

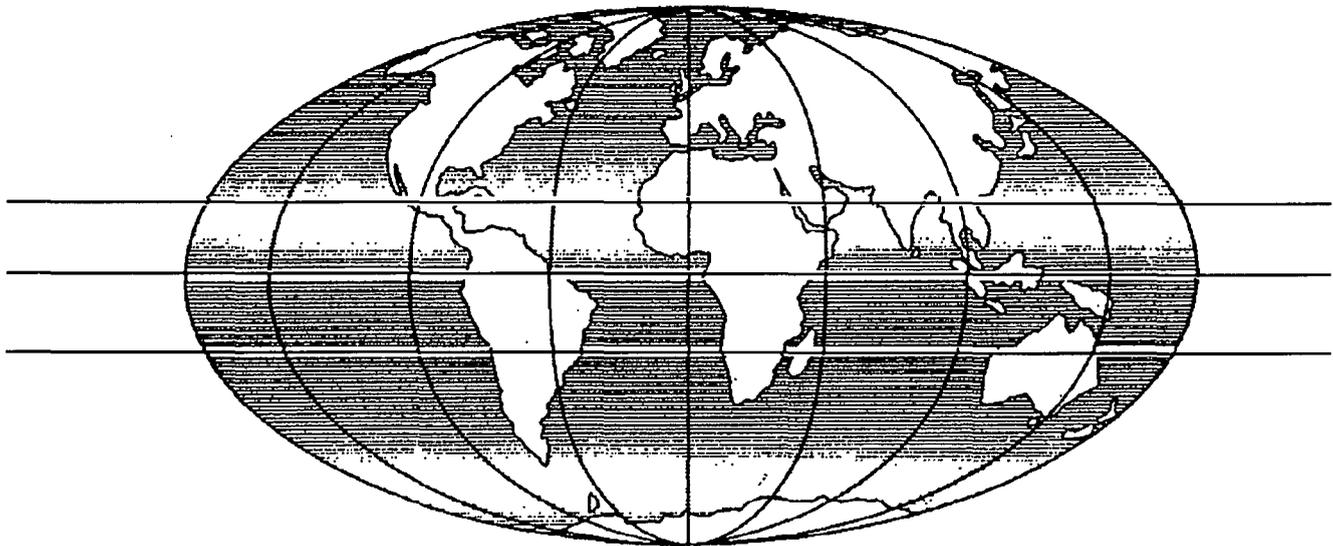


ODA

Reprint

**TITLE Predicting changes in accident rates in
developing countries following
modifications in road design**

by **A Aeron-Thomas and Dr G D Jacobs**



**Overseas Centre
Transport Research Laboratory
Crowthorne Berkshire United Kingdom**

PA3129/95 AERON-THOMAS, A and G D JACOBS (1995). The relationship between accident rates and geometric design in developing countries. *International Forum on Road Safety Research, Shangri-la Hotel, Bangkok, Thailand, 25-27 October 1995.*

PREDICTING CHANGES IN ACCIDENT RATES IN DEVELOPING COUNTRIES FOLLOWING MODIFICATIONS IN ROAD DESIGN

BY

AMY AERON-THOMAS AND DR G D JACOBS

1. Introduction

Due to their complexity and uncertainty, accident costs have traditionally been excluded from highway investment modelling in developing countries. The growing realization of the substantial costs of road accidents (often over 1 per cent of GNP) has renewed the desire to include possible accident savings along with reductions in vehicle operating costs and time savings.

As part of the ongoing International Study of Highway Development and Management Tools (ISOHDM), an evaluation was undertaken by TRL of the current ability to predict changes in accident rates in developing countries following modifications in road design. This paper summarises the work carried out as part of the ISOHDM Study and presents a review of work conducted in the developing world together with the lessons learned from developed countries' experiences in this field. It should be noted that the very different features of road and traffic conditions in developing countries, (e.g. high pedestrian and non-motorized vehicle usage, conflicting land uses, and road user behaviour), substantially limits the potential for transferring information from industrialised countries to the developing world.

The current ISOHDM Study offered an opportunity to evaluate the present ability to incorporate accident costs and benefits into highway investment modelling in developing countries. Accordingly, this paper reviews the work over the past two decades investigating the relationship between road geometry and accident rates relevant to developing countries. Several developing country case studies are reviewed and their results compared. A summary of the role of safety benefits in road appraisal methods in industrialized countries is also analysed to provide guidance for developing countries.

2. Country research

2.1 Literature Review

Early TRL work in Kenya and Jamaica

In 1976, TRL published its first work on this topic, a study of accident rates on rural roads in developing countries, which investigated the relationship between road geometry and accident rates. Case studies were conducted in Kenya and Jamaica where TRL had ongoing work and access to good databases. In Kenya, the Nairobi-Mombassa highway was selected whereas in Jamaica, 29 sections of various rural roads (total length 473 miles) were studied. Table 1 lists the geometric variables investigated under the various case studies.

