le\beta \\ 0 & for \quad x>\beta \end{cases}$$

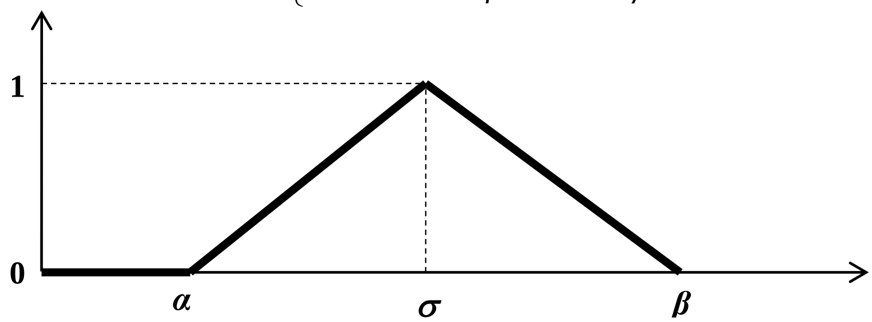

Figure 5.4: Representation of a A –function

5.4 Premise Variable

In fuzzy logic, the intention representing the dominant condition is represented as a linguistic variable, named as premise variables. It certainly can carry a value or sentence to be grouped according to their membership functions, further that value can belong to several sub groups depending on the boundary characteristics.

5.5 Consequence Variable

This represents the strategy corresponding to a particular combination of premise variables. It is a fuzzy number representing the approximate value of the course of action. This fuzzy number is approximately equal to a crisp value. This process also called defuzzification.

5.6 Fuzzy Inference System (FIS)

Fuzzy logic deals with linguistic variables through fairly accurate reasoning. Fuzzy inference is based on approximate reasoning. The fuzzy inference system is the process of verbalizing the mapping from a given input to an output.

The statement of if-then (or rules) is the main theory in the fuzzy inference system. This fuzzy inference system makes the system regular and beneficial to synthesize complex human behaviour in the loop system. The components of a fuzzy inference system are the fuzzification, rules, aggregation and defuzzification as illustrated in Figure 5.5.

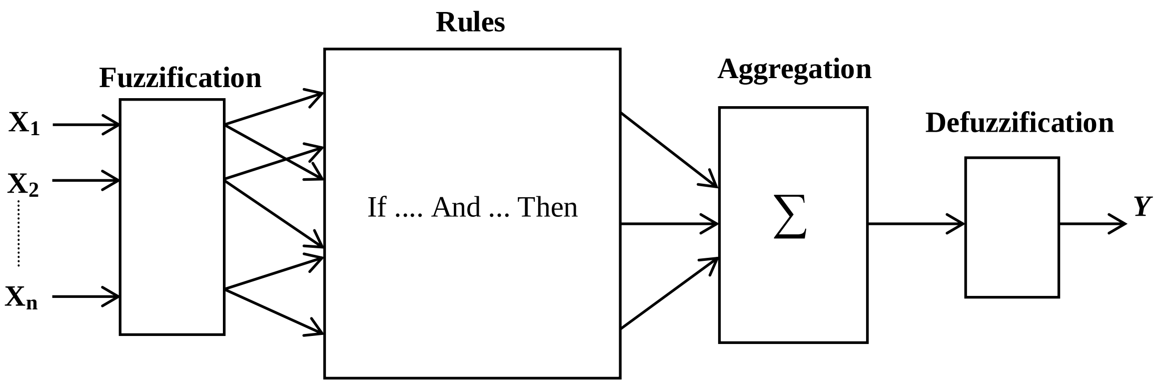

Figure 5.5: Schematic diagram of a Fuzzy Inference System (FIS)

<u>Fuzzification</u>

The process of the fuzzification is to transform a precise numerical value from a range of the input variable into a linguistic variable and corresponding degree of truth. This step takes the current value of an input variable and gives degrees of truth in input fuzzy sets, in order to make it compatible with the fuzzy set representation of the process state variable in the rule-antecedent. The degree of truth is equal to the degree of membership in the qualifying linguistic set which can take any value from the closed interval [0, 1].

Rules

Fuzzy sets and fuzzy operators are the subjects and verbs of fuzzy logic. These if-then rule statements are used to formulate the conditional statements that comprise fuzzy logic. A single fuzzy if-then rule assumes the form as "if x is A then y is B". Where A and B are linguistic values defined by fuzzy sets on the ranges (universes of discourse) X and Y, respectively. The if-part of the rule "x is A" is called the *antecedent* or premise, while the then-part of the rule "y is B" is called the *consequent* or conclusion.

Aggregation

In the aggregation of the results across the rules phase, the outputs of all rules are combined. Thus, a further reduction method is necessary for this phase, such as the maximum, the algebraic sum and the sum method. The maximum method takes the maximum of the degree membership function for the output. The algebraic sum method computes the algebraic sum of the outputs and the sum method is to add the output degrees. The results of these methods produce slightly different results and the most appropriate one depending on the purpose of the application. The aggregation produces one fuzzy set as an output of the fuzzy system.

Defuzzification

Defuzzification is the process of producing a quantifiable result in fuzzy logic, given fuzzy sets and corresponding membership degrees. Defuzzification is interpreting the membership degrees of the fuzzy sets into a specific decision or real value.

5.7 Fuzzy Clustering

Data clustering is the process of dividing data elements into classes or clusters so that items in the same class are as similar as possible and items in different classes are as dissimilar as possible. Depending on the nature of the data and the purpose for which clustering is being used, different measures of similarity may be used to place items into classes, where the similarity measure controls how the clusters are formed.

In fuzzy clustering, data elements can belong to more than one cluster and associated with each element is a set of membership levels. These indicate the strength of the association between that data element and a particular cluster. Fuzzy clustering is a process of assigning these membership levels and then using them to assign data elements to one or more clusters.

5.8 Model Development

Proposed model is the quantifying the speed of the vehicle travelling along the ramp of the interchange considering various geometrics elements of alignment of the highway as premise variables. The components of proposed model using fuzzy inference system (FIS) are the fuzzification, rules, aggregation and defuzzification as illustrated in Figure 5.6

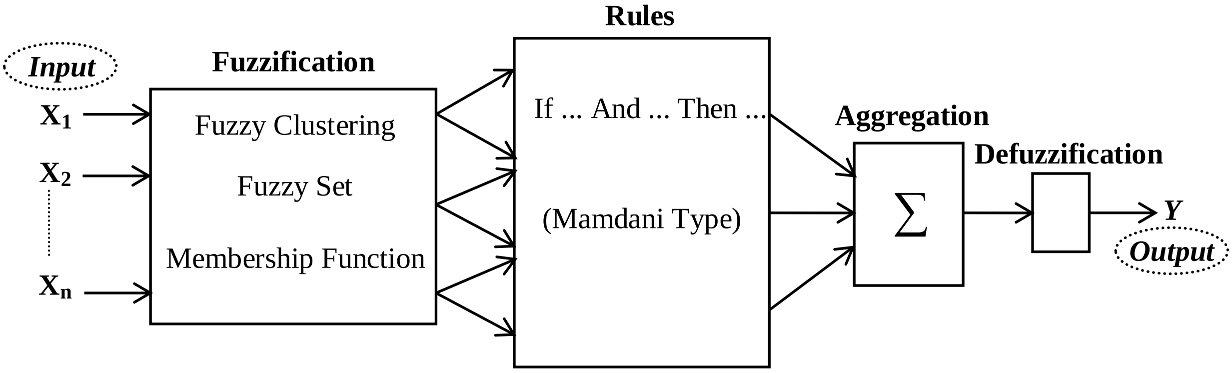

Figure 5.6 Schematic Diagram of Proposed Model Structure

The proposed model developed as Mamdani type fuzzy inference system for quantifying the vehicular speed with the help of fuzzy logic toolbox in MATLAB release R2009a as illustrated in Figure 5.7.

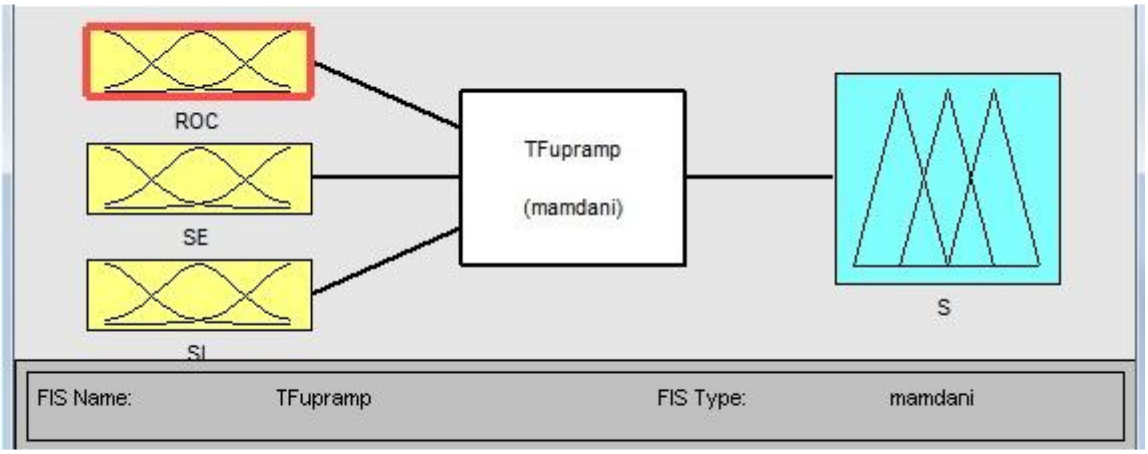

Figure 5.7: Mamdani Type Fuzzy Inference System (MATLAB R2009)

Table 5.1: Descriptive Statistics of the Validation set of Up-Ramp

Variables	Min	Max	Mean	Std. Deviation
Radius of curvature	25	65	45	13.693
Super elevation	0.04	0.07	0.055	0.0108
Slope	0.025	0.07	0.0475	0.0151

Table 5.2: Descriptive Statistics of the Validation set of Down - Ramp

Variables	Min	Max	Mean	Std. Deviation
Radius of curvature	25	65	45	13.693
Frictional coefficient	0.15	1	0.575	0.07
Slope	0.05	0.09	0.337	0.084

5.9 Fuzzy Clustering of Variables

Fuzzy c-mean clustering method is applied in this model for defining the parameter of the membership function of input variables and grouped according to their membership values with the help of fuzzy logic toolbox in MATLAB. The output result of fuzzy c-mean clustering aids to develop the membership function on modelling.

