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ABSTRACT

Application of the Road Geometry Data Acquisition System (RGDAS)

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In the autumn of 1992, New Zealand's entire sealed state highway network was surveyed in both directions with the Australian Road Research Board's road geometry instrumented vehicle (RGDAS) as part of the Transit New Zealand research project "Road Environment and Accidents". Some 22,000 lane-kilometres were surveyed at a cost of NZ\$140,000, and represented the first national network application of the RGDAS system which had been previously used for route planning and accident site investigations by Australian state road authorities.

This paper describes the RGDAS system and its use in investigating relationships, for two lane rural highways, between road geometry and traffic accidents as recorded in the Land Transport Safety Authority's traffic accident records (TAR) database. Other New Zealand research and operational applications of the RGDAS derived road alignment and geometry data are also presented.

1. INTRODUCTION

Transit New Zealand, New Zealand's national roading authority, commissioned Works Consultancy Services, Central Laboratories to survey in both directions the 10,000 km of sealed state highways using the Australian Road Research Board's road geometry data acquisition system (RGDAS). This survey was carried out between March and June 1992.

The purpose of this paper is firstly to describe the procedures adopted in constructing a database of 200 m sections of two lane sealed rural state highway which linked RGDAS road geometry data to accident records held in the Land Transport Safety Authority's traffic accident records (TAR) database, and road construction and condition and traffic records held in Transit New Zealand's road assessment and maintenance management (RAMM) system. Secondly, to present the findings of statistical analyses performed on the resulting road environment and accident database, and possible application of these findings to evaluate potential accident savings from physical road improvements. Thirdly, to briefly outline New Zealand operational and research uses of RGDAS data in the highway engineering field.

2. THE ARRB ROAD GEOMETRY INSTRUMENTED VEHICLE

The micro processor based RGDAS was developed in the mid 1980's by the Australian Road Research Board (ARRB) to automatically measure and record road alignment data in a dedicated vehicle travelling at highway speed. The items recorded by RGDAS are distance, gradient, cross slope (crossfall and superelevation), horizontal curvature, vertical curvature, survey speed, route and location information, and comments. The recorded road alignment parameters are in turn used to calculate advisory speed, altitude change, direction change, and relative mapping coordinates.

The RGDAS measurement system comprises a rate gyroscope and two accelerometers aligned longitudinally and transversely. These transducers are sampled at a rate of 100 samples per second and averaged at the end of each 8 m measurement cycle corresponding to four revolutions of the host vehicle's differential. Direct measures of horizontal curvature, grade and cross slope are obtained, whereas vertical curvature is calculated from the rate of change of grade.

Post survey, the alignment parameters are smoothed over seven measurement cycles (about 56 m) using a moving average technique. No smoothing is applied to vertical curvature as the least squares procedure used in its derivation has a sufficient smoothing effect. On completion of the smoothing process, all parameters are stored, at 10 m intervals, in a summary table.

Menu driven software is provided to allow the smoothed RGDAS data to be displayed on a personal computer. This software generates displays of road survey data versus distance, plan map (north-south, east-west) of the road path, and altitude versus distance. The latter two plots can display other data, such as advisory speed or grade, as a scaled "comb" plot superimposed on the road path line and altitude profile respectively. There is also a "DRIVE" program which generates a screen display of the view of the road alignment as if driving along the road.

The RGDAS system can only perform relative, dead-reckoning mapping. Therefore it can produce a shape for the path of the road between reference points, but it does not know the correct orientation of the road. It does not know where north is, where sea level is, or where it is on a mapping grid. Software provided with RGDAS allows for map corrections. By giving known east (E) and north (N) coordinate pairs, altitudes and road bearings, at a few sparse identifiable points along the highway surveyed, say at between 20-50 km intervals, the map and vertical profile can be corrected to have a familiar appearance. However, to perform fine corrections of shape details so that a better conformance with the true coordinates results requires very accurate map correction data, i.e. E and N accurate to 10 m, altitude to better than 10 m, and bearing to 1°. Such data can be supplied by conventional survey techniques or by a GPS (geographic positioning satellite) receiver. The latest version of RGDAS, now renamed GipsiTrac, incorporates GPS to automatically provide accurate coordinate data.