Road User Cost case studies in India

Similar to the TRL approach, two case studies were undertaken as part of the Road User Cost Study in India in the early 1980's. 114 non-urban kilometres of the Bombay-Pune Road in Maharashtra were selected but with road width, surface irregularity, and traffic flows assumed constant, thus allowing a focus on the junction frequency, and horizontal and vertical curvature. As in Jamaica, the second case study included 34 selected routes with varying roadway characteristics. While the Bombay-Pune study used uniform road sections of one kilometre for analysis, the Second Indian Roads Study had roads ranging from 9 to 509 kilometres in length.

Table 1. Geometric features considered in case studies

| KENYA | JAMAICA | BOMBAY-PUNE | SELECTED INDIAN ROADS | CHILE |
|----------------------|----------------------|----------------------|-----------------------|----------------------|
| no. of junctions | no. of junctions | no. of junctions | no. of junctions | no. of junctions |
| horizontal curvature | horizontal curvature | horizontal curvature | horizontal curvature | horizontal curvature |
| vertical curvature | vertical curvature | vertical curvature | vertical curvature | vertical curvature |
| width | width | | width | |
| surface irregularity | surface irregularity | | | |

Hills and Jones-Lee Hypothetical Case

At the summer PTRC conference in 1981, a hypothetical case was presented which estimated safety impacts from various road improvement options. The scenario involved two Indian cities, populations of 1 million and 400,000, to be connected by a two-lane stabilized gravel road 190 kilometres long. The options for improvement were:

1. Paving existing road with only minor alignment improvements and minimal local widening.
2. Paving existing road and substantial alignment improvements (including width and alignment of right of way, reconstruction of drainage culverts).
3. Constructing a new and shorter road with access restrictions and design speed of 100 km per hour.

The first option was expected to increase accidents by as much as 30% while the second option would not change the accident rate. Only a new and properly designed road would reduce the accident rate (30%) (Hills and Jones-Lee, 1981). These estimates of expected changes on accident levels were solely value judgements as they were not based on any empirical results.

TRL work in Cyprus and Jordan

Between 1982-84, TRL was asked to cost accidents and predict possible savings from road improvements in Cyprus and Jordan. Due to the uncertainty in predicting accident reduction, a range of possible percentage reductions in accidents was produced. In Cyprus, proposed road improvements between the main port and a tourist centre included road widening from an average of 6 to 7.5 metres, a reduction in the number of junctions per kilometre from 1.7 to 0.5, improved sight distances and reduced road roughness. Based on the earlier TRL research, a reduction in accidents between 25-35 per cent was predicted. These savings increased the Net Present Value (NPV) by 10-20, per cent depending on the costing method used.

Another example from Cyprus, the proposed Larnaca link study (with two roads connecting the second port to a new dual carriage highway), predicted accident savings that increased the NPV by 10 to 25 per cent. Increasing the width to 7 metres on both roads involved, would only increase the NPV by 10-11 per cent compared to 20-25 per cent if both were dual. Converting only one of the links to dual carriageway while increasing the road width of the other link increased NPV by 15-16

per cent. If both roads were made dual carriageway, injury accidents were expected to be halved with fatalities and serious injury accidents reduced by 25 per cent.

Whilst these expected accident reductions were higher than what the Hills and Jones-Lee hypothetical study would have anticipated, they were similar to what has been measured on the new dual carriageway located at a terminus of the proposed Lanarka link. As displayed in Table 2, a before-geometric data pertaining to either the old or the new road is available for comparison.

Table 2. Accident Rates on Old and New (Dual Carriageway) Nicosia-Limassol, Cyprus

| | OLD ROAD (1980) | NEW ROAD (1984/85) |
|--|-----------------|--------------------|
| Vehicle miles (million) | 144 | 180 |
| Injury acc/year | 193 | 102 |
| Fatal & Serious inj acc/year | 63 | 54 |
| Injury acc/mil veh miles | 1.3 | .6 |
| Fatal & Serious injury acc/mil veh miles | .44 | .3 |

In Jordan, proposed projects included upgrading 8.4 kilometres of the Salt-Suweilih road from single to dual two-lane carriageway and upgrading 2.2 kilometres of the Zarqua-Rusaeifa road from single to dual carriageway. An upgrading to dual carriageway was estimated to reduce accidents by 30-50 per cent. On the Salt-Suweilih road, accident savings were thought to increase the estimated first year rate of return by between 10-16%, with the higher obtained if pain, grief and suffering were included. On the Zarqua-Rusaeifa road, where accidents were as high as 20 per kilometre per year, accident cost savings were predicted between 40-60% and equivalent to as high as 50 per cent of time and VOC savings.

Chile

In 1983, a paper (Jara Diaz) was presented at the PTRC Summer Annual Meeting which summarized the results of a study of the effects of road geometry on accident rates in Chile. 42 observations were made on 15 two-lane paved road sections and the analysis compared multiple regression techniques as used in the previous case studies with flexible quadratic forms. Unfortunately, little background on data collection was provided.

Papau New Guinea

As part of the Papau New Guinea Co-operative Programme of Road Safety Research, TRL has begun work investigating the relationship between road geometry and accidents on the Highlands Highway. Preliminary results were published in 1988 (Hills and Thompson) but were restricted to a simple regression analysis. Further research is underway with geometric data provided from a purpose designed road inventory survey that used uniform length (one kilometre) sections except in urban areas where section lengths were halved. The proposed analysis will consider road width, shoulder width, gradient, horizontal and vertical curvature, as well as sight distance and drainage ditch/side slope profile.