Table 5.3: Summary of Fuzzy Clustering of Up-Ramp (TFup)

Input Variables	Fuzzy Clustering		
	Group	Group Center	Group Range
Radius of curvature	1	38	25 – 45
	2	50	40 – 65
Superelevation	1	4.8	4 – 5.5
	2	6	5 – 7
Slope	1	0.04	0.025 – 0.05
	2	0.055	0.045 – 0.07

Table 5.4: Summary of Fuzzy Clustering of Down-Ramp (TFdn)

Input Variables	**Fuzzy Clustering**		
	Group	**Group Center**	**Group Range**
Radius of curvature	1	38	25 – 45
	2	50	40 – 65
Frictional coefficient	1	0.23	0.15 – 0.3
	2	0.4	0.28 – 0.5
	3	0.6	0.45 – 1
Slope	1	0.06	0.05 – 0.07
	2	0.075	0.065 – 0.09

5.10 Fuzzification of Variables

Fuzzification is the initial process of a fuzzy model where fuzzy subsets of universal set of fuzzy variable are constructed. Fuzzification needs two main stages; derivation of the membership functions for both input and output variables and the linguistic representation of these functions. Four input variables and one output variable are considered for the fuzzy modelling study and same as illustrated in Table 5.5.

Table 5.5: Linguistic variables and labels of the Fuzzy set and Fuzzy subset

Type	**Fuzzy sets**	**Fuzzy subset**
Input	Radius of curvature (RC)	Sharp (SH)
		Gradual (G)
	Superelevation (SE)	Low (L)
		Moderate (MO)
		High (H)
	Frictional Coefficient (FC)	Smooth (SM)
		Satisfactory (SA)
		Rough (R)
	Slope (Sl)	Gradual (G)
		Steep (ST)
Output	Speed (S)	Extremely low (EL)
		Very low (VL)
		Low (L)
		Moderate (M)
		Desirable (D)
		Most Desirable (MD)
		High (H)
		Very High (VH)
		Extremely High (EH)

5.10.1 Fuzzification of Input Variables of TFup

The deterministic values of the input variables are turned in membership degree to fuzzy sets. These sets are labelled with commonly used linguistic values. Triangular, trapezoidal types of membership function have been used for this model.

The variable RC is divided into two triangular fuzzy subsets due to the distribution of the data. Figure 5.8 shows the data distribution for RC for the calibration set.

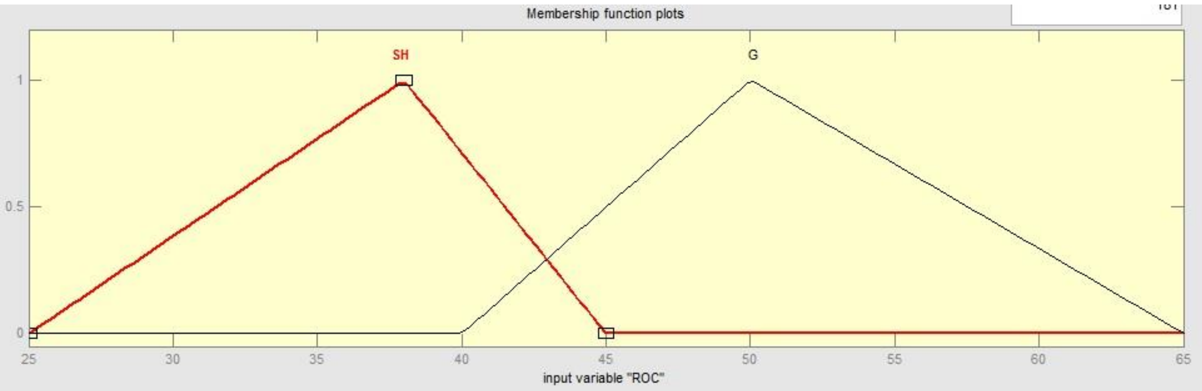

Figure 5.8: Fuzzification of the Input Variable RC

Mathematical expression of the variable Radius of curvature (RC) has been described in below section. The membership function μ(SH), describing the set "Sharp" is described as

$$\mu(sh) = \begin{cases} 0 & x < 25 \\ \dfrac{x-25}{38-25};\dfrac{45-x}{45-38} & 25 < x < 38;\ 38 < x < 45 \\ 0 & x > 45 \end{cases}$$

Similarly, the membership function μ(g), describing the set "Gradual" is

$$\mu(g) = \begin{cases} 0 & x < 40 \\ \dfrac{x-40}{50-40};\dfrac{60-x}{60-50} & 40 < x < 50;\ 50 < x < 60 \\ 0 & x > 60 \end{cases}$$

The variable SE is divided into three triangular fuzzy subsets due to the distribution of the data. Figure 5.9 shows the data distribution for SE for the calibration set.

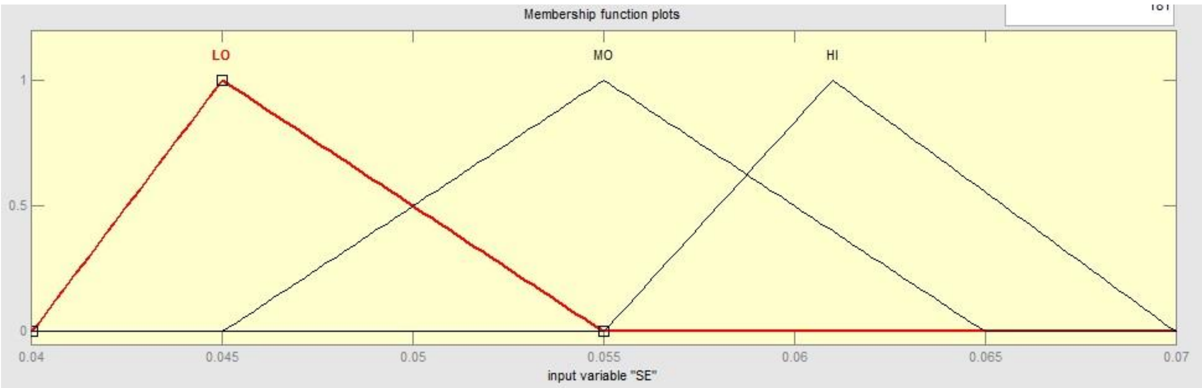

Figure 5.9: Fuzzification of the Input Variable SE

Mathematical expression of the variable Super elevation (SE) has been described in below section. The membership function μ(lo), describing the set “Low” is described as

$$\mu(lo) = \begin{cases} 0 & x < 0.04 \\ \dfrac{x - 0.045}{0.045 - 0.040}; \dfrac{0.045 - x}{0.055 - 0.045} & 0.04 < x < 0.045\ ; 0.045 < x < 0.055 \\ 0 & x > 0.055 \end{cases}$$

Similarly, the membership function μ(mo),describing the set “Moderate” is

$$\mu(mo) = \begin{cases} 0 & x < 0.045 \\ \dfrac{x - 0.045}{0.055 - 0.045}; \dfrac{0.065 - x}{0.065 - 0.055} & 0.045 < x < 0.055\ ; 0.055 < x < 0.065 \\ 0 & x > 0.065 \end{cases}$$

Similarly, the membership function μ(hi), describing the set “High” is

$$\mu(hi) = \begin{cases} 0 & x < 0.055 \\ \dfrac{x - 0.055}{0.061 - 0.055}; \dfrac{0.07 - x}{0.07 - 0.061} & 0.055 < x < 0.061\ ; 0.061 < x < 0.07 \\ 0 & x > 0.07 \end{cases}$$

The variable Sl is divided into two triangular fuzzy subsets due to the distribution of the data. Figure 5.10 shows the data distribution for Sl for the calibration set.

