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SAFETY EVALUVATION OF COMBINED CURVES

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Abstract - *Safe and efficient movement of people and goods is stated as the goal of transportation. But accident statistics show that number of accidents is increasing in developing countries. Geometry is the major factor that guides a user to adopt his desired speed in a rural highway. The specific alignment feature considered in the study is the combined horizontal and crest vertical curves. The objective of the work is to identify relationships between road geometry and safety through consistency and to develop specific criteria for evaluating combined curves on two-lane highways. If the combination of horizontal and vertical features includes an unexpected or extreme feature, the workload is increased even more. Such inconsistencies can lead to road accidents and fatalities. To control these inconsistencies researchers have been working on developing several measures for evaluating the geometry. A review of literature has revealed that among the various approaches available for evaluating geometric design consistency, speed based approach is considered as the best method. This is because speed is the visible indicator of driving behavior. Exhaustive field surveys were conducted to collect information regarding geometry and speed. Data for more than 15 combined curves were used to derive the relationship between operating speed and highway geometry. Accident data were collected from various police stations and accident severity indexing method was used to develop an equivalent count of accidents at each site. The work involved is the development of operating speed models for different categories of combined crest curves and also for different category of vehicles like car, two-wheeler, bus and heavy vehicle. Variables affecting the operating speed at combined horizontal and crest vertical curves found to vary for different classes of vehicles. Radius, length of horizontal curve, grade, super elevation are some of the features that affect the driving behaviour . A variety of speed based consistency measures were formulated and assessed for their suitability in evaluating performance of two-lane rural highways from safety point of view.*

Key Words: geometric data, consistency, operating speed

1.INTRODUCTION

Researchers are still seeking a better understanding of the parameters that affect safety in combined curves. Curves are one of the most critical sections of the road network contributing to a high percentage of serious runoff accidents and lane-changing crashes. Moreover, driving in curves requires combined control of both steering and speed, taking into account the dynamic response. The prime objective of the study is to develop models for predicting operating speed that could be a useful tool for evaluation of alternate highway designs and selection of right design choice. Using the operating speed data and traffic accident record of the sites under study, an attempt was made to develop a criterion for the consistency evaluation of combined horizontal and crest vertical curves. Estimated operating speeds can be used in the design of active traffic management strategies and devices. Scope of the study is limited to development of operating speed models for car, two-wheeler, bus and truck and the targeted alignment feature is the combined horizontal and crest vertical curves of two-lane rural highways.

1.1 LITERATURE REVIEW

A combined curve shows the coexistence of horizontal as well as vertical curves. The effect of such a curve on driver expectations is seldom studied. Fitzpatrick *et al.* [1] concluded that radius of horizontal curve is the surrogate measure for operating speed in combined curves except for crest curves with unlimited sight distance. Gibreel *et al.* [2] added some more variables in the set of independent variables *viz.*, deflection angle of horizontal curve, length of vertical curve, gradients, algebraic difference in grades and super elevation rate.

Many researchers have pointed out that a combined curve puts forward a wrong perception to the drivers. Smith and Lamm [3] hypothesized that an overlapping crest curve can cause the horizontal curve to look sharper while an overlapping sag curve can cause the horizontal curve to look flatter than it actually is. Mori *et al.* [4] found that poor alignment coordination leads to erroneous perception of roadway features like radius. It may be hazardous if a sharp curve is perceived as a flat curve and drivers manoeuvre the curve at a higher speed. Radius and grade are the two geometric variables identified by Lamm *et al.* [5]. For a radius greater than 400 m and grade less than 5 percent, chances for collision are less. For grades steeper than 6 percent, sharp increase in accidents is noticed. Drivers approaching the crest combination curve found to reduce the speed because of the misperception. Hassan *et al.* [7] further studied on the value of perceived radius and found that its value depends on actual radius, type of vertical curve and turning direction. Lamm and Smith [8] proposed that design speed of horizontal curve should at least be equal to that of a crest or sag vertical curve and not more than 15 km/h less than the measured or estimated operating speed at the approach. Hassan et al. [9] observed that higher the operating speed on horizontal curves, higher is the collision on crest vertical curves.

