EVALUATING TRAFFIC CAPACITY AND IMPROVEMENTS TO ROAD GEOMETRY

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Abstract— Road transport plays a vital role in economic development, trade, and social integration, which rely on the conveyance of both people and goods. Vehicular traffic carrying goods and people increases with the increasing economy, resulting in an increase of traffic accidents. Three major factors causing traffic accidents are human, road and vehicles. The human factor has the most significant effect on accident. However, this factor is governed by an individual thought process and cannot be studied empirically. Moreover, any design solution mitigating this kind of individual human behavior cannot be predicted only some safety rules can be enforced. Also, different mechanical behavior of vehicles factors are not the scope of civil engineering study. Hence, road factors are only considered as a part of this study. It is very important for the highway to establish a harmony between the all three factors at the design stage of a highway. With a geometrically good design, it is possible to compensate for the other factors and thus decrease the number of traffic accidents (A.F. Iyinam et al., 1997).

1. INTRODUCTION

Motor vehicle accidents kill about 1.2 million people a year worldwide and the number will grow to more than 2 million in 2020 unless steps are taken, a study released by the World Health Organization (WHO) and the World Bank has found. WHO has revealed in its first Global Status Report on Road Safety that more people die in India due to road accidents than anywhere else in the world, including the more populous China.

Road transport plays a vital role in economic development, trade and social integration, which rely on the conveyance of both people and goods. Vehicular traffic carrying goods and people increases with the increasing economy, resulting in an increase of traffic accidents. Three major factors causing traffic accidents are human, road and vehicles. The human factor has the most significant effect on accident. However, this factor is governed by an individual thought process and cannot be studied empirically. Moreover, any design solution mitigating this kind of individual human behavior cannot be predicted only some safety rules can be enforced. Also, different mechanical behavior of vehicles factors are not the scope of civil engineering study. Hence, road factors are only considered as a part of this study. It is very important for the highway to establish a harmony between all three factors at the design stage of a highway. With a geometrically good design, it is possible to compensate for the other factors and thus decrease the number of traffic accidents (A.F. Iyinam et al., 1997).

2. LITERATURE SURVEY

Accident Causative Factors Overview:

Feng-Bor Lin (1990) studied on flattening of horizontal curve on rural two-lane highways and found that horizontal curves on highways are on average more hazardous than tangent sections. As their curvatures increase, horizontal curves tend to have higher accident rates. He suggests that the differences between the 85th percentile speeds and the safe speeds have no statistically significant relationships with the accident rates. In contrast, the magnitudes of speed reduction, when a vehicle moves from a tangent section to a curve, have a significant impact on traffic safety. Such speed reductions on horizontal curves with gentle grades are strongly correlated with the curvatures of the curves. Therefore, curvatures can be used as a safety indicator of the curves.

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 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 overlapped with a sag curve.

Zhang Yingxue (2009) analysed the relation between highway horizontal curve and traffic safety and found that curve radius, super-elevation, widening, transition curve and sight distance have the important effect on traffic accidents.

Accident Prediction Model:

Eric T. Donnell et al. (2009) studied on appraisal of the interactive highway safety design model's crash prediction and design consistency modules and evaluated the safety and operational effects of geometric on two lane rural highways through interactive highway safety design model (IHSDM).

The design consistency module can evaluate the alignment complexity and thus predict the accident.

Jaisung Choi et al. (2011) studied on the safety effects of highway terrain types in a crash model and suggested that when the design speed is changed, the terrain types will have some safety effects using regression analysis. The statistical analysis was performed with an ordinal logistic regression model in order to relate several independent variables of highway geometric elements, such as terrain type, tangent length, curve length, radius of curvature, and vertical grade to actual crash occurrences. Through this investigation, terrain type was found to be a significant independent variable that explains crash occurrences for rural arterial roads in South Korea.

O. F. Cansiz et al. (2011) studied an artificial neural network to predict collisions on horizontal tangents of 3D two-lane highways and explored the safety effects of horizontal tangents combined with vertical curves using artificial neural network (ANN) models. The collision prediction models were established using an artificial neural network for these horizontal tangents and were compared with the existing regression models. The ANN method provided better results for predicting collision frequency on horizontal tangents. They identified the variables that are related to vertical curves, horizontal tangents, and cross-sections. The regression models were estimated using the significant variables for all combinations.