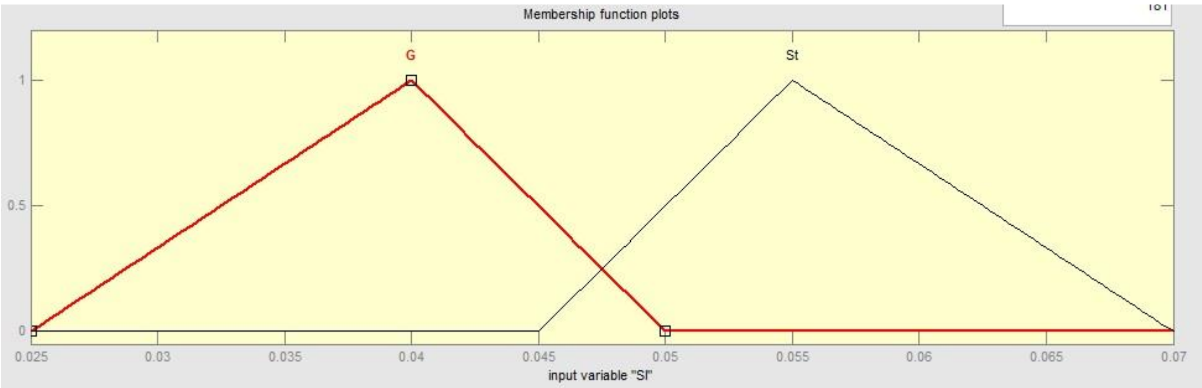

Figure 5.10: Fuzzification of the Input Variable Sl

Mathematical expression of the variable Slope (Sl) has been described in below section. The membership function μ(g), describing the set "Gradual" is described as

$$\mu(g) = \begin{cases} 0 & x < 0.025 \\ \dfrac{x - 0.025}{0.04 - 0.025}; \dfrac{0.05 - x}{0.05 - 0.04} & 0.025 < x < 0.04;\ 0.04 < x < 0.05 \\ 0 & x > 0.05 \end{cases}$$

Similarly, the membership functionμ(s), describing the set "Steep" is

$$\mu(s) = \begin{cases} 0 & x < 0.045 \\ \dfrac{x - 0.045}{0.055 - 0.045}; \dfrac{0.07 - x}{0.07 - 0.055} & 0.045 < x < 0.055;\ 0.055 < x < 0.07 \\ 0 & x > 0.07 \end{cases}$$

5.10.2 Fuzzification of Input Variables of TFdn

The deterministic values of the input variables are turned in membership degree to fuzzy sets. These sets are labelled with commonly used linguistic values. Triangular, trapezoidal types of membership function have been used for this model.

The variable RC is divided into two triangular fuzzy subsets due to the distribution of the data. Figure 5.11 shows the data distribution for RC for the calibration set.

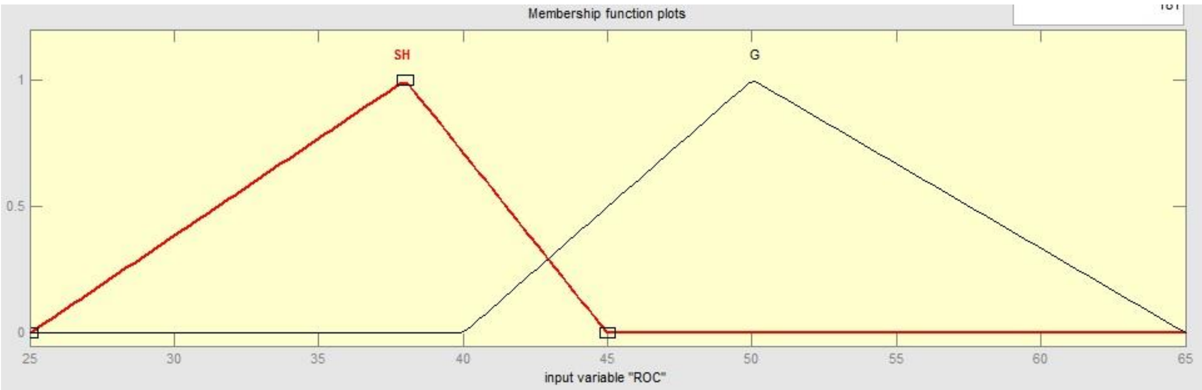

Figure 5.11: Fuzzification of the Input Variable RC

The membership function μ(SH), describing the set "Sharp" is described as

$$\mu(sh) = \begin{cases} 0 & x < 25 \\ \dfrac{x-25}{38-25}; \dfrac{45-x}{45-38} & 25 < x < 38;\ 38 < x < 45 \\ 0 & x > 45 \end{cases}$$

Similarly, the membership function μ(g), describing the set "Gradual" is

$$\mu(g) = \begin{cases} 0 & x < 40 \\ \dfrac{x-40}{50-40}; \dfrac{60-x}{60-50} & 40 < x < 50;\ 50 < x < 60 \\ 0 & x > 60 \end{cases}$$

The variable FC is divided into three triangular fuzzy subsets due to the distribution of the data. Figure 5.12 shows the data distribution for FC for the calibration set.

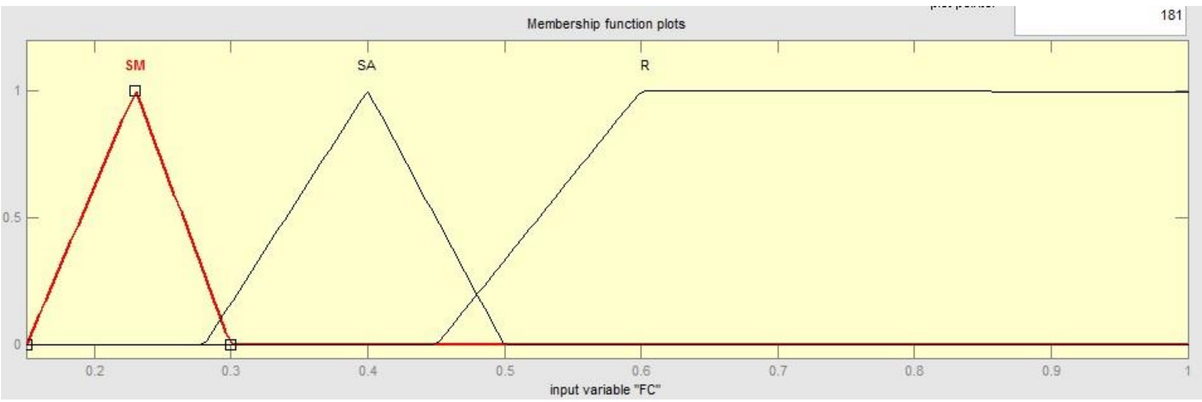

Figure 5.12: Fuzzification of the Input Variable FC

Mathematical expression of the variable Frictional coefficient (FC) has been described in below section. The membership function μ(sm), describing the set "Smooth" is described as

$$\mu(lo) = \begin{cases} 0 & x < 0.15 \\ \frac{x - 0.15}{0.23 - 0.15}; \frac{0.3 - x}{0.3 - 0.23} & 0.15 < x < 0.23 \; ; 0.23 < x < 0.3 \\ 0 & x > 0.3 \end{cases}$$

Similarly, the membership function μ(sa), describing the set "Satisfactory" is

$$\mu(mo) = \begin{cases} 0 & x < 0.28 \\ \frac{x - 0.28}{0.4 - 0.5}; \frac{0.5 - x}{0.5 - 0.4} & 0.4 < x < 0.28 \; ; 0.4 < x < 0.5 \\ 0 & x > 0.5 \end{cases}$$

Similarly, the membership function μ(r), describing the set "Rough" is

$$\mu(hi) = \begin{cases} 0 & x < 0.45 \\ \frac{x - 0.45}{0.6 - 0.45}; \frac{0.1 - x}{0.1 - 0.6} & 0.45 < x < 0.6 \; ; 0.6 < x < 1 \\ 1 & x > 1 \end{cases}$$

The variable Sl is divided into two triangular fuzzy subsets due to the distribution of the data. Figure 5.13 shows the data distribution for Sl for the calibration set.

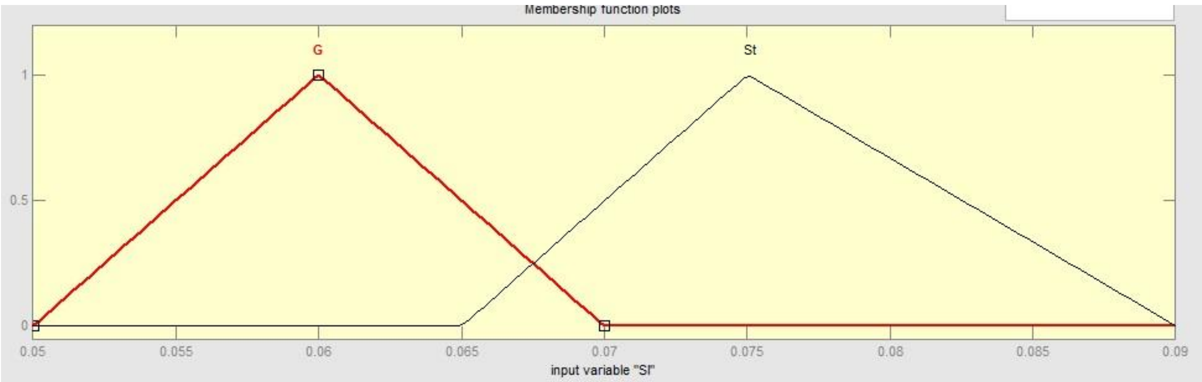

Figure 5.13: Fuzzification of the Input Variable Sl

Mathematical expression of the variable Slope (Sl) has been described in below section.