No map corrections were made to the RGDAS database used in the traffic accident study which forms the basis of this paper as we considered correct orientation of the road to be secondary to accurate definition of the curve geometry.

Figure 1 shows the level of agreement between dynamic RGDAS measures of longitudinal gradient and cross slope and static measurements made at 20 m intervals with a precision electronic level along a 95 m constant radius curve. The main limitation of the RGDAS system is the smoothing of short features. For example, if a curve is shorter than the smoothing length (i.e. seven measurement cycles which corresponds to about 56 m) then some portion of adjoining straight is always averaged into the smoothed geometry values pertaining to the curve. This will increase the radius of such short curves and introduces errors in the other measured road geometry parameters. However, we assessed the smoothing effect of short features as immaterial when compared with location inaccuracies present in the accident and road alignment databases.

Despite the 1992 survey being the first application in New Zealand of the RGDAS at a network level, covering some 22,000 lane-kms, we experienced no significant system problems or operating difficulties attesting to the

robustness of the system and associated graphics software. More complete details of the RGDAS system can be found in Rawlinson (1983).

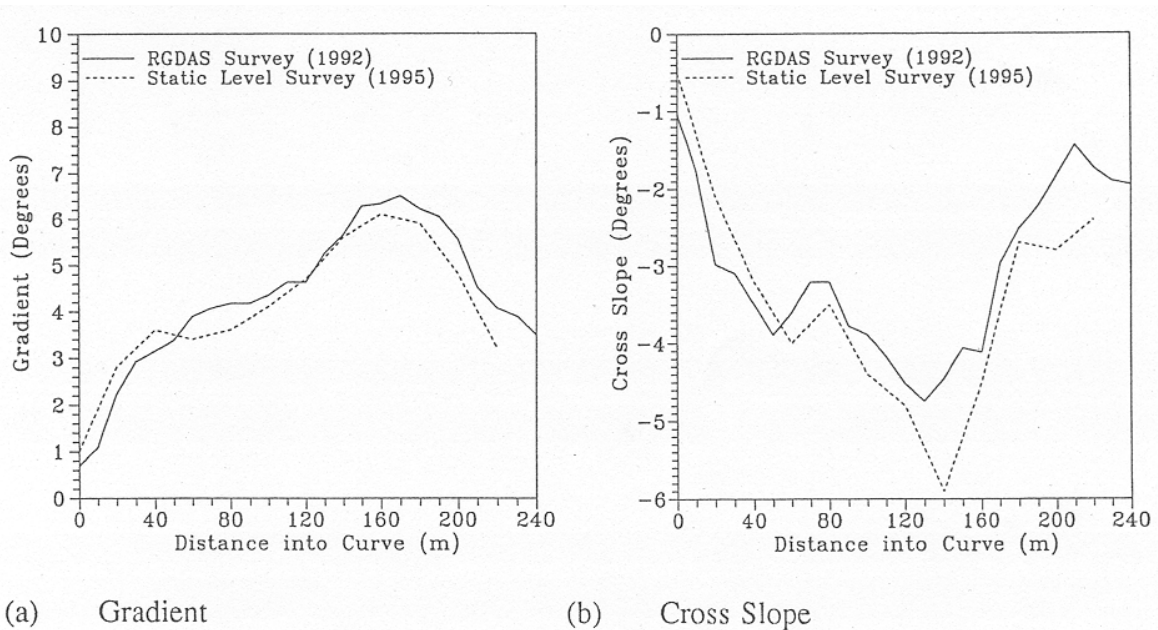


Figure 1: Comparison of RGDAS (dynamic) and electronic level (static) measures of gradient and cross slope.

3. USE OF RGDAS DATA IN A STUDY OF CURVE ACCIDENTS

3.1 Overview

In recent years the concept of speed environment (refer AUSTRROADS, 1989) has governed the design of New Zealand rural roads. However, it has not been possible to determine what effect this is having on traffic accident rates because of the lack of detailed information on road geometry over the roading network. The RGDAS survey of New Zealand's sealed state highway network performed between March and June 1992 addressed this issue, and provided an opportunity to link road alignment data with two other network related databases:

- (a) the road assessment and maintenance management (RAMM) system maintained by Transit New Zealand, containing road design features and traffic characteristics; and
- (b) the traffic accident record (TAR) database maintained by the Land Transport Safety Authority).