1.2 GEOMETRIC VARIABLES

The geometry of the curve is defined by many factors like super elevation, grade, length of curve, radius of curve, width of road, deflection angle, tangent length, curvature etc. These factors influence the driver maneuver in the curve. Other than the geometry of curve, the accidents occurring is also influenced by the traffic volume, friction and other psychological characteristics of the driver in a curve. The operating speed of a vehicle in a curve is greatly influenced by the radius of the curve, length of curve, grade, super elevation.

2. METHODOLOGY

Identifying the real causes that significantly affect the operating speed of vehicles is essential for designing combined curves that perform up to the expectations of the user. Hence, a methodology is developed to verify all the above possibilities by collecting necessary data.

Only those sites that are without any intersections, bridges, schools, etc. are selected for the study. The specific criteria for selecting the combined curves are given below.

- Maximum horizontal length between the horizontal point of intersection and vertical point of intersection is limited to 100 m and significant overlap should be present between the lengths of vertical and horizontal curves.
- The algebraic difference in ascending and descending grades has to be minimum 0.5 percent.
- Length of vertical curve has to be at least 40 m.
- Minimum length of straight and level stretch before the curve is 100 m.

Correlation between the independent variables and dependent variable determines whether the changes in independent variables influence the changes in dependent variable. The consistency of the model depends on this correlation.

Table -1: Geometric variables

Curve	Radius (m)	Length (m)	Super Elevation (%)	Grade (%)	Operating speed (km/hr)
1	80	51.29	5	3	74.4
2	51	53	5.9	3.1	71.2
3	95	37	5.7	3.8	75
4	76	88	5.3	5.15	70
5	55	43	5.05	2.6	71.9
6	60	48.29	7.7	4.46	70
7	60	18.23	10	3.91	73
8	75	78	9.5	4.8	72.6
9	40	83	4.4	4.14	68
10	50	46.61	5.6	3.64	70
11	14	25.5	6.8	6.7	45.7
12	38.5	41.5	3.2	2.7	53
13	77.3	98.4	2.4	4.3	73
14	41.4	59.4	1.2	1.8	68
15	22.5	25.8	2.8	3.2	59

Since we are using speed based approach of analysis, operating speed of vehicles in curves is taken as the dependent variable. Operating speed of different class of vehicles was collected from the curve locations. A 20m section on the curve is measured and the time taken for each vehicle to pass this section is recorded to get the operating speed of vehicles. The geometric factors such as radius of the curve, length of the curve, super elevation, grade of the curve is taken as the independent variables.

Table –2: Correlation

	operation speed	radius	length	super elevation	grade
operation speed	1.000	.767	-.535	.253	-.334
radius	.767	1.000	-.064	.118	.205
length	-.535	-.064	1.000	-.310	.553
super elevati	.253	.118	-.310	1.000	.376

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grade	-.334	.205	.553	.376	1.000

Pearson correlation is a measure of the linear correlation between two variables X and Y. It has values between -1 and +1. The radius of the curve has maximum correlation with the operating speed.

3. REGRESSION ANALYSIS

Linear regression is the next step up after correlation. It is used when we want to predict the value of variable based on the value of another variable. When multiple variables are used to determine the value of other variable it is called multiple regression. The variable we want to predict is called dependent variable or the outcome variable. The variables using to predict the dependent variable is called independent variables.

Assumptions of linear regression

- The correlation between the independent variables and dependent variable is high.
- The correlation between the independent variables is low.

Using the data collected from different combined curves various regression models were developed for different class of vehicles. Operating speed is taken as the dependent variable. The radius of curve, length of curve, super elevation and grade is taken as the independent variable.

Table –3: Coefficients

Model	coefficients
(Constant)	68.440
radius	.112
grade	-1.780
super elevation	.447

The regression equation of the model created is given by

$$y = 68.440 + (.112\ x_1) + (-1.78\ x_2) + (.447\ x_3)$$

2/3 of the collected data is used for making this model. This equation helps in determining the operation speed on a curve for a set of radius , super elevation and grade. The remaining 1/3 of the data is used for checking the consistency of the model.