Accident Optimization Model:

A.F. Iyinam et al. (1997) studied the relationship between highway safety and road geometric design elements and observed that the relationship between safety and road geometry has meaningful relationships through regression analysis. They suggested that the control of the road factor is much easier than the human factor and by making a geometrically good design, it was even possible to compensate for the other factors and thus decrease the number of traffic accidents through a regression analysis is made between the geometric parameters and accident rates.

Highway geometric elements have great influence in traffic accidents and also effective factors on highway safety. As the relationships between highway accidents and highway geometric elements are considered, some relationships are seen intuitively at a first approach. However, the important point is to determine the intensity of these relationships quantitatively. Apart from the above study, many researchers recommended other promising methodologies like artificial neural networks, fuzzy methods and genetic algorithms for development of crash model.

3. EMPIRICAL DATA COLLECTION AND EXTRACTION

For this study, two roads in plain & rolling terrain National Highway (NH) 5 & 65 and two roads in mountainous & steep terrain National Highway 47 & 33 were selected. Various field data such as 3D Topographic features, Accident records and Traffic volume were collected for these roads. Careful observation and collection of such data with accuracy were carried out.

National Highway 5 (NH-5) is a 1000 km National Highway in South India that runs from Kolkata through Orissa and Andhra Pradesh up to Chennai on the Bay of Bengal border. The study corridor takes off from km 230/0 near Guntur, traverses in a south-northeast direction and end at km 330/0 near village of Chilakaluripet. This part of the road falls in the state of Andhra Pradesh and is situated between 31 18.78' N & 31 44.48' N latitude, 77 27.28' E & 78 44.14' E
longitude. Total length of the study corridor is about 30km and study area is given under Figure 3.1a.

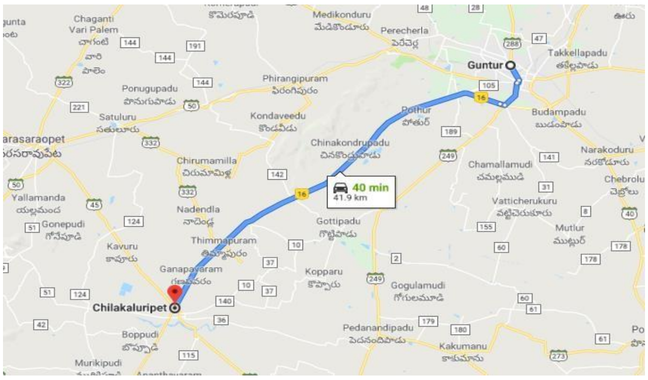


Figure 3.1: Location Map of NH-5

Topographic Survey

The topographic survey has been carried out with Total Station survey equipment at accident locations. Total Station is a high-precision surveying equipment to carry out 3-3-dimensional features of the existing road. This survey equipment can measure distance, angle, and co- coordinates with relative to the known position and it calculates using coordinate geometry and triangulation. All the measurements are controlled by an internal Programme & interfaced via computer. The captured digital data has been downloaded into a CAD Programme (AutoCAD) to visualize the surveying data as vector entities. Finally, this data has been analysed later with the design application software (MX Road) which is extensively used for highway design.

Topographic Survey Methodology

In order to have the accurate topographical survey work, a network of horizontal control has been established using differential GPS techniques and levelling network using Digital Auto Levels. The fixing of major control stations, the station points are embedded in the ground, in pair with inter visibility with a distance of around 200m. The horizontal control coordinates were observed and worked out by use of GPS instrument for each pair and the elevation were provided by an independent levelling survey by Digital Auto Level. These Major Control Stations were kept at a distance of 500m at a safe location.

The control traverse is the base framework for all the further survey work. This provides a coordinated horizontal grid and a level reference system to ensure accuracy. Thus the measured coordinates of these survey grids (Northing and Easting) and the levels are to be tied to GTS benchmark wherever available, to verify the accuracy of survey. The GPS/ Benchmark points and Reference Benchmark points established acted as both horizontal and vertical control points.