A research study, funded by Transit New Zealand, was therefore undertaken to establish the relation between the road environment and accident risk.

This involved a statistical analysis of all curve accidents held in the TAR database spanning a five year period. The procedures adopted in constructing the database for the study and the resulting findings are summarised below.

3.2 Preparation of Database

The data used in the accident study were assembled from three source databases. Road geometry data from RGDAS, road condition and traffic data from RAMM, and accident data from TAR. In all cases some work was required to bring the data to a compatible condition so that linking of these sources could be conveniently achieved. The time period covered by the database extracts was a compromise to provide data relevant to the highway network at the time of the RGDAS survey while also providing a reasonably large number of accidents. The RAMM data used were current at April 1992 and the TAR data were for the five year period 1 July 1987 to 30 June 1992.

3.2.1 RGDAS Data

3.2.1.1 Rubberbanding

The smoothed RGDAS data (reported at 10 m intervals for the entire sealed length of the New Zealand state highway system) were found to be imprecise in the spatial location. Attempts were made to correct the spatial coordinates but abandoned as unwarranted. However, traffic distances in each measurement run were adjusted to the official distances between the start and end reference stations (and also intermediate reference stations on the longer highways) by a process of "duplicating" or removing a record at appropriate intervals.

3.2.1.2 Segmenting

To make the total volume of RGDAS geometry data more manageable and to facilitate accident environment matching, the highway network was divided into 200 m segments, with each segment having data for both highway directions. Two geometry databases were constructed on a segment basis, one containing selected data at the rubberbanded 10 m intervals, the other containing selected summary statistics representing the 10 m data (20 data points) of the current 200 m segment, and also some summary data derived from the 10 m data for up to 1 km of the previous highway.

The data selected for the 10 m interval database were the spatial coordinates (x,y,z), the vertical and horizontal curvatures, and the cross slopes.

The data selected for the 200 m segment summary statistics were the average, the maximum and the minimum of the grades, the horizontal and vertical curvatures, and the cross slopes. An average compass direction for the segment (resolved to the nearest of the eight primary compass points) was derived from the imprecise bearing data which was considered adequate

for this purpose. Also included in the summary statistics were the average and minimum advisory speeds for the current segment and for previous segments as described below.

3.2.1.3 Advisory Speeds

A likely important derived geometry variable was the advisory speed (AS). The advisory speed at each 10 m data point was calculated from the horizontal curvature (H) and cross slope (X) as follows (a maximum of 200 km/h was set for nearly straight road):

$$AS = \sqrt{(bk)^2 + 2k \left(a + \frac{X}{100} \right)} - bk \quad \text{km/h} \quad (1)$$

where a = 0.3

b = 0.0017

k = 63,500/H (km)

X = absolute value of % cross slope

H = absolute value of curvature (radians/km)

Segment summary data included the minimum advisory speed and average advisory speed for the current 200 m segment, as well as the minimum and average for the previous two segments (0.4 km) and the previous five segments (1 km).

The relationship between road geometry and vehicle speed given by equation (1) was validated by comparing RGDAS advisory speed with 85 percentile mid curve vehicle speeds measured at 31 curve sites, 22 of which were located on the flat. The results are graphically presented in Figure 2 and show a clear linear relationship, with a good coefficient of determination (r^2) of about 0.71.