Role of surface type

Another project (as part of the above PNG study) will evaluate the effect of the sealing of the

Highlands Highway on traffic volumes and accident rates. Surface type was not considered in any of the previous case studies although an earlier Kenyan accident study analysed accidents by both road surface and accident type and found:

1. Engineered gravel roads had 18% of all accidents but 5% total miles travelled.
2. Gravel and earth roads had single vehicle accidents constituting half of their accidents whereas surface roads had the highest percentage of vehicle-pedestrian accidents.

Table 3. Type of accident and road surface, Kenya

| | PAVED | GRAVEL | EARTH | UNKNOWN | TOTAL |
|---------------------|-------|--------|-------|---------|-------|
| Single vehicle | 842 | 546 | 63 | 39 | 1490 |
| Vehicle-vehicle | 843 | 91 | 18 | 37 | 989 |
| Vehicle-motor cycle | 181 | 13 | | 1 | 195 |
| Vehicle-cycle | 536 | 76 | 5 | 14 | 631 |
| Vehicle-pedestrian | 1803 | 253 | 41 | 36 | 2133 |

In 'Economic Warrants for Surfacing Roads', a table compared the accident rates for different road surfaces in the Cape Province of South Africa but no background data was available. (Bitumen and Tar Association, 1989). Paving a road was found to decrease the overall collision rate with reductions in the share of fatal crashes and damage only incidents. Both serious and slight injury accident percentages however were found to increase. The average cost of a collision was thought to be reduced by 15%.

Table 4. Rates and severity of accidents by surface type, Cape Province, South Africa

| | ROAD TYPE | |
|----------------|------------|----------------|
| | GRAVEL | TWO-LANE PAVED |
| Collision rate | 2.3/veh km | 1.0/veh km |
| Fatal | 11% | 8% |
| Serious | 6% | 9% |
| Slight | 11% | 18% |
| Damage only | 72% | 65% |

Surface irregularity is often taken as a proxy for surface type but poorly shaped paved roads can often have high surface irregularity values. Moreover, few studies even considered road roughness. Surface irregularity was considered in the Kenyan and Jamaican studies with the Jamaican roads having a wider range of road roughness.

Swedish Model

At the recent ISO-HDM conference, two methods were presented for evaluating road safety benefits in road appraisals in developing countries. While only theoretical, the Swedish developed model is the first model that reflects the potential of road improvements to increase accident risks; it applies a speed/flow equation which increases the accident risk proportionally to increases in speed. The model also calculates risk separately for protected (motorized vehicle occupants) and unprotected road users. Accident reduction estimates were also proposed for pedestrian separation and side ditch design while junction type and medians were also mentioned as influencing accident risk. Data requirements for this theoretical model vary between being extremely specific with accident types and side ditch design details needed while exposure risks used can be based on national averages.

South Africa

The South African formula for predicting accidents on rural highways is being tested on the main highway connecting South Africa with Swaziland. The model is simple and easy to use but requires assumptions that may only apply to the more advanced developing countries. It uses base rates that are calculated for road type (multi-lane highway, surfaced single carriageway roads, and single carriageway gravel roads) before adjusting these rates to specific road conditions including grade separated intersections, median type, curves, verges, shoulder width and surface, and lane width. After determining total personal injury collisions (per 100 million vehicle kilometres), national fixed ratios are applied to determine accident severity rather than using local figures.

The model has several weaknesses, including a simplistic treatment of horizontal curves and verges with road sections allowed to have varying types of curves and terrain. Its transferability to other countries should be considered carefully as it is rare for a situation to exist that allows for model transfer without any adaptation. Road improvements were modelled as improving road safety, thus disregarding the negative associations of speed increases. It also considers junction type rather than frequency of junctions, although junction spacing was the only variable found significant by all the earlier case studies. The project road did not appear to have any non-motorized or pedestrian traffic. The South African formula may only apply to roads with motorized traffic and where lane discipline is good enough for lane width rather than road width to be a factor.

2.2 Case Study Analysis Results

Regression Analysis

In the Kenya and Jamaica studies, simple regression analysis was conducted to establish the correlation of the individual variables with the accident rate defined as accidents per million vehicle kilometres. Vehicle flow (averaged over a 12 hour 7 am-7 pm) period had the strongest correlation to the accident in both studies, although with similar flows, Jamaica was found to have a higher accident rate. Flow correlations were significant at the 5 percent level.

Of the geometric features, the number of junctions proved to be the most significant. The correlation was stronger for Kenya (R^2 value of .49) although the number of junctions per kilometre never exceeded 2 while Jamaica often had as many as 8 junctions per kilometre. Road width was important in Jamaica with wider roads having fewer accidents. Comparisons could not be made with the Kenya study as road width varied little.