The membership function μ(g), describing the set "Gradual" is described as

$$\mu(g) = \begin{cases} 0 & x < 0.05 \\ \dfrac{x-0.05}{0.06-0.05}; \dfrac{0.07-x}{0.07-0.06} & 0.05 < x < 0.06;\ 0.06 < x < 0.07 \\ 0 & x > 0.07 \end{cases}$$

Similarly, the membership function μ(s), describing the set "Steep" is

$$\mu(s) = \begin{cases} 0 & x < 0.065 \\ \dfrac{x-0.065}{0.075-0.065}; \dfrac{0.09-x}{0.09-0.075} & 0.065 < x < 0.075;\ 0.075 < x < 0.09 \\ 0 & x > 0.09 \end{cases}$$

5.10.3 Fuzzification of Output Variable

The variable S is divided into nine triangular fuzzy subsets due to the distribution of the data in both fuzzy model (**TFup & TFdn**). Figure 5.14 shows the data distribution for S for the calibration set.

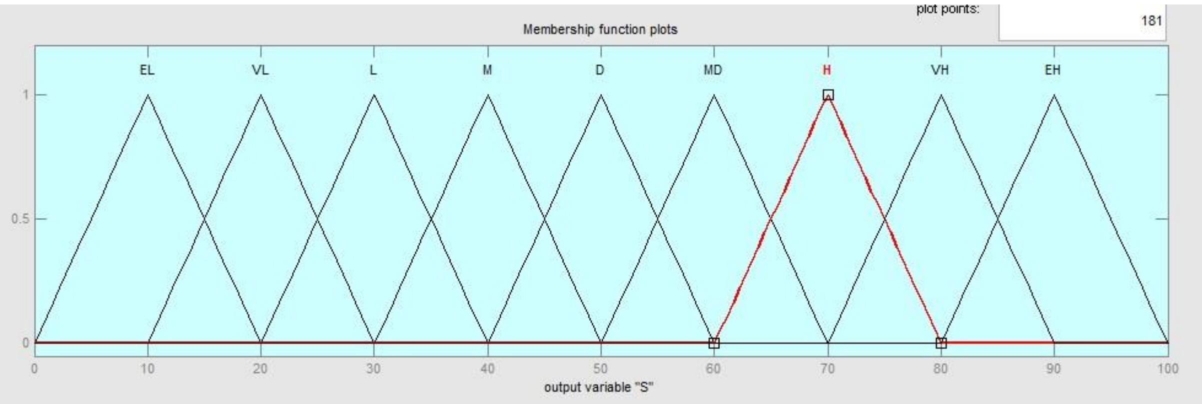

Figure 5.14: Fuzzification of the Output Variable S

Mathematical expression of the variable Speed (S) has been described in below section. The membership function μ(EL), describing the set "Extremely Low" is described as

$$\mu(EL) = \begin{cases} 0 & x < 5 \\ \dfrac{x-5}{10-5}; \dfrac{20-x}{20-10} & 5 < x < 10;\ 10 < x < 20 \\ 0 & x > 20 \end{cases}$$

Similarly, the membership function μ(VL), describing the set "Very Low" is

$$\mu(EL) = \begin{cases} 0 & x < 10 \\ \frac{x-10}{20-10}; \frac{30-x}{30-20} & 10 < x < 20;\ 20 < x < 30 \\ 0 & x > 30 \end{cases}$$

Similarly, the membership function μ(L), describing the set " Low" is

$$\mu(EL) = \begin{cases} 0 & x < 20 \\ \frac{x-20}{30-20}; \frac{40-x}{40-30} & 20 < x < 30;\ 30 < x < 40 \\ 0 & x > 40 \end{cases}$$

Similarly, the membership function μ(M), describing the set "Moderate" is

$$\mu(M) = \begin{cases} 0 & x < 30 \\ \frac{x-30}{40-30}; \frac{50-x}{50-40} & 30 < x < 40;\ 40 < x < 50 \\ 0 & x > 50 \end{cases}$$

Similarly, the membership function μ(D), describing the set "Desirable" is

$$\mu(D) = \begin{cases} 0 & x < 40 \\ \frac{x-40}{50-40}; \frac{60-x}{60-50} & 40 < x < 50;\ 50 < x < 60 \\ 0 & x > 60 \end{cases}$$

Similarly, the membership function μ(MD), describing the set "Most Desirable" is

$$\mu(MD) = \begin{cases} 0 & x < 50 \\ \frac{x-50}{60-50}; \frac{70-x}{70-60} & 50 < x < 60;\ 60 < x < 70 \\ 0 & x > 70 \end{cases}$$

Similarly, the membership function μ(H), describing the set "High" is

$$\mu(H) = \begin{cases} 0 & x < 60 \\ \frac{x-60}{70-60}; \frac{80-x}{80-70} & 60 < x < 70;\ 70 < x < 80 \\ 0 & x > 80 \end{cases}$$

Similarly, the membership function μ(VH), describing the set “Very High” is

$$\mu(EL) = \begin{cases} 0 & x < 70 \\ \dfrac{x-70}{80-70}; \dfrac{90-x}{90-80} & 70 < x < 80;\ 80 < x < 90 \\ 0 & x > 90 \end{cases}$$

Similarly, the membership function μ(EH), describing the set “Extremely High” is

$$\mu(EL) = \begin{cases} 0 & x < 80 \\ \dfrac{x-80}{100-80}; \dfrac{100-x}{100-90} & 80 < x < 90;\ 90 < x < 100 \\ 0 & x > 100 \end{cases}$$

5.11 Production of the Rule Base

In this model study, fuzzy rules relating input variables to output variable has been fabricated from the calibration data set.

Three input variables and two fuzzy subset of three variables, & three subset of one variable has been identified to evaluate all the possibilities that variables form with each other, and subsequently, 24 rules has been established as a result of (2 x 2 x 3 x 2) =24 relations. Mamdani type of rule system is engaged for the study.

In this process, the truth value of each rule is computed, and then applied to the corresponding part of each rule. Fuzzy Rule Base contains all the possible fuzzy relations between input variables and the output variable.

Interpreting an If-Then rule production is a three part process. These are as below;

(i) *Fuzzify inputs*: Resolve all fuzzy statements in the antecedent to a degree of membership between 0 and 1.

(ii) *Apply fuzzy operator to multiple part antecedents*: If there are multiple parts to the antecedent, apply fuzzy logic operators and resolve the antecedent to a single number between 0 and 1, is the degree of support for the rule.

(iii) *Apply the implication method*: Using the degree of support for the entire rule to shape the output fuzzy set. If the rule has more than one antecedent, the fuzzy operator is applied to obtain one number that represents the result of applying that rule.

Following rules are constituted for proposed fuzzy model.

R is up – ramp, Sl is slope (gradual or steep) RC is radius of curvature (critical or gradual) SE is super elevation (low or moderate or high) and S is speed

Rule 1: If (R is UP) and (Sl is G) and (RC is C) and (SE is L) then (S is L)

Rule 2: If (R is UP) and (Sl is G) and (RC is C) and (SE is H) then (S is M)

Rule 3: If (R is UP) and (Sl is G) and (RC is G) and (SE is L) then (S is MD)

R is down ramp, Sl is slope (gradual or steep) FF is friction factor (smooth or satisfactory or rough) RC is radius of curvature (critical or gradual) and S is speed

Rule 22: If (R is DN) and (Sl is G) and (FF is S) and (RC is C) then (S is M)

Rule 23: If (R is DN) and (Sl is G) and (FF is S) and (RC is C) then (S is MD)

Rule 24: If (R is DN) and (Sl is G) and (FF is S) and (RC is G) then (S is H)

Similarly the rules for the other conditions are developed. For the existing variations 24 scenarios of condition occurs.

5.12 Aggregation Process

Each fuzzy rule gives a single number that represents the truth value of that rule. The input for the implication process is a single number given by the antecedent, and the output is a fuzzy set. The summation operation method has been used for aggregation process. MATLAB coding of the Fuzzy Models of **TFup** and **TFdn**. Next stage is the defuzzification process to get crisp output from the aggregated fuzzy output.

5.13 Defuzzification Process

In this process each aggregated fuzzy output converting into a single crisp value through the developed fuzzy rules. center of gravity (CoG) defuzzification method has been applied for the fuzzy model. Following equation is the mathematical expression of the CoG defuzzification method for the discrete fuzzy systems.

$$y^* = \frac{\sum_{i=1}^{n} y_i.\mu_U.(y_i)}{\sum_{i=1}^{n} \mu_U.(y_i)}$$

Where y* is the output variable of one set of input variables.