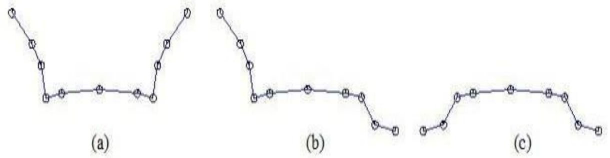


Figure 3.2: Topographic Points on Cross Sectional View

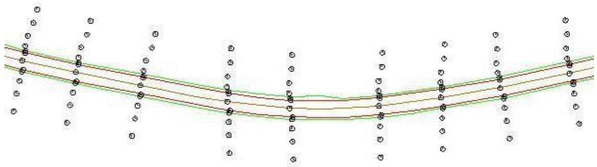


Figure 3.3: Topographic Points on Plan View

Data Extraction

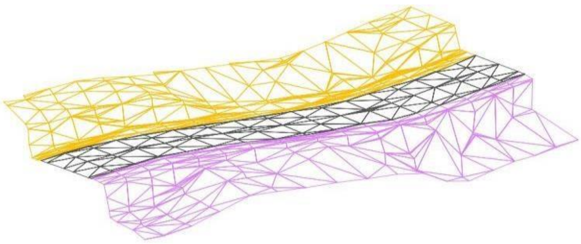


Figure 3.4: Typical Triangulation Integrated Network (TIN) of Existing Alignment

To find out the geometric parameters of the existing road, topographic survey points (X, Y and Z / Easting, Northing and Elevation), road center line, carriageway edge and shoulder edge line has been imported to MX Road software and a 3-dimensional digital terrain model (DTM) was developed. Then Triangulation Integrated Network (TIN) was modelled as 3- dimensional surface. After this, geometric elements such as horizontal curve radius and Horizontal curve length, deflection angle, super elevation / crossfall, vertical gradient, vertical curve length and sight distance have been extracted. The Triangulation Integrated Network (3D Model) developed along the road is given under Figure 3.4.

Data Extraction Methodology

The geometric elements of existing road at accident locations have been extracted as described under sub sections.

Horizontal Radius

The existing radius has been measured from the best fitted radius with the existing road alignment. In this process, the two tangents are fixed with the existing center line and then, radius fitted with the two tangents, which is the best fit with existing alignment. The unit of the radius is metre. Horizontal parameters extracted from existing alignment on an accident location have been furnished in Figure 3.5 (using AutoCAD) as expressive sample.

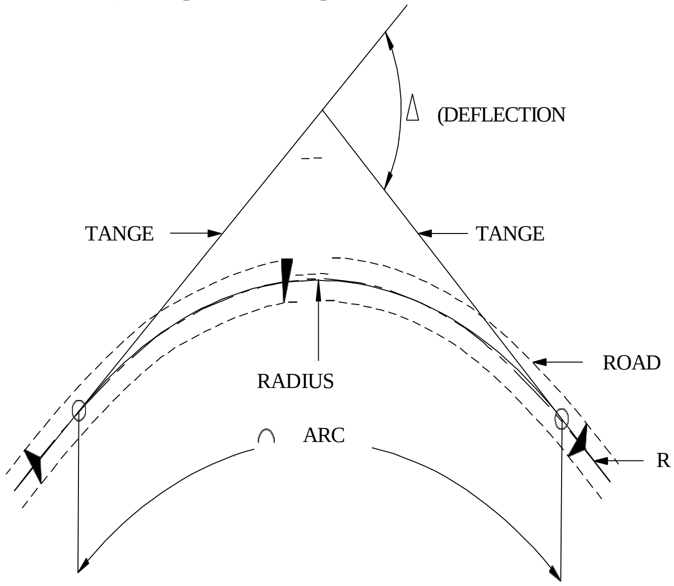


Figure 3.5: Data Extraction on Horizontal Alignment

Deflection Angle

The tangents have been fixed on the existing road alignment on curve approaches. The total angle between the two tangents is called deflection angle and measured the same. The unit of the deflection angle is degree-minutes-seconds (DMS) or decimal degree.

Horizontal Arc Length

The arc length has been measured from the best fit radius with the two tangents in existing road alignment. The unit of the arc length is metre.

Super elevation / Cross Fall

The cross section of the existing road alignment has been developed from Digital Terrain Model (DTM) in every 10m interval through software on accident location. The maximum super elevation has been considered on outer side edge of carriageway in the horizontal curvature section. The unit of the super elevation is %.

4. ANALYSIS OF EMPIRICAL DATA AND RESULTS

Accident analysis has been carried out in order to determine the effects of different geometric elements of the highway with accident rate of the same highway. These geometric elements are horizontal radius, deflection angle, horizontal arc length, super elevation, rate of change of super elevation, vertical gradient, vertical curve length, K-value and visibility/sight distance. Finally, these geometric elements are statistically analysed and considered for model development which are statistically significant.