Preliminary analysis of the Papua New Guinea data was restricted to simple regression with only gradient and curvature considered. While curvature and gradient were strongly correlated, gradient had the higher correlation with accident per vehicle kilometre at 0.64 (R^2 value of .42) compared to that of curvature at 0.52 (R^2 value of 0.27). Gradient's correlation with accident per kilometre was less at 0.08 (R^2 value of 0.70).

Simple correlation matrices were presented in both Indian studies and the Chilean analysis and are presented in Appendix A. Traffic flow had a correlation of 0.83 with accidents for Selected Indian Roads and 0.75 for Chile (quadratic form).

Analysis method and dependent variable choice

In the Selected Indian Roads Study, the high correlation between horizontal and vertical curvature (0.85) caused horizontal curvature only to be used in the final analysis although alternative equations were tested with vertical curvature. Surface irregularity had such a high correlation with road width in Jamaica (significant at the 5 per cent level) that surface irregularity was insignificant in the multiple regression analysis even at the 10 per cent level.

Multiple regression analysis was conducted in all the case studies, with the Chile study also using a flexible quadratic form to evaluate second order effects of both traffic flow and road geometry. The dependent variables did differ in the analyses. As seen in Tables 5 and 6, personal injury accident rate per million vehicle-kilometres was used for Kenya and Jamaica, whilst for Chile, the total annual accident per year per kilometre was used in both its linear and flexible quadratic equations.

The Indian case studies developed equations for both dependent variables with the Selected Indian Roads Study arguing that due to its higher R^2 value, the simpler equation of accident per kilometre per year should be used. In the same study, equations were also developed testing the average pavement width factor and regional variations.

Role of flow

The Selected Indian Roads Study found accident rate to be dependent on flow. Traffic volume and the accident rate per million vehicle kilometre per year had a correlation coefficient 0.4. No such correlation was found in Kenya or Jamaica and the Bombay-Pune study assumed traffic to be constant.

The Chilean study argued that the significance of flow was better understood (and shown to be stronger) when second order effects were considered. However the correlation coefficient for traffic flow only increased from 0.44 from a simple regression to 0.45 for a multiple regression including horizontal and vertical curvature, and number of junction in addition to flow. With a flexible quadratic form, the correlation coefficient for flow increased by 40 percent to 0.62. No subsequent in-depth analysis has been conducted in developing countries to test these conclusions.

Save for the Bombay-Pune equation for personal injury accident rate which had no details given and the junction and width coefficients in the Selected Indian Roads equation, all coefficients were significant at a minimum of 5 percent.

Table 5. Personal Injury accident rate per million vehicle kilometre

| | |
|----------------------------|--|
| KENYA 5% significance | $1.45 + 1.02 (\text{junction}) + 0.017 (\text{horizontal curvature})$ |
| JAMAICA 5% significance | $5.77 - 0.755 (\text{width}) + 0.275 (\text{junction})$ |
| BOMBAY-PUNE | $-0.1526 + 0.0216 (\text{vertical curvature}) + 0.0031 (\text{horizontal curvature}) + 0.4793 (\text{junction})$ |

Table 6. Total accident rate per kilometre per annum

| | |
|--|--|
| BOMBAY-PUNE $R^2 = 0.8$ | $-0.6576 + 0.0932 (\text{vertical curvature}) + 0.0133 (\text{horizontal curvature}) + 2.0657 (\text{junction})$ |
| SELECTED INDIAN ROADS $R^2 = 0.76$ | $0.2171 + 0.002884 (\text{horizontal curvature}) + 0.4126 (\text{junction}) - 0.3447 (\text{width}) + 0.001274 (\text{ADT})$ |
| CHILE $R^2 = 0.66$ (linear model) | $0.45121 + 0.59494 (\text{junction}) + 0.00563 (\text{horizontal curvature}) + 0.02568 (\text{vertical curvature})$ |
| CHILE $R^2 = 0.82$ (flexible form) | $0.61544 + 0.01864 (\text{horizontal curvature}) + 0.88104 (\text{junction}) - 0.0463 \times 10^{-3} (\text{horizontal curvature}^2) - 0.0158 (\text{vertical curvature}^2) - 2.12543 (\text{junction}^2) + 0.164643 \times 10^{-1} (\text{ADT} \times \text{junction}) + 0.40724 \times 10^{-2} (\text{horizontal curvature} \times \text{vertical curvature})$ |

Junction frequency was the only variable which proved significant in all the equations although horizontal curvature was found significant in all but the Jamaican analysis. Neither surface irregularity nor vertical curvature proved significant in the Kenyan or Jamaican analysis although vertical curvature had the greatest significance in the Bombay-Pune equation.

Inter-model comparison

Comparison with a model developed by Silyanov (1973) (developed by combining studies of several different countries) found both Kenya and Jamaica to have much higher accident rates for similar levels of vehicle flow. Jamaica was also found to have a much higher rate of accidents for the same road width. Comparison with Silyanov's equation (determined with data from developed countries only) produced a personal injury accident rate of 1.2 per million vehicle km for Bombay-Pune which was similar to the rate for roads in developed countries.