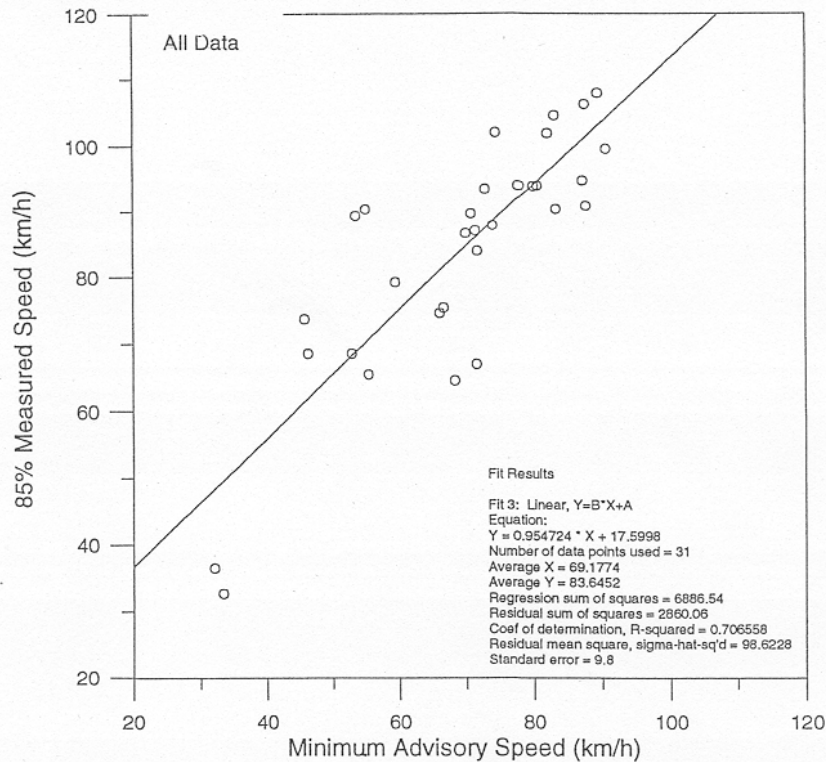


Figure 2: Relationship between RGDAS derived advisory speed and measured 85 percentile mid curve vehicle speeds.

3.2.2 RAMM Data

A tailored RAMM database was extracted from the parent RAMM databases selecting information on road conditions judged to be potentially relevant to traffic accidents. The surface type, date of surface and width of surface were selected as well as the vehicle exposure factors such as the annual average daily traffic volume (AADT), the number of lanes (also if divided or not and if motorway or not), and if the location was urban or rural.

The selected data were assembled in 200 m segments to match the geometry data. Where RAMM factors changed within a segment, the change was transferred to the nearest segment boundary, but the segment was flagged as containing a change in one or more factors.

3.2.3 TAR Data

The complete database of reported injury accidents on the state highway network was used, but accidents in urban areas and accidents unlikely to be related to road geometry or road conditions were excluded. Extreme conditions such as snow and ice were also excluded. The exclusions specifically were as follows:

- urban accidents (i.e. speed limit less than or equal to 70 km/h plus Limited Speed Zones);
- accidents at intersections or driveway junctions;
- all vehicle "movement codes" entered in TAR other than overtaking, head-on, loss of control, and cornering related directly or otherwise to a cornering manoeuvre;
- all "contributing factors" unless there were factors of speed, cornering or overtaking;
- all "slippery road" factors other than rain, e.g. oil, mud, snow and ice.

These exclusions reduced the total number of accidents to be considered from about 18,500 to about 3,500.

For selected accidents, data on the location, direction of travel, time and date, movement code and contributing factors, curve severity, and wet or dry road was extracted.

3.2.4 Data Integrity

There was some concern regarding the accuracy of location of accidents and the location reliability of the geometry data. Both were linked back to the state highway network reference stations, but high accuracy in the reporting/linking processes could not be assured. A broad test of positioning accuracy was made by comparing the "curve severity" description in the TAR data with the minimum advisory speed (ASMIN) in the 200 m segment as derived from the RGDAS data. There are four curve severity categories (straight, easy, moderate, severe) but the data showed that the ASMIN were similarly distributed for the "easy" and "moderate" categories, and therefore these two were combined.

Figure 3(a) shows the minimum advisory speed distributions for the three remaining categories and the distribution of all the selected accident data. The total distribution is strongly bimodal (verging on trimodal), and the three component distributions indicate that this arises from "accidents on straight road", "accidents on gentle curves" and, in lower numbers, "accidents on severe curves". Of concern was the substantial number of accidents where the curve severity category and the minimum advisory speed value did not reconcile. There were examples of this in all categories, and it was supposed that many of these could be cases of incorrect accident location/segment location.