Accident Rate

The accident rate is defined as the ratio between the number of accidents which happened in a given year and the number of vehicles with kilometers of travels length during that same year. It is generally expressed in crashes per million vehicle-kilometers of travel.

$$AR = \frac{C \times 100,000,000}{V \times 365 \times N \times L}$$

The variables in this equation are:

AR = Accident Rate expressed as crashes per 100 million vehicle-kms of travel (100mvkm) C = Total number of crashes in the study period

V = Traffic volumes using Annual Average Daily Traffic (AADT)

N = Number of years of data

L = Length of the roadway in km

5. PROPOSED MODEL

In the literature studies, generally the traffic accident models were developed as statistical prediction model with limited parameters. The nature of the traffic accidents required a flexible model that can accept imprecise data. For more complex issues, fuzzy logic is very convenient in explaining traffic accidents, in which uncertainty is principal.

This chapter is about the proposed fuzzy logic model, where an attempt has been made to predict the Accident Rate (AR) with respect to the various highway geometric elements mentioned in chapter 4. Two models have been developed due to the complexity of the geometric parameters of rural highway on different terrain conditions. First one is Highway Accident Rate Prediction Model for Plain & Rolling Terrain (HARPMPRT) and second one is Highway Accident Rate Prediction Model for Mountainous & Steep Terrain (HARPMMST).

HARPMPRT has been proposed which provide the accident rate of the highway as output variables considering radius, super elevation, K-value and visibility as input variables. HARPMMST has been proposed which provide the accident rate of the highway as output variables considering radius, super elevation, vertical gradient and visibility as input variables.

Fuzzy logic is very powerful mathematical tool for modeling the common-sense reasoning in decision making in the absence of complete and precise information. Their role is significant when applied to complex phenomena not easily described by traditional mathematical methods, especially when the goal is to find a good approximate solution.

This study aims to contribute all related numeric or linguistic parameters of traffic accidents to the accident rate prediction model. Hence, for all the stated reasons Fuzzy Inference System (FIS) of fuzzy logic modeling approach has been ideal for modeling the accident rate on rural highway.

Introduction to Fuzzy Logic

Lotfi A. Zadeh (1965) introduced the mathematical expression of an infinite-valued logic by his Fuzzy Sets and defined the concept of Fuzzy Sets as “A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function which assigns to each object a grade of membership ranging between zero and one. The notions of inclusion, union, intersection, complement, relation, convexity, etc., are extended to such sets and various properties of these notions in the context of fuzzy sets are established. In particular, a separation theorem for convex fuzzy sets is proved without requiring that fuzzy sets to be disjoint”.

Basics of Fuzzy Sets

A fuzzy set is defined as the extension of a crisp (classical) set which allows only full membership or no membership to its elements (Zadeh, 1965). A set is a collection of similar elements having common group properties. When the belonging to the group is complete without any doubt, the set is called a classical or crisp set.

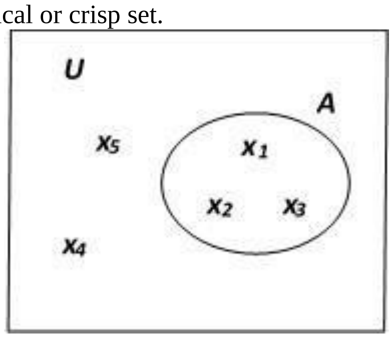


Figure 5.1: Representation of a crisp set

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 not be complete. 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 difference between a crisp set and a fuzzy set lies in the nature of their boundary. In a crisp set, the boundary is crisp, i.e., well defined. Whereas, 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 to 1.
So, a fuzzy set ~ can be defined as:

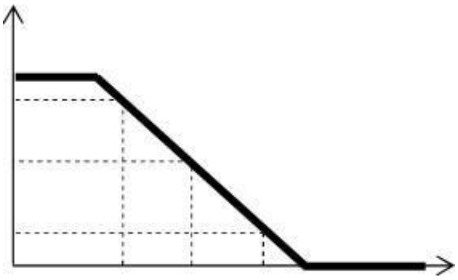


Figure 5.2: Representation of a fuzzy set
Where, µÃ is called the membership function of x in set Ã, value of µÃ is in between 0 to 1.