Table –4: Consistency check

Curve	Radius	Length	Super Elevation	Grade	Observed value	Theoretical value
11	14	25.5	6.8	6.7	45.7	61.1216
12	38.5	41.5	3.2	2.7	53	69.3764
13	77.3	98.4	2.4	4.3	73	70.5164
14	41.4	59.4	1.2	1.8	68	70.4092
15	22.5	25.8	2.8	3.2	59	66.5156

The difference between the observed value and theoretical value is less than 20 km/hr , hence the level of consistency of the model is good.

4. ACCIDENT SEVERITY INDEX

Blackspots are the locations where a number of accidents repeatedly occur. The basic elements in traffic accidents are road users, vehicles, road condition, road geometry, environmental factors etc. Road accidents cannot be totally prevented, but by using suitable traffic engineering safety plan and management measures, the accident rate can be reduced. Even after an accident occurs, the common city roads have to face many problems such as traffic jams which cause loss of valuable time. Severity index method was used for finding the hotspots. In this method, a severity value was obtained for each crash location based on number of people died, number of people severely injured, and number of people who got minor injuries and so on. Thus Accident Severity Index (ASI) can be defined as a dimensionless value indicating the hazardousness of a spot in the road.

Table –5: Accident data

curve	fatal	major injury	minor injury	total	
1	2	2	5	9	aroor
2		1	3	4	unnakuppa
3	1	2	2	5	east marady
4			2	2	east marady
5	2	3	1	6	thottumkalpeedika
6	2	1	1	4	ellichuvada road
7		2	2	4	ellichuvada road
8	1		3	4	st george jn
9		1	2	3	st george jn
10		3	4	7	kottaram road

11		1	2	3	pillapara
12		2		2	pillapara
13	1	3	2	6	charpa
14	1	1	3	5	vettilapara
15	1	1	1	3	vettilapara

The concept of this method is that the number of fatal or injury accidents at a location is given a greater weight than property damage only accidents. Accident Severity Index is a dimensionless value indicating the hazardous of a location. The following equation has been used:

$$ASI= NfWf + NsWs + NmWm$$

Where,

Nf = No of fatal accidents at the spot in the last 3 years.
Wf = Weight assigned to fatal accident = 6
Ns = No of serious accidents at the spot in the last 3 years.
Ws = Weight assigned to serious accident = 3
Nm = No of minor accidents at the spot in the last 3 years.
Wm = Weight assigned to minor accident = 1

Table –6: Accident severity index

Curve		ASI
1	aroor	23
5	thottumkalpeedika	22
13	charpa	17
3	east marady	14
10	kottaram road	13
14	vettilapara	12
6	ellichuvada road	10
15	vettilapara	10
8	st george jn	9
7	ellichuvada road	8
2	unnakuppa	6
12	pillapara	6
9	st george jn	5
11	pillapara	5
4	east marady	2

The accident severity index was used to rank the accident locations. Based on the analysis curve 1 in Aroor was identified as most vulnerable accident prone area. In order to avoid accidents in the curve severe safety measures has to be taken such as proper road marking and signals, illumination of street light, night time visibility, proper road conditions, concrete or steel barriers etc.

3. CONCLUSIONS

In reality, highway alignment is three dimensional in nature and consists of a variety of combinations of horizontal and vertical curves. The output of the present study proved the existence of a relationship between geometry and operating speed of vehicles. Radius is found to influence operating speed directly for all vehicle categories. Other variables affecting the operating speed at combined curves are length of horizontal curve, grade, super elevation. A variety of speed based consistency measures were formulated and assessed for their suitability in evaluating performance of two-lane rural highways from safety point of view. Operating speed Deviation from Design speed (ODD) at Mid curve. EPDO (equivalent property damage only) was found to be the best safety measure. Design of combined curve can be considered consistent if the ODD value is less than 20 km/h. This values would help a designer to evaluate a highway alignment feature as good, fair or poor in design consistency. As this method requires only the information about the geometry of highway alignment. It will become handy tool for designers, planners and road safety auditors for evaluation of roads at the expense of minimum resources.

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