A "neighbouring segment" search scheme was implemented to check the

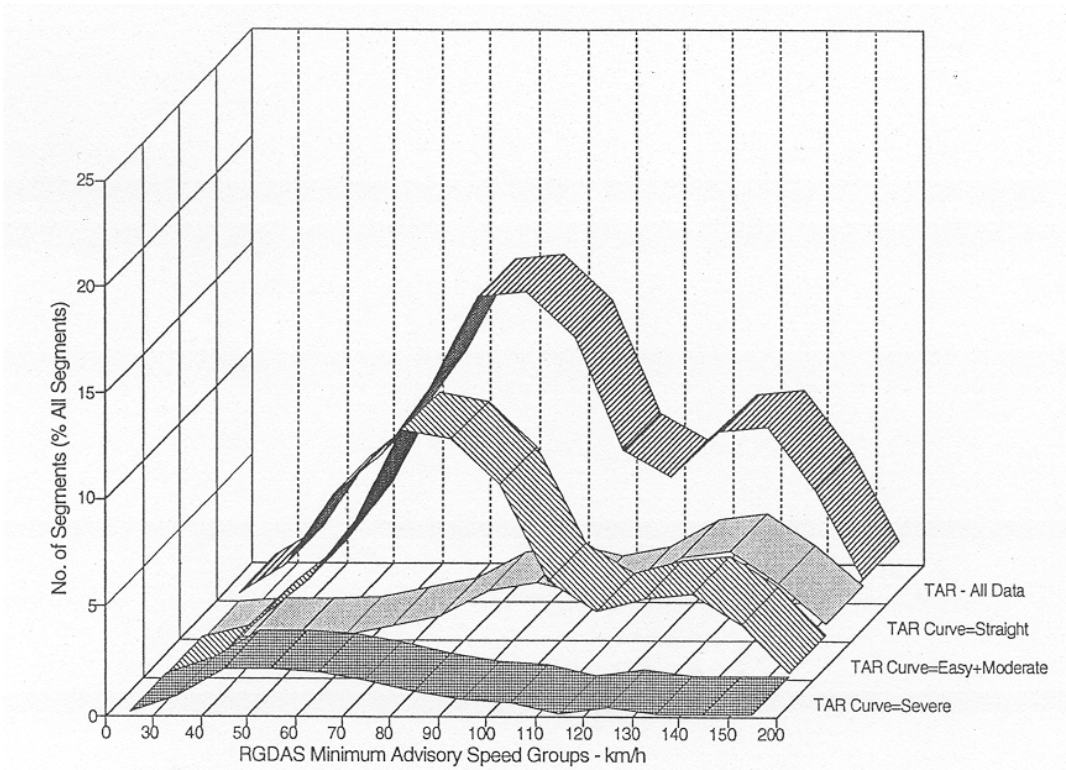
possibility that the minimum advisory speed of a nearby segment would give a better match to the curve severity description reported with the accident. In the search a weighting was given to relocating by only ± 1 segment, but the search was extended up to ± 5 segments if the original mismatch was substantial. Figure 3(b) shows the distributions of the adjusted data. The number of mismatches has clearly been reduced, and a trimodal "all data" distribution is more pronounced.

Another integrity check that also involved some data adjustments was carried out as part of the segment adjustment scheme above. Four of the "key vehicle movement codes" reported with the accidents should directly relate to the horizontal curvature values in the RGDAS summary data as follows. Codes DA (cornering - lost control turning right) and BB (head on - cutting corner) should correspond to positive curvature, while codes DB (cornering - lost control turning left) and BC (head on - swinging wide) should correspond to negative curvature. When this correspondence was checked, only 65% of the cases agreed and no conclusive reason for the 35% in error could be found. To resolve the situation, correspondence was forced by interchanging the codes in the cornering cases and by reversing the direction of travel of the "key vehicle" (i.e. using data from the opposite direction on the highway) in the head on cases.