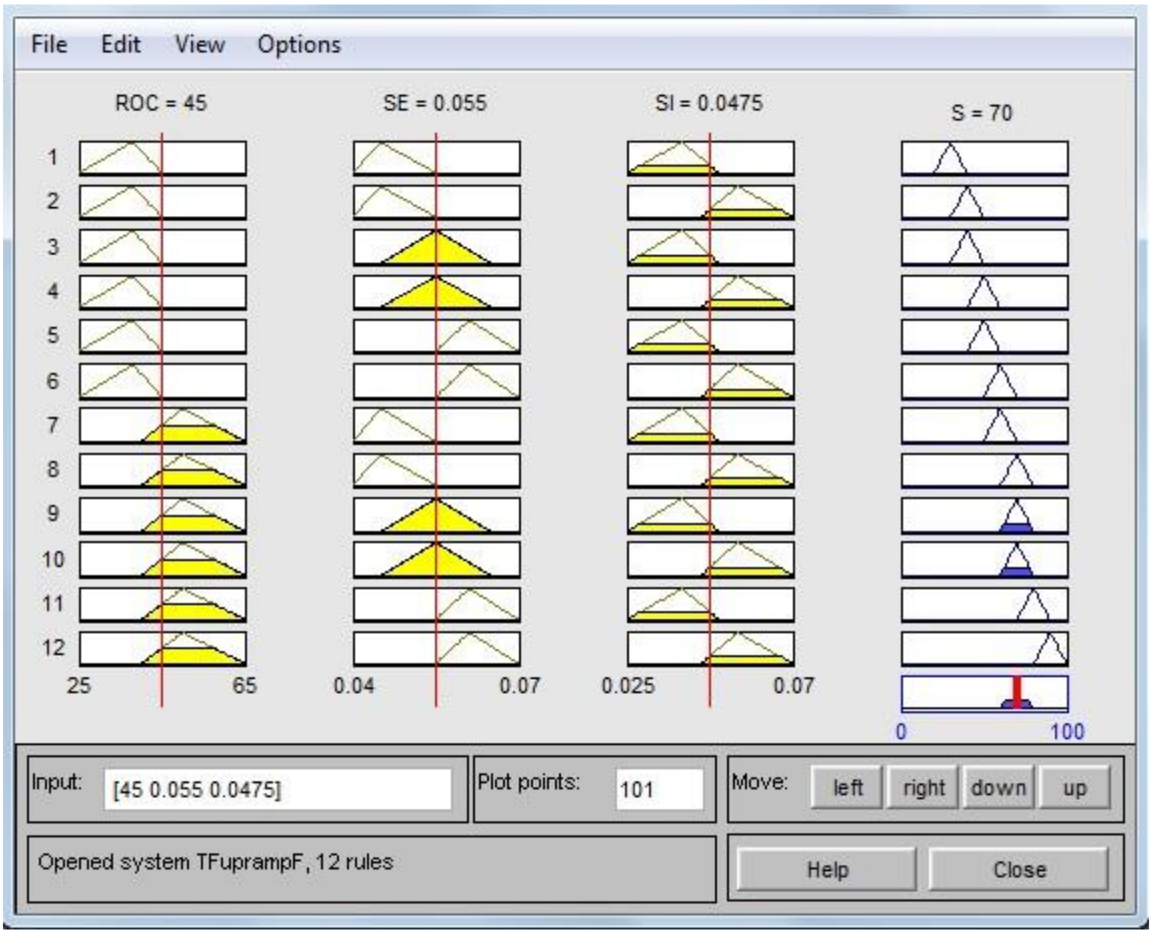

Figure 5.15: Rules for Up-Ramp condition

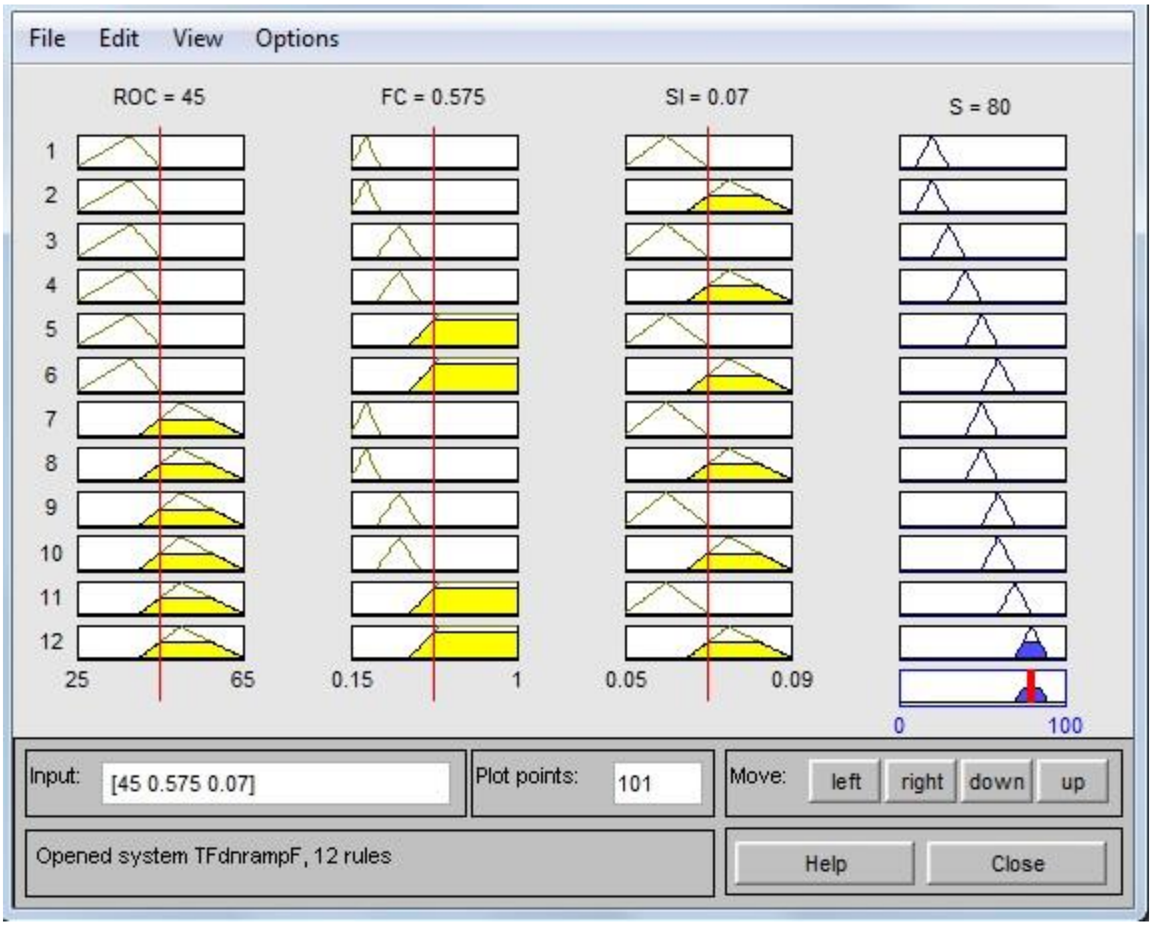

Figure 5.16: Rules for Down – ramp condition

5.14 Surface view

The Surface Viewer is a guidance tool that examines the output surface of a Fuzzy Inference System, for any one or two inputs. The tool aids to influence the resultant surface from different angles. If there are more than two inputs to FIS system, in the reference input section, the constant values associated with other unspecified input is sustained.