Linguistic variables are used in conjunction with fuzzy membership function for fuzzy analysis. While variables in mathematics usually take numerical values, in fuzzy logic application, the non-numeric linguistic variables are often used to facilitate the expression of rules and facts.

Basics of Fuzzy Membership Function

The membership function of a fuzzy set is a generalization of the indicator function in classical sets. In fuzzy logic, it represents the degree of truth as an extension of valuation. Degrees of truth are often confused with probabilities, although they are conceptually distinct because fuzzy truth represents membership in vaguely defined sets, not likelihood of some event or condition. Fuzzy membership functions may take on many forms according to the experts. However, in practical applications triangular and trapezoidal functions are preferred as simple linear functions.

6. Validation

Validation of HARPMPRT: 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 validation data set are expressed as scatter diagram in Figure 6.1.

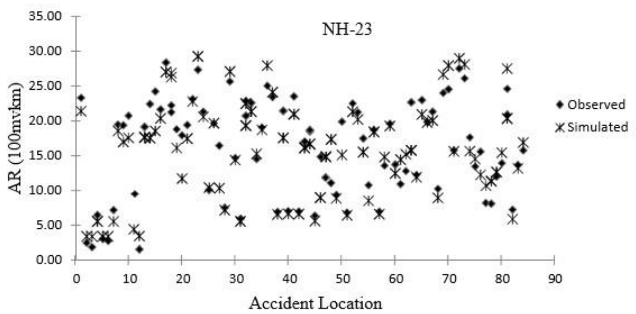
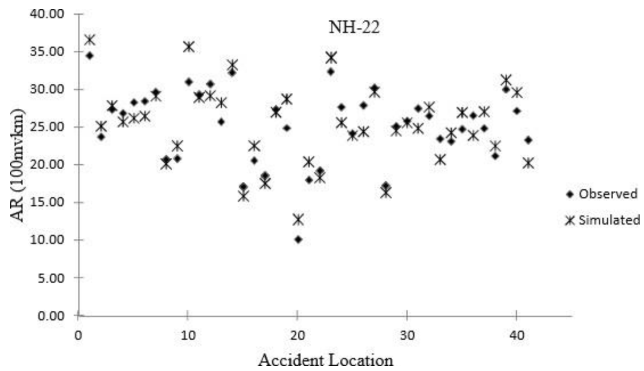


Figure 6.1: Simulated Accident Rate (AR) versus Accident Location of NH-23

Validation of HARPMMST: 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 validation data set are expressed as scatter diagram in Figure 6.2.



Sensitivity Analysis of Variables

Sensitivity analysis is a technique applies to determine how different values of an independent variable will impact on a particular dependent variable under a given set of assumptions. One of the very simplest and most common approaches is that of changing one- factor-at-a-time (keeping other factors constant) to see what effect this produces on the output.

HARPMPRT

Each input variable has been entered into the proposed model for plain & rolling terrain highway (HARPMPRT) and each output result has been taken. Also same has been expressed as scatter diagram in Figure 6.3.

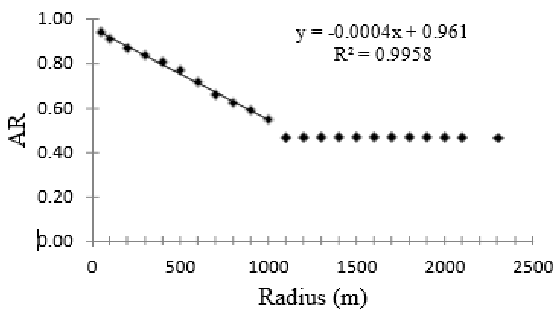


Figure 6.3: Accident Rate (AR) versus Horizontal Radius

7. CONCLUSION

Unlike many other disciplines of the engineering, the situations that are interesting to a traffic engineer cannot be reproduced in a laboratory. Even if road and vehicles could be set up in large laboratories, it is impossible to simulate the behavior of drivers in the laboratory. Therefore, traffic stream characteristics need to be collected only from the field. From the above procedures and measures as planned we could avoid occurrence of road accidents on NH5 by advanced marking and signaling systems and make the people to follow the road rules, giving speed limit to vehicles, giving a high road grip, giving correct elevations and curves, designing proper super elevation. Thus, by following these principles we will decrease the death rate due to road accidents in NH5.

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