Test section

All studies have stressed the need to restrict future application of models derived to sections with road geometry similar to that studied. The Bombay-Pune equation was suggested for use on other roads with varying traffic levels but factors such as riding quality must be similar. A look-up table was

developed by the Selected Roads study in India which predicted accident rates according to terrain and road lane type, traffic volume, and junctions per kilometre. This table was not recommended for use on roads with geometric features outside the range of the values tested.

The Road User Cost Study applied the Kenya equation to a representative section of the Bombay-Pune road with the following design features:

- | | |
|-------------------------|---------------|
| 1) Road width | 7 metres |
| 2) Horizontal curvature | 10 degree/km |
| 3) Vertical Curvature | 10 m/km |
| 4) Surface irregularity | 2000 mm/km |
| 5) Junctions | 2 per km |
| 6) ADT | 4747 vehicles |

This road section can be tested with other equations although a review of the ranges covered is required as not all studies included sections with the parameters of the test section. Appendix A reviews the mean, standard deviation and range of variables provided by the studies. In brief, while comparable to the Kenya study on all parameters, the test section's horizontal curvature is slightly less than the minimum found in the Jamaica study (25 degree/km) or in the Indian Selected Roads study (16 degree/km). Both of these studies had considerably higher horizontal curvature means with 193 degree/km for Jamaica and 160 degree/km for the roads in India.

The Chile study compares worse with the Bombay-Pune test section, for while no range was given, the Chilean study had a junction frequency of .45 (more than 5 standard deviations away from the test section's value). Traffic flows were much lower as well with a mean of 2728 vehicles only. Having acknowledged these discrepancies, the test section was applied to all equations shown in Tables 2-3 to show the variation in results and the sensitivity of applying the equation to outside study parameters. Only the two Indian case studies produced similar results while the Bombay-Pune equation for personal injury accident rate produced a figure 60% that of the Kenya equation.

Table 7. Comparison of predicted test section accident rates.

*Comparison published in Road User Cost Study assumed Kenya equation to refer to total accidents rather than personal injury accidents and applied incorrect equation.

| | Personal Injury Acc/ mil veh km | Total Acc/ km/year |
|---------------------|------------------------------------|-----------------------|
| Kenya (5% sig) | 3.66 | N/A |
| (10% sig) | 3.86 | N/A |
| Jamaica | 1.04 | N/A |
| Bombay-Pune Rd* | 1.05 | 4.54 |
| Selected Indian Rds | 2.26 | 4.71 |
| Chile (linear form) | N/A | 1.95 |
| (flexible form) | N/A | -5.85 |

The early TRL work in Kenya and Jamaica concluded that due to the incompatibility of the equations produced, one standard regression equation could not be recommended for use elsewhere. As further work has produced further differing equations and even brought analysis methods into question, this

conclusion still holds. These studies acknowledged the need for further research with main areas including sight distance, shoulder condition, and the presence of ribbon development as well as traffic composition. Unfortunately, following the early efforts, relatively little work on this subject has been carried out elsewhere (by TRL or others).

The Chilean paper concluded that linear forms are inappropriate for analysis as they fail to measure the second order effects and that flexible quadratic forms are needed to accurately evaluate the effects of road geometry and traffic flow. For example, under the linear form, road geometry appeared to have no impact on pedestrian accidents until second order terms were included.

As no consensus has been achieved between models, nor even between indicators or analysis methods, it is not presently possible to adopt one method from these case studies as a guideline for all developing countries.

2.2 Developed countries research

Despite the extensive number of studies, developed countries (perhaps surprisingly) have not been able to model accidents adequately on the basis of geometric parameters. Nor have they even been able conclusively to determine a preferred analysis method or the role of traffic flows.

Much relevant research has been recently sponsored in the US due to the Surface Transportation Act of 1982 which mandated a study on the cost-effectiveness of geometric design standards. The subsequent Transportation Research Board publication did develop a model for evaluating safety benefits but it was not proposed for national use and various state models still exist.

A review of European countries cost benefit methods for new roads found most to assume different accident rates by road type or area location rather than geometric design as in Belgium and Spain. Due to the 'severe constraints on the robustness of impact assessments', it was concluded that assessment methods should be limited to criteria whose impacts are easily identifiable and significant.

Due to the acknowledged inability to predict accidents based on design characteristics, the UK road investment model, COBA, uses look-up tables for accident predictions. Roads are divided only according to classification and urban/rural settings with default personal injury accident rates (per million vehicle kilometres) used when local information is unavailable. The estimated number of accidents is thereby determined by road type, length, and traffic flow (urban roads with few junctions may use the rural road rate). COBA assumes that accident numbers are directly proportional to flow although there is evidence to the contrary, with accident rates decreasing as traffic flow increases.

3. Modelling Weaknesses

With road accidents typically caused by the interaction of several factors, including road geometry, driver and vehicle condition, etc., any attempt to predict accidents based on road geometry alone can only offer at best an incomplete explanation while at worst may be misleading and divert scarce funds from actual problem areas.

Road improvements, that by geometrical design criteria should have improved the safety of a road, have often had the opposite effect. Road widening and alignment improvements allow, if not encourage, greater speeds, which can increase the accident severity.

To help explain why accident prediction models based on geometric design parameters in developing countries so often fail, the main weaknesses of such models are reviewed below.