5.14.1 Surface view of Speed in Up-Ramp condition

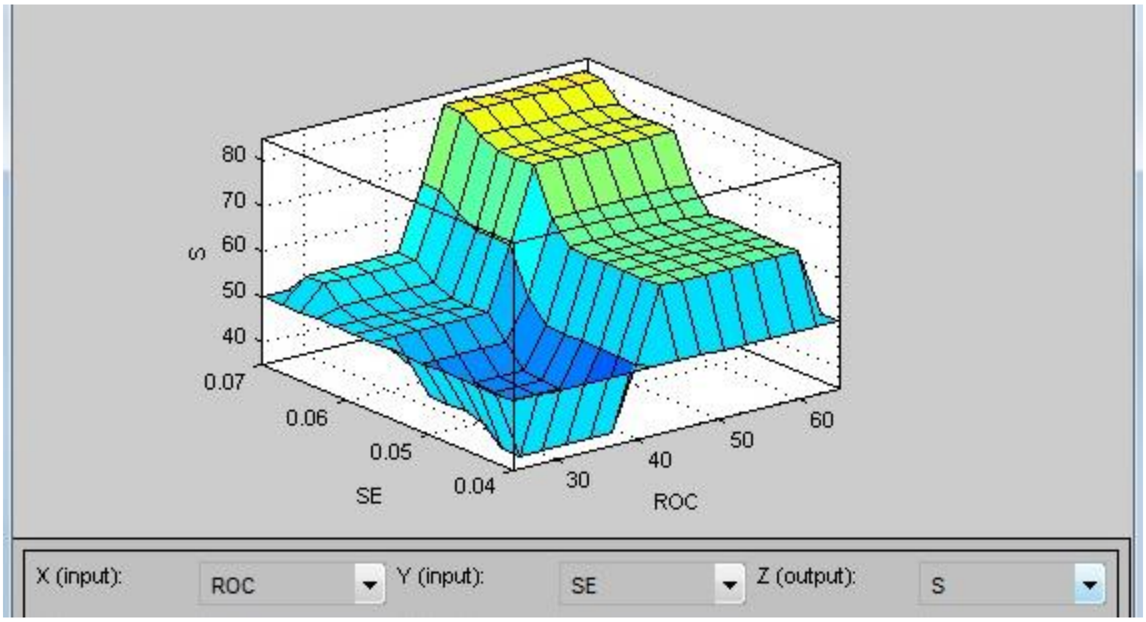

Figure 5.17: Surface view of Speed variation versus ROC, SE

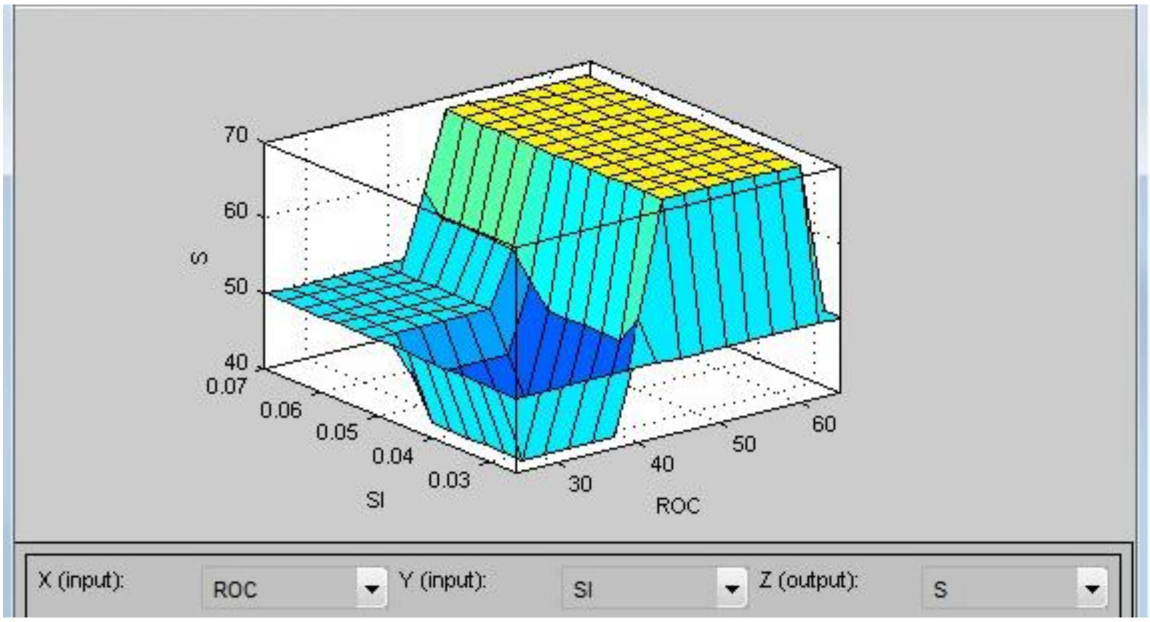

Figure 5.18: Surface view of Speed variation versus ROC, Sl

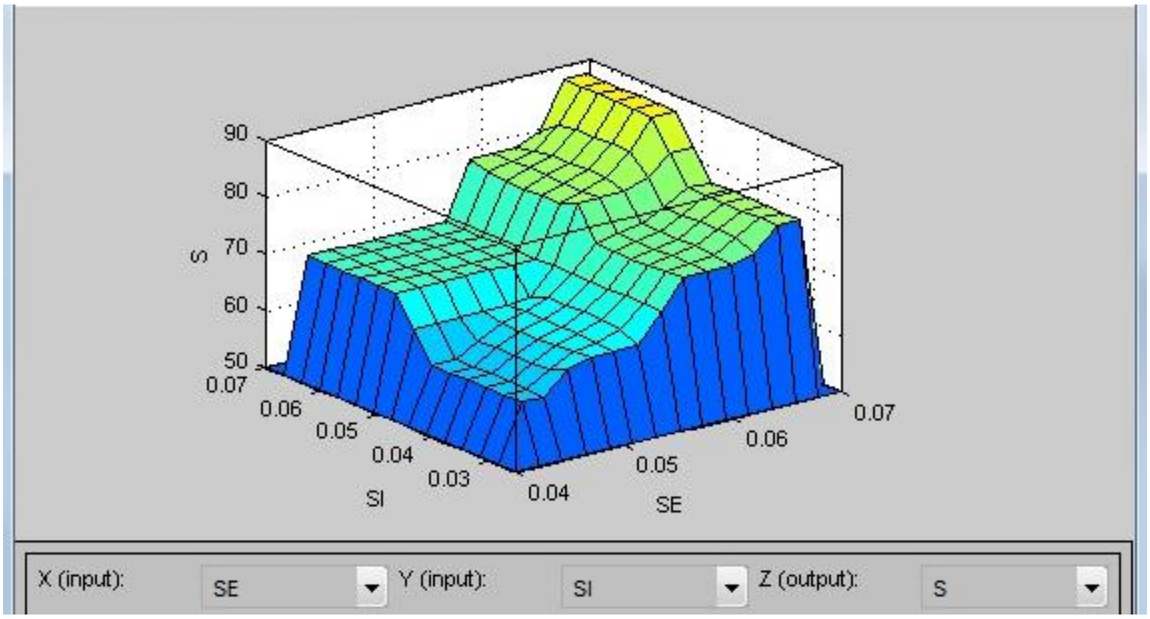

Figure 5.19: Surface view of Speed variation versus SE, Sl

5.14.2 Surface view of Speed in Down-Ramp condition

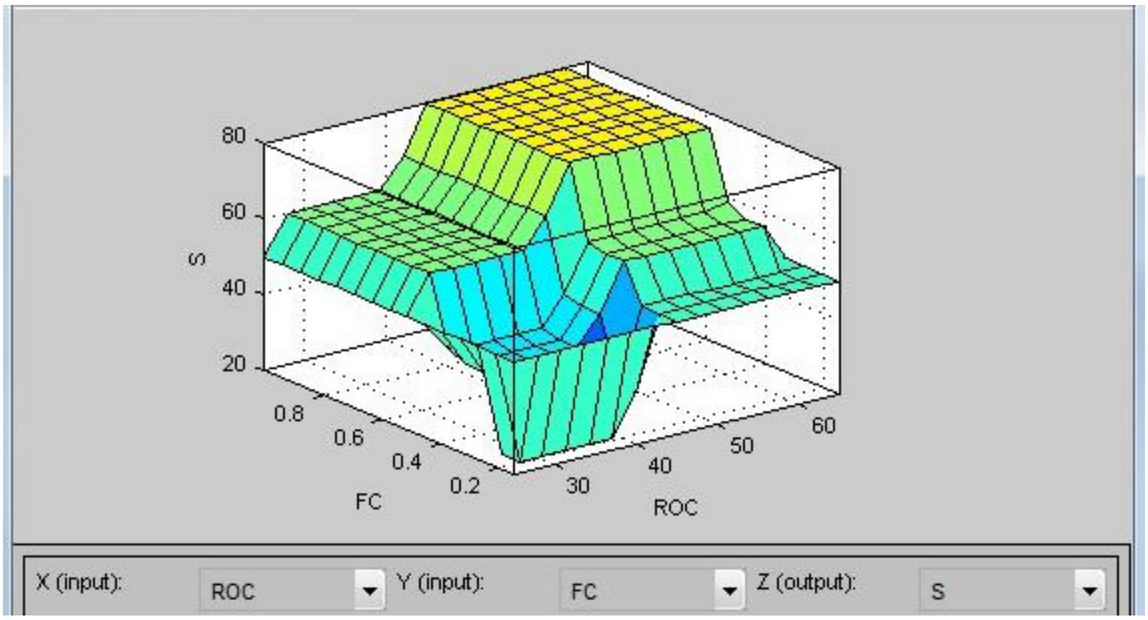

Figure 5.20: Surface view of Speed variation versus ROC, FC

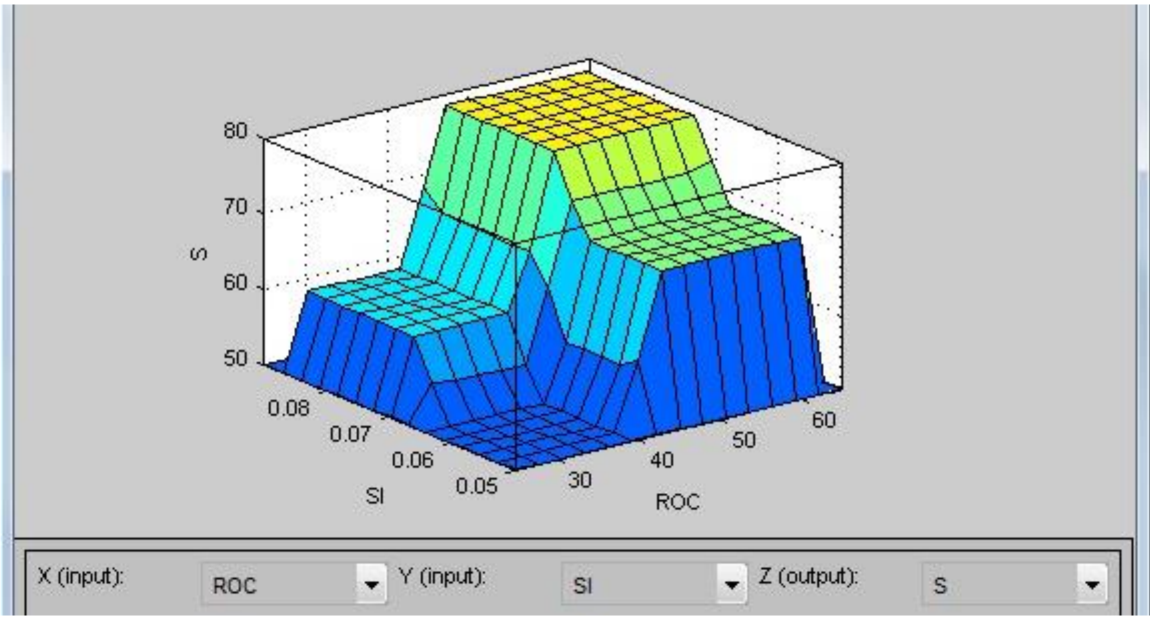

Figure 5.21: Surface view of Speed variation versus ROC, Sl

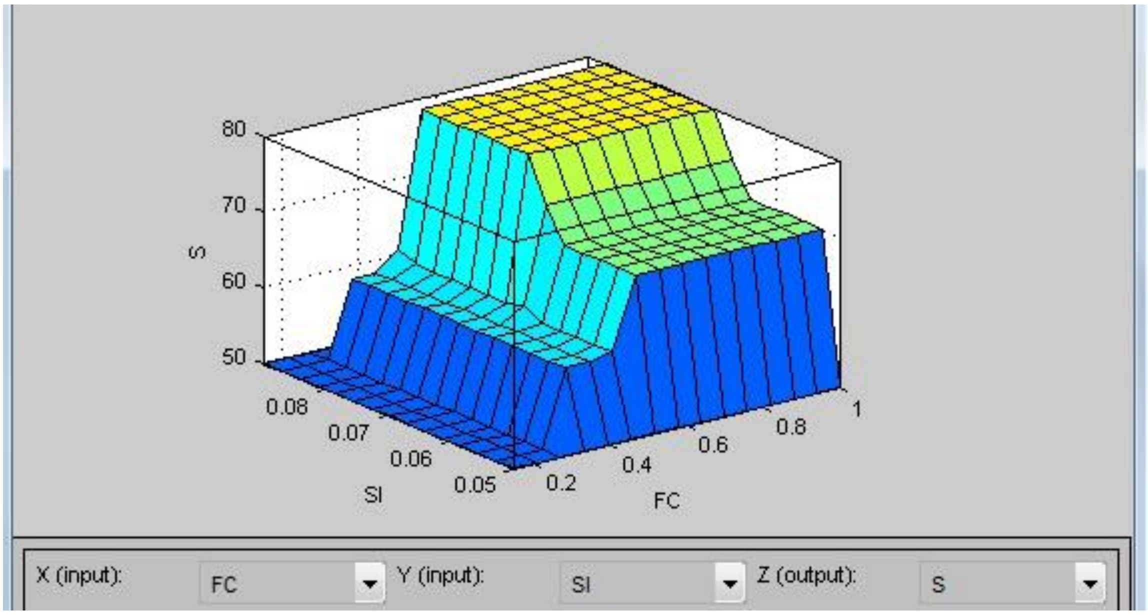

Figure 5.22: Surface view of Speed variation versus FC, Sl

5.15 Model Results and Discussions

Each set of input data has been entered to the Fuzzy Inference System (FIS) and each output result has been taken. The each crisp output result was obtained for critical conditions. The ***TFup*** model results is expressed in Figure 5.26 and the ***TFdn*** model results is expressed in Figure 5.27

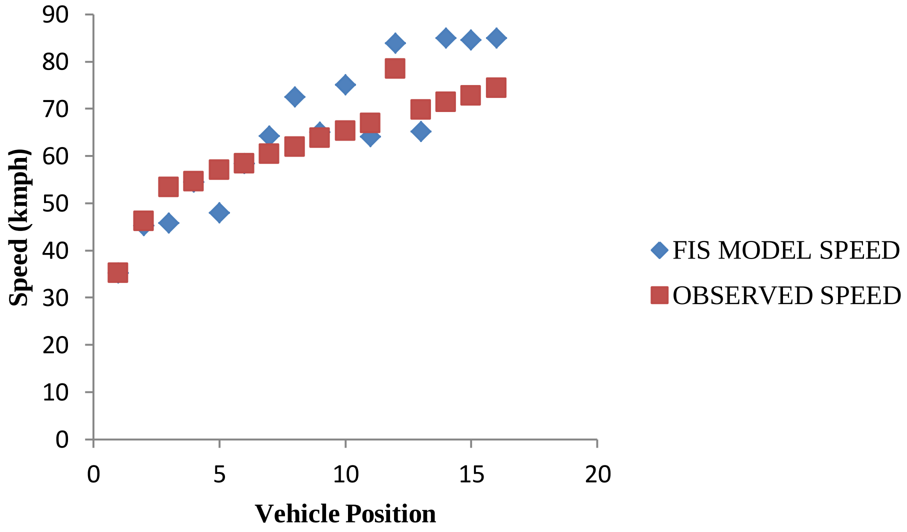

Figure 5.23: Speed comparison – Up ramp

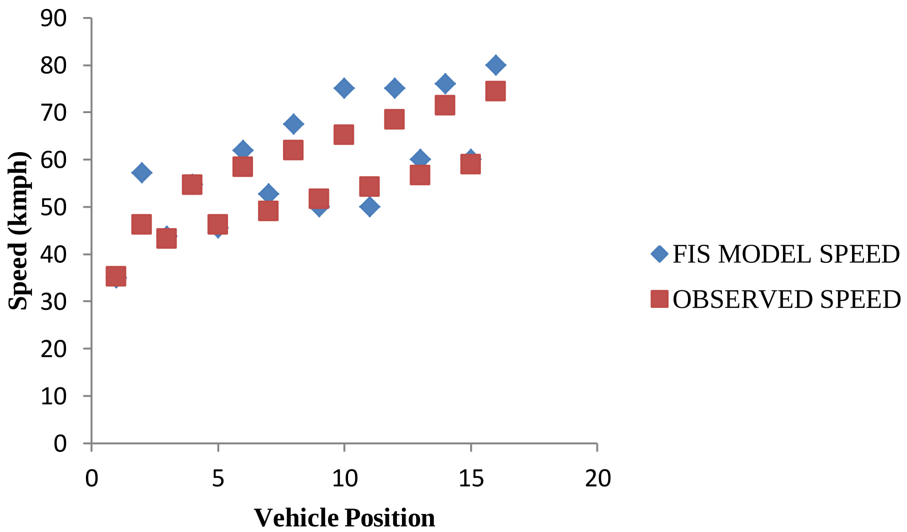

Figure 5.24: Speed comparison – Down ramp

CHAPTER 6

VALIDATION

6.1 Background