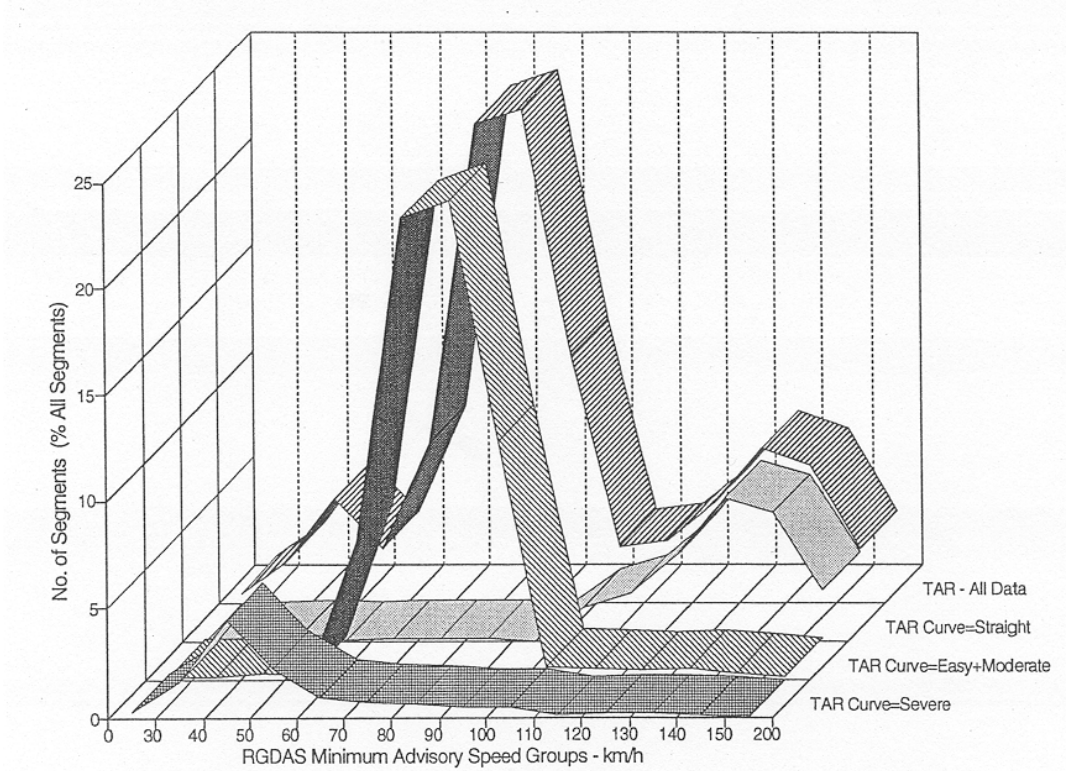
The unproven rationale for this resolution scheme is:

In reporting head on collisions on curves, there could be confusion at the event over the coded direction of the "key" vehicle. For example, it is not absolutely clear from the movement coding sheet that the key vehicle is the one that "cut the corner" (BB) or "swung wide" (BC), although these would be the natural interpretations.

In reporting cornering accidents not involving head on collision with a second vehicle, there could be confusion at the event between "lost control turning right" and "lost control to the right" and vice versa. The first phrase is the actual description for a DA movement. The second is what probably happens in a DB movement but this, it is argued, could be confused and coded DA.



(a) Unadjusted data



(b) Adjusted data

Figure 3: Distribution of road accident frequency as a function of advisory speed and curve severity category.

3.2.5 Data for the Statistical Analysis

The state highway system was divided into 200 m segments. For each segment and direction we have the following data:

- horizontal curvature (radian/km) maximum, minimum and average (HMAX, HMIN, HAV)
- cross slope (in percent) maximum, minimum and average (XMAX, XMIN, XAV)
- gradient (in percent) maximum, minimum and average (GMAX, GMIN, GAV)
- vertical curvature (radian/km) maximum, minimum and average (VMAX, VMIN, VAV)
- advisory speed (km/h) minimum and average (ASMIN, ASAV)
- advisory speed over previous two segments (0.4 km), minimum and average (PASMIN2, PASAV2)
- advisory speed over previous five segments (1 km), minimum and average (PASMIN5, PASAV5)
- average direction (DIR).

For each segment, but not by direction, we have:

- an estimate of annual average daily traffic (AADT)
- width of sealed carriageway (SCW)
- number of lanes, urban or rural, is it divided, is it a motorway, seal type and date of seal.

In addition, we have an accident file which gives the segment identifier of each accident that occurred during the period of the study and some details of the accident. Accidents were limited to those for which road geometry may have been a factor. The severity of the accident was not taken into account.

Using the adjusted data described in the previous section seemed to produce seriously anomalous results, suggesting that the adjustments made were too severe. Consequently, the unadjusted data were used for the analysis. Undoubtedly some accidents have been assigned to wrong segments, so probably the effects we find in the present analysis are somewhat less than

is really the case.