3.1 Traffic flow and composition

Assuming traffic counts have been conducted frequently and long enough accurately to describe average annual daily total traffic flow (AADT), (which is in itself unlikely), few counts collect data on all road users, i.e. non-motorized vehicles (NMV) and pedestrians in addition to motorized modes. In developing countries, NMV and pedestrians often compose the majority of traffic and due to their vulnerability, deserve extra consideration. In India a flow of about 100 bicycles per hour in each direction was found to produce a strip effect reducing the effective carriageway width (CRRI, 1982).

Percentage of trucks and commercial vehicles should also be highlighted as they have greater damage potential. Trucks and buses are often over-represented in accident statistics which is more reason to note their presence. While the recent TRB study found no correlation, the Bombay-Pune study mentioned the effect of trucks on accident rate.

3.2 Accident Severity and Type

Accident studies still argue over the correct way to measure success of safety improvements, as road fatalities and injury accidents frequently move in opposite directions. Likewise, whether to predict accidents on a kilometre basis or to relate it to vehicle flow (per million vehicle kilometres) is still undecided.

Secondly, certain types of accidents have a higher correlation to geometrical features. For instance, single vehicle run-off road and head-on crashes are more susceptible to road design than pedestrian accidents, which are often explained by roadside friction. Any accident study investigating geometric design parameters should include a breakdown by type of accident, type of vehicle involved etc. and use the relevant rates for these classifications.

3.3 Appropriateness of Indicators

Averages of geometric features are used in the modelling equations, although these averages come from studies where road sections were often determined by geographical features, or main junctions rather than the desired uniform geometric design features. Extremely long road sections are found in several of the developing country case studies and geometric consistency is unlikely, thus negating the relevance of the design parameter mean. If geometric means are to be used, road sections need to be based on geometric homogeneity rather than uniform lengths or convenience. The data collection implications could be severe in ensuring each section had minimal variations in the basic design features of vertical curvature, horizontal curvature and road width.

'A Study of Road Needs in Rural Jamaica', provided the details on the data collection of the road inventory and geometric features used in the Jamaica study. This study reviewed the assumptions made in accepting section averages as indicative of the local road geometry.

Vertical Curvature

It concluded that average gradient failed to reveal the severity of individual gradients. Gradients in excess of 7 percent were found on sections containing average gradients of only 1.1 per cent. In general, roads with average grades of 3 per cent would have higher gradients for about 40% of the length while sections with average gradient of 5% would have higher gradients on half of the length. Where roads are being designed for the first time in their evolution and where terrain is mountainous, individual gradients can change dramatically.

Horizontal Curvature

As mentioned earlier, horizontal curvature typically is taken from readings on a small scale (1:12,500) map. While encountering some transferral problems, relating map curvature measurements to road sections was not thought to significantly affect the results.

As with vertical curvature, values of average horizontal curvature hid some wide ranges; one section mentioned had an average curvature of 190.8 degrees per mile but ranged from 1265 degrees per mile to 32 degrees per mile. Many sections exceeded the maximum curve of 580 degrees per mile allowed for a design speed of 45 miles per hour.

Concern over the method of measuring horizontal curvature used in Kenya, India and Chile has been raised as it varied from that used in developed countries (Ergun, 1988). Average degree of curvature was criticized for failing to differentiate the sharpness of the curve when the external angle remained the same. It combines the sharpness, length and frequency of curves into one value whereas studies from Germany and USA specified both curve measurements and frequency. The recent Finnish model included several variables pertaining to horizontal curvature.

Surface Irregularity

While surface irregularity is often assumed to serve as a proxy for pavement type, 45% of the machine laid surfaces were rated indifferent or worse as roads were not shaped properly before surfacing. Caution must be taken in interpreting the results of the surface irregularity testing as the norm in developing countries is much higher than in developed countries. Average values of surface irregularity often hide considerable variation. Thus a reasonably smooth road with occasional deep and dangerous potholes may have a similar average road roughness value to a consistently worn (but not potholed) surface.

Sight Distance

Due to time constraints and the need to measure sight distances on the many roads being studied, methods used were often crude. In Jamaica for example, markers were placed on the edge of the road as opposed to the centre and were sited such that sight distance could only be assessed in multiples of 100 ft. (the intervals between markers).

Number of Junctions

In Jamaica, junctions were counted along both sides of the road, thus a crossroads would be counted as two junctions while a five-way road would be counted as three junctions. By this method, a staggered t-junction would be weighed the same as a crossroad junction although staggered t-junctions have better safety records.

The Jamaican road inventory counted accesses (driveways used by four-wheeled motor vehicles) in addition to junctions as they also present conflict points. In the Papua New Guinea study, all right angle accidents were excluded to eliminate the role of junctions.

3.4 Speed

The issue of speed merits attention for two main reasons; lack of concern for the variation in speed on roads in developing countries; and secondly, the assumption that speed is assumed to be represented by geometric design parameters. Alignment improvements are modelled unidirectionally,

i.e. any improvement can only have a positive effect on road safety whereas speed increases can make roads less safe.