In this chapter, each set of input data of validation set group has been entered to the Fuzzy Inference System (FIS) and each output result has been taken using both *Traffic Models (TFup & TFdn)*. Also, the simulation results using the proposed model are presented.

6.2 Validation of TFup : Comparison with Observation Results

Simulation results are produced corresponding with each set of input data of validation set group and compared with the combined linear regression analysis results as described in Chapter-4. Simulated results and the observed result of linear regression analysis are expressed as scatter diagram in Figure 6.1.

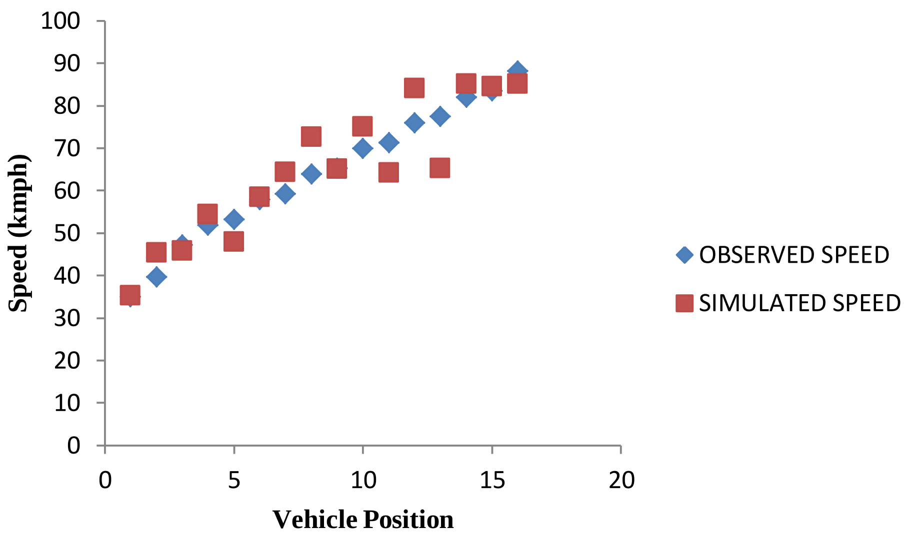

Figure 6.1: Simulated speed versus observed speed – Up ramp

6.3 Validation of TFdn : Comparison with Observation Results

Simulation results are produced corresponding with each set of input data of validation set group and compared with the combined linear regression analysis results as described in Chapter-4. Simulated results and the observed result of linear regression analysis are expressed as scatter diagram in Figure 6.2.

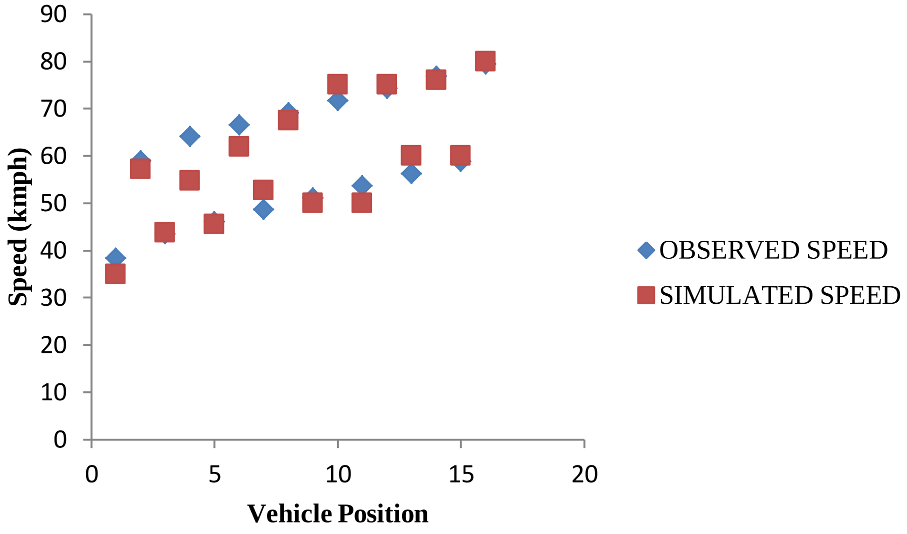

Figure 6.2: Simulated speed versus observed speed – Down ramp

6.4 Sensitivity Analysis of Variables

Sensitivity analysis is the study of how the uncertainty in the output of a model is inferred from the uncertainty in its inputs. One of the simplest and most common approaches is that of changing one-factor-at-a-time to see what effect this produces on the output.