In the present study we restricted attention to road segments classified as rural, two lane, not divided, not motorway, and with no missing values in the data. Also roads with unusually wide or narrow sealed carriage widths were omitted, as were a few road segments with obviously incorrect data. This remaining dataset has 87,196 road segments (each direction counted separately) and 2,365 accidents.

3.3 Results of Statistical Analysis

Two methods of analysis were used. The first used one and two way tables to show how accident rates varied according to the main explanatory variables. The second used a Poisson regression model to relate accident risk to the explanatory variables.

3.3.1 The Tables

Road segments were classified by ranges of each of a number of explanatory variables and then the accident rate calculated for each of the ranges, and the results expressed in a table.

Each table gives the ranges of the classifying variable, the observed number of accidents in each of the ranges, the total AADT in that range, and the accident rate in accidents per 10^9 VKT (vehicle-kilometres travelled)⁽¹⁾. Here, and elsewhere, AADT means the two way AADT.

3.3.1.1 One Way Tables

Classification by AADT

AADT	<500	50-1k	1-2k	2-5k	5-10k	10-20k	>20k
Observed	81	254	432	980	447	161	1
AADT (000)	5271	15,72	29,09	68,07	40,32	15,20	2008
Accident	84	1	1	5	8	2	3
Rate (10^9 VKT)		88	81	79	61	58	

⁽¹⁾ The accident rates may need some interpretation. An isolated curve in a road is essentially a point on a road, and vehicle-kilometres travelled over it is not a meaningful concept. More appropriate would simply be total vehicles travelled. However, if we think of the risk item being a 200 m section of road, including a bend, then VKT does make sense.

This table probably under-estimates the accident rate for the low AADT roads because minor accidents are less likely to be reported on these roads than on the higher AADT roads. Nevertheless the table shows a somewhat higher accident rate for the low AADT roads.

The rate for roads with AADT at least 20,000 is exceptionally low. These road segments are sections of State Highways 1 and 2 and a section of State Highway 30 in the tourist area of Rotorua. Most likely they should be thought of as essentially urban roads and should be excluded from the study.

Classification by ASMIN

ASMIN	<60	60-80	80-100	100-120	120-140	140-160	>160
Observed	350	586	612	303	376	124	5
AADT (000)	8321	17,94	35,06	33,438	54,569	24,731	1627
Accident	230	9	2	50	38	27	17
Rate (10 ⁹ VKT)		179	96				

Minimum advisory speed gives a better relationship with accident rates than average advisory speed, so that is what is considered here. The rates for very low ASMIN are probably under-estimates due to reduced reporting rates.

Classification by HAV

HAV	<-5	-5 to -3	-3 to -1	-1 to +1	+1 to +3	+3 to +5	>+5
Observed	80	176	444	1081	387	124	64
AADT (000)	1672	4547	21,013	123,46	19,190	4249	1561
Accident	262	212	116	4	110	160	224
Rate (10 ⁹ VKT)				48			

Note: Horizontal curvature is the reciprocal of radius, therefore HAV=5 corresponds to a curve radius of 200 m, whereas HAV=1 corresponds to a curve radius of 1000 m.

As expected, this shows a low accident rate for HAV (average horizontal curvature) near to zero and increasing as curvature increases either to the left or right.

Classification by HDIFF = HMAX – HMIN

HDIFF	<0.1	0.5 to 1	1 to 2	2 to 3	3 to 5	5 to 10	>10
Observed	276	241	255	251	408	468	457
AADT (000)	51,56	31,086	27,09	18,71	21,30	15,223	10,71
Accident	2	42	2	3	1	168	9
Rate (10 ⁹ VKT)	29		52	73	105		233

HDIFF is the difference between maximum and minimum horizontal curvature (HMAX and HMIN), and captures an aspect of the geometry not completely captured by the average curvature, namely road alignment prior to curve entry. Risk rises with increasing HDIFF.

3.3.1.2 Two Way Tables

When considering only one variable at a time we cannot say if any effect in accident rate is due to the variable in question or is due to some other variable which is correlated with the variable in question. As an example, lower AADT roads have higher accident rates. Probably the major reason for this is that lower AADT is associated with more difficult roads, and it is the nature of the road that is causing the higher accident rates rather than the low AADT. The classification variables are considered two at a time in order to try to disentangle this effect.