Accidents have been found to be more closely related to the range in speed than the mean speed itself. As the wider the variance in vehicle speed, the greater the accident risk potential for developing countries with their mix of non-motorized and motorized vehicles. Models from industrialised countries regularly have a minimum speed limit as a prerequisite. As seen with COBA, any rural road with a low speed limit is treated as an urban road.

Due to its close correlation, speed is assumed to be represented by the geometric design parameters and accordingly omitted in almost all models. The result is that any alignment improvement is assumed to improve the safety level with no consideration given to the potential increase in speed. As previously mentioned, the Swedish model is outstanding in its acknowledgement of the danger associated with improved roads that have become faster, but whether the speed flow equation holds for traffic mix with widely varying operating characteristics is unknown and unlikely.

3.5 Behaviour Patterns

The likelihood of developing a model to be used throughout the developing world must be questioned, given the wide ranging safety performance levels. While fatalities per million vehicle kilometres range only between 1-2 in industrialised countries, they can range more than a factor of twenty in developing countries. Developing countries can vary drastically in their development of road safety (i.e. enforcement, driver training, vehicle testing) with different accident reporting and analysis capabilities. Comparing fatality rates (road accident deaths per 10,000 vehicles registered in each city), cities of developed countries range from 1.4 in Tokyo to 2.8 in Greater Manchester. Third World cities have much higher accident fatality rates and are much widely spread, i.e. 10 in Bangkok to 43 in Seoul and 45 in Amman, Jordan.

4. Conclusions and Recommendations

This study carried out by the authors identified five in-depth case studies conducted on the relationship between road geometry and accidents in the developing world. TRL studied the Nairobi-Mombassa road in Kenya and 29 routes scattered throughout Jamaica. The Road User Cost Study in India adopted the same approach and chose the Bombay-Pune road (114 non-urban km) and a second study of 34 routes with varying roadway characteristics. In Chile, 42 observations made on 15 two-lane paved road sections comprises the last case study. The most recent of these was presented in 1984.

Junction frequency, horizontal curvature and vertical curvature were common variables while the TRL studies also analysed surface irregularity. Road width was considered in the Selected Indian Roads Study as well as in Kenya and Jamaica. Section lengths varied from uniform kilometre long sections in Bombay-Pune to roads of 509 kilometres in the Second Indian Case Study. No study used geometric homogeneity to describe section length despite the assumption that the mean values of geometric design parameters used were representative.

The models differed in the choice of dependent variable, the variables found significant, and the analysis method. The TRL studies used personal injury accidents per million vehicle kilometre whilst the Chilean study chose total accidents per kilometre. The Indian studies developed equations for both indicators but preferred the latter as it was both simpler and had a higher R squared value. While the models developed all had high R squared values and significance levels, only junction frequency was found significant in all the equations.

The Chilean study argued that a flexible quadratic equation which considered second order effects was better at predicting accidents than the linear regression models used by the previous studies. The regression coefficient for flow increased by 40% under the flexible form compared to the linear equation and the flexible form had a higher R squared value.

None of these studies compared surfaced roads with earth roads. Nor did surface irregularity (often seen as a proxy for surface type) prove significant in either of the TRL studies, with it being highly correlated to the more dominant variable road width in Jamaica. A separate study on the Kenyan data found gravel roads to have a higher accident rate with 18% of total accidents but only 5% of the traffic. A South African study found total accidents to decrease when gravel roads were paved and while the proportion of fatalities and property damage-only accidents decreased, the share of injury accidents (both serious and slight) increased.

Unfortunately (particularly in light of TRL's activities in the early 1980's) little work has occurred in the past decade although accident and road inventory data has been collected in Papua New Guinea but has yet to be fully analyzed. Preliminary analysis (simple regression only) found grade to have a strong correlation with accidents.

Whilst the developed countries have had limited success modelling accidents with respect to geometric design parameters, the complexity of developing countries' road and traffic characteristics can only imply greater difficulties. Traffic flows are by no means homogeneous with significant numbers of heavy commercial vehicles, pedestrians and non-motorized road users. Wide variations in speed merit consideration as speed variations have a higher correlation to accidents than does mean speed alone.

As no consensus has been achieved between models, nor even between dependent variables or analysis methods, it is not possible to advocate the use of any one equation as a guideline for use elsewhere. In addition to the statistical discrepancies, the use of geometric means to represent road sections that were determined by geographical features or uniform lengths rather than homogeneous geometric design increases scepticism in the model. In Jamaica, a review of the data found wide ranges of values being obscured by the use of means.

The prospect of producing a model for developing countries in general needs to be reconsidered. Unlike developed countries where fatality rates (deaths per 10,000 vehicles) vary little, the road safety situation varies tremendously in developing countries. For example, is it possible to develop one model for the developing world where fatality rates vary by at least twenty-fold between countries?

The complexity and uncertainty of accident predictions does not imply less need for their consideration. Accident costs are known to be substantial and need to be included in the design stage. A compromise adopted in the developed world, as seen by the example of COBA, (the highway cost-benefit analysis package used in the UK) is to develop a simple look-up table. Instead of pursuing equations based on geometric features, developing countries could focus on collecting before and after data on roads that have been widened or surfaced. Look up tables giving indication of changes in accident rate as a result of improving from one category to another (e.g. earth road to bituminous surface) could then be developed. Their use should be restricted to the host country as rates would be expected to vary widely between countries.