6.4.1 *TFup*

Each input variables has been entered to the proposed model for up – ramp (*TFup*) and each output result has been taken. Also same has been expressed as scatter diagram in Figure 6.3.

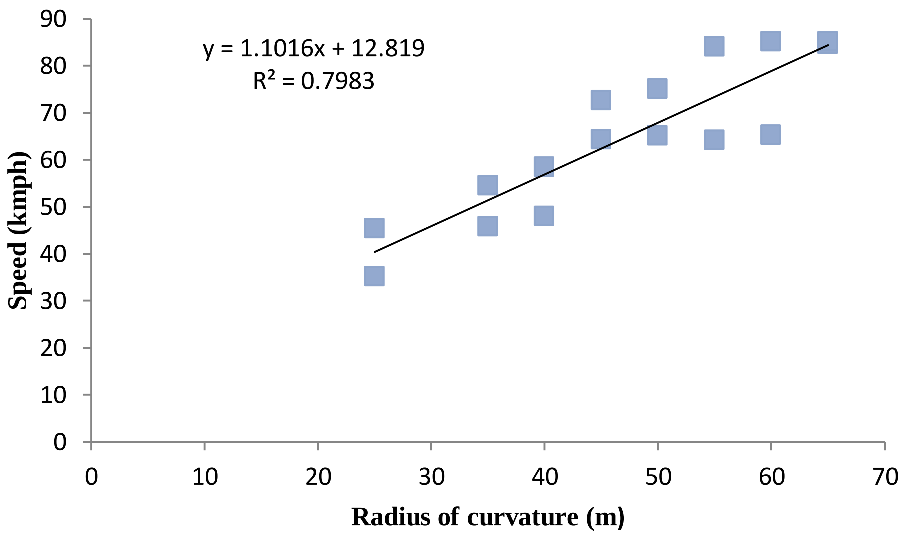

Figure 6.3(a): Speed Versus Radius of curvature

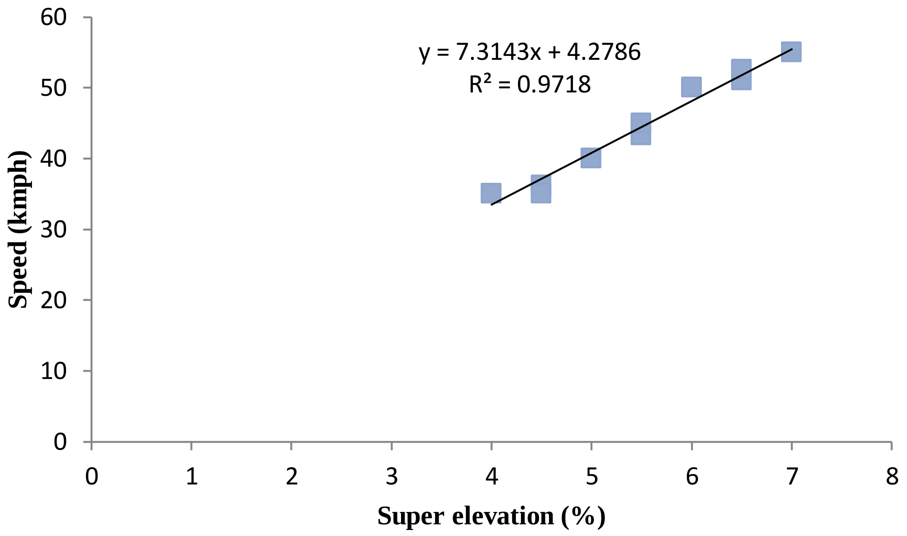

Figure 6.3(b): Speed Versus Super elevation

Above analysis shows that radius of curvature & super elevation has great impact on vehicle speed on the up – ramp of interchange and hence these elements are very sensitive in alignment.

6.4.2 *TFdn*

Each input variables has been entered to the proposed model for down – ramp (*TFdn*) and each output result has been taken. Also same has been expressed as scatter diagram in Figure 6.4.

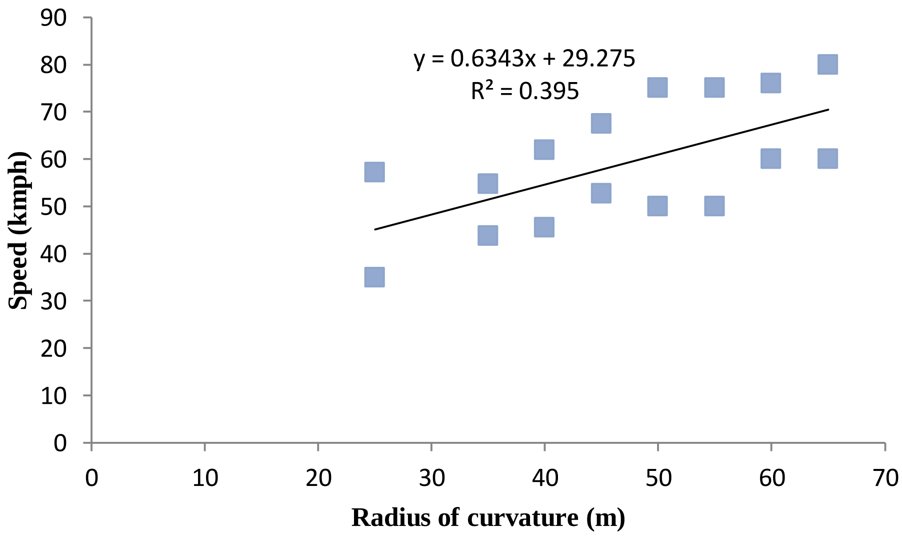

Figure 6.4(a): Speed Versus Radius of curvature

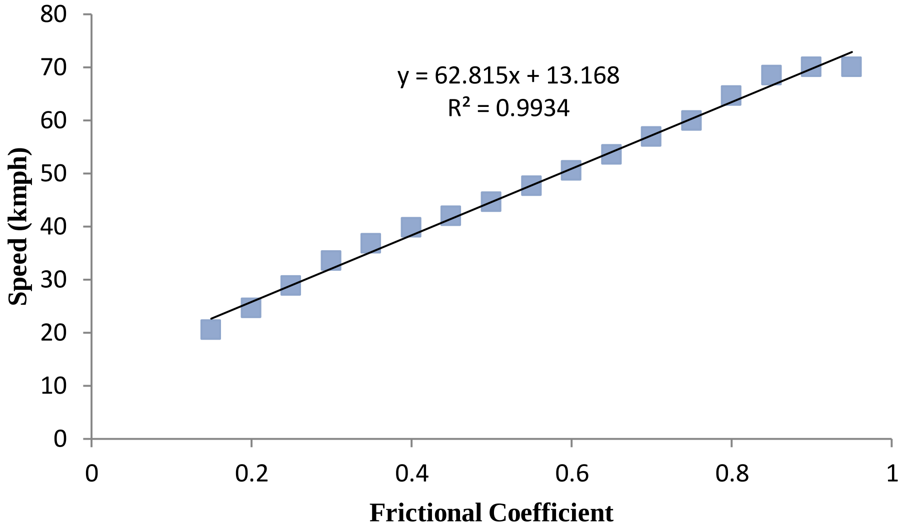

Figure 6.4(b): Speed versus Frictional Coefficient

Above analysis shows that radius of curvature & frictional coefficient has great impact on vehicle speed on the down – ramp of interchange and hence these elements are very sensitive in alignment.

6.5 Model Results and Discussions

When the model results are examined in details, it was observed that as far as the simulation results are concerned, the Speed (S) value obtained from statistical analysis and obtained from the model are almost same with the model error as 8.75 % in *TFup* and 6.85 % in *TFdn*. Hence, the models can be used to predict the speed of the vehicle travelling on the loops of the interchange.

CHAPTER 7

SUMMARY AND CONCLUSIONS

The objective of the study was to develop a model that can be used to estimate the vehicular speed on the ramps of the interchange. Eventually, this study produced traffic flow model considering driver and vehicular behaviour. In this model, a system was established between the output data, speed (S) and input data such as various highway geometric elements i.e., radius of curvature, super elevation, frictional coefficient and slope of the ramp.

In interpretation of complication between the highway geometric elements, Fuzzy Inference System (FIS) based speed analysis was proposed. The conventional algorithms are conservative in comparison to fuzzy logic as it provides an extensive use of linguistic data set variables and to implement expertise decisions. Two traffic flow models were proposed which provide the speed of the vehicle on the ramp such as ***TFup*** (***Traffic flow model for Up-Ramp***) and ***TFdn*** (***Traffic flow model for Down-Ramp***.

Simulation results and Statistical analysis indicated that, several highway geometrics parameter are very significant to determine vehicle speed. The governing factors, radius of curvature & super elevation has great impact on vehicle speed moving on the up–ramp of interchange. Also the radius of curvature & frictional coefficient has greater influence on vehicle speed moving on the down–ramp of interchange.

Further studies are encouraged in defining more geometric factors that governs the speed of the vehicle moving against gravity. It is significant to develop more precise traffic model that can predict the impact of each geometric alignment elements on the travelling vehicle and effectively represent the realistic travelling scenario.

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