As past methods have proven over ambitious and inconclusive, these look-up tables need to be simple but should reflect the possible increase in accidents if dangerous speeds result from road improvements. Given the relationships between speed, accidents and traffic flow, data should be collected with a view to look up tables providing guidance on accident rates by flow bands.

5. References

Bitumen and Tar Association and the Division of Roads and Transport and Technology (1989): Economic warrants for surfacing roads, SURF Manual 7, Pretoria, 1989.

Central Road Research Institute (1982): Road user cost study in India, Final Report, New Delhi, India, 1982.

Commission of the European Communities Directorate Generale for Transport (1994): Concerted Action 1.1 Cost-Benefit and Multi-criteria Analysis for New Road Construction, Final Report, EURET, April 1994.

Ergun, Gokmen (1988): A critical review of safety countermeasures for two-lane highways, Third IRF Middle East Regional Meeting Proceedings, 1988.

FHWA (1987): Safety Cost Effectiveness of Incremental Changes in Cross-Section Design - Informational Guide. FHWA/RD-87/094. US.

FHWA (1991a): Design Risk Analysis (Vol.1) FHWA-FLP-91-010.US.

FHWA (1991b): Cost-Effective Geometric Improvements for Safety Upgrading of Horizontal Curves. FHWA-RD-90-021. US.

Hiersche, Ulrich (1984): Correlation between road design and traffic safety--results of new investigations, 10th IRF World Meeting, Rio de Janeiro, October 1984.

Hills, B L and N Thompson (1988): Co-operative programme of road safety research, Progress Report 2, March 1988.

Hills, B L and N Thompson (1990): Road safety research in Papua New Guinea, Proceedings of the Sixth Conference of REAAA, Kuala Lumpur, 4-10 March 1990.

Hills, B L, Mansfield R S and R Robinson (1984): Appropriate geometric design standards for roads in developing countries, Comptes Rendu, Paris, 1984.

Hills, P J and M W Jones-Lee (1981): The costs of traffic accidents and evaluation of accident prevention in developing countries. PTRC Summer Annual Meeting, University of Warwick, July 1981.

Hoban, C (1987): Evaluating Traffic Capacity and Improvements to Road Geometry, World Bank Technical Paper 74, Washington, DC, 1987.

Jacobs, G D (1976): A study of accident rates on rural roads in developing countries, TRRL Laboratory Report 732, Crowthorne, 1976.

Jacobs, G D (1989): The inclusion of accident savings in highway cost-benefit analyses, Second African Road Safety Congress, Addis Ababa, 16-20 October 1989.

Jara Diaz, Sergio R, and Sergio M. Gonzalez (1983): Flexible models for accidents on Chilean roads, unpublished paper, June 1983.

Johansson, Osten (1994): International Study of Highway Development and Management Tools, Safety Analysis Framework I,II, III,, The University of Birmingham, June 1994.

Kallberg (1993): Note Outlining Recent Research Findings. VYI, ESPOO, Finland.

Kanellaidis, and Ionnis Dimitopoulos (1994): Subjective and objective evaluation of risk on roadway curves, Traffic Engineering and Control, July/August 1994.

Kosasih, D, R Robinson and J Snell (1987): A review of some recent geometric road standards and their application to developing countries, TRRL Research Report 114, Crowthorne, 1987.

Maltby and Bennett (1986): Variations in accident frequencies on rural single carriageway roads in England. PTRC 14th Summer Annual Meeting, 1986.

McGuigan (1987): An Examination of Relationships between Road Accidents and Traffic flow. PhD Thesis, University of Newcastle upon Tyne, England, 1987.

Miaou, Shaw-pin and Harry Lum (1993): Modelling vehicle accidents and highway geometric design relationships, Accident Analysis and Prevention, Vol 25, No.6, p. 689-709, 1993.

Miaou, Shaw-pin (1994): The relationship between truck accidents and geometric design of road sections: poisson versus negative binomial regressions, Accident Analysis and Prevention, Vol 26, No.4, p. 471-482, 1994.

Road Research Laboratory, A study of road needs in rural Jamaica.

Robinson, R (1981): The selection of geometric design standards for rural roads in developing countries, Latin American Meeting on highway technology for developing countries, Mexico City, February 1981.

Roine and Kulmala (1992): Accidents as a function of Road and Traffic Characteristics. Nordic Road and Transport Research No1, pp8-11, 1992, VTI. Linkoping, Sweden.

Silyanov, V V (1973): Comparison of the pattern of accident rates on roads of different countries, Traffic Engineering and Control, January 1973, p. 432-35.

Transportation Research Board (1987): Designing Safer Roads, National Research Council, Washington, DC, 1987

Transportation Research Board (1987): Relationship between Safety and Key Highway Features, National Research Council, Washington, DC, 1987.

Transportation Research Board (1994): Roadway Widths for Low-Traffic Volume Roads, Washington, DC, 1994.