The following two way tables correspond to the accident rate line (last line) of the preceding one way tables. Because the number of accidents contained in each cell of the two way tables is much smaller than for the one way tables, the statistical fluctuation in the rates is rather larger. We have put the rates in bold when the corresponding observed number of accidents is at least 25 since there is not much accuracy in the data when the number of accidents is less.

Accident Rate : Classification by ASMIN and AADT

AADT	Accidents per 10 ⁹ VKT						
	<500	500-1k	1-2k	2-5k	5-10k	10-20k	>20k
ASMIN<60	155	230	271	247	208	94	
60-80	138	161	146	251	126	132	0
80-100	75	91	87	105	84	102	0
100-120	39	46	45	53	55	43	13
120-140	67	37	42	41	32	34	0
140-160	41	33	22	28	30	23	0
>160	0	0	21	26	0	0	

This shows that generally for a given ASMIN, the accident rate is not highly dependent on AADT.

Accident Rate : Classification by ASMIN and PASMIN2

PASMIN2	Accidents per 10 ⁹ VKT						
	<60	60-80	80-100	100-120	120-140	140-160	>160
ASMIN<60	196	328	290	339	147	0	
60-80	142	172	186	245	251	160	
80-100	92	117	92	95	72	124	0
100-120	54	78	55	42	44	31	0
120-140	76	67	49	36	30	28	0
140-160	107	58	35	26	25	22	0
>160	0	0	0	0	19	26	0

There is some evidence of the risk rising towards the top right hand side of the table corresponding to a sudden transition from a high advisory speed to a low advisory speed.

3.3.2 Poisson Regression Analysis

This section describes the fitting of the Poisson generalised linear model. Each road segment corresponds to an observation. We suppose the number of accidents on this road segment has a Poisson distribution with expected value depending on the AADT and the road geometry.

Suppose Y_i denotes the number of accidents in the i th road segment (where i runs from 1 to n), and $x_{i,1}, \dots, x_{i,m}$ denote m explanatory variables (e.g.

geometry variables). The generalised linear model for the Poisson distribution with log link function supposes that the Y_i are independently distributed with Poisson distributions and

$$E(Y_i) = \lambda_i = \gamma_i \exp \left(\beta_0 + \sum_1^m x_{i,j} \beta_j \right) = \gamma_i e^{\beta_0} \prod_1^m \exp(x_{i,j} \beta_j) \quad (2)$$

where the β_j are the unknown regression coefficients which need to be estimated. We let γ_i be the AADT for the segment since we expect the number of accidents to be approximately proportional to the AADT. The last expression can be interpreted as expressing the accident risk as a product of risk factors. We used the S-plus statistical package for fitting the Poisson model. S-plus includes this as one of its standard analyses. One can test for the statistical significance of each of the explanatory variables in much the same way as one does in an analysis of variance using a quantity known as the deviance⁽²⁾.

We cannot expect a generalised linear model to fit over a wide range of values of the explanatory variables, so we removed the data with extreme values of AADT and horizontal curvature. This left 24,896 road segments and 1053 accidents in our analysis using the most restricted set of data. We carried out two analyses. One used HAV, HDIFF and XAV (average cross slope). The other used ASMIN (minimum average advisory speed) and PASMIN2 (minimum average advisory speed over the previous two segments). Both also included log(AADT), gradient, vertical curvature, sealed carriageway width and direction as possible explanatory variables. In the first analysis we found HAV, HDIFF as the most statistically significant explanatory variables, and gradient and direction also being significant. In the second analysis, ASMIN and PASMIN2 were strongly significant, with gradient and direction also being significant as before. We entered most of the variables as polynomial functions to allow for non-linearity in the relationship.

The relative risk due to each factor can be derived from equation (2). They are easiest to understand when expressed graphically. We have done this for the first analysis in Figure 4. In each case, the middle line is the estimate and the outer lines are confidence intervals corresponding to two standard errors so they are about 95% confidence intervals.

In order to illustrate the use of these graphs, consider a 200 m road segment

(2) Note that we cannot use the residual deviance for assessing goodness of fit as is commonly done because of the small average number of accidents per segment.

with average horizontal curvature (HAV) equal to 3 (i.e. 333 m radius), and difference between the maximum and minimum curvature (HDIFF) equal to 4 (say corresponding to a 250 m radius curve and a straight). Now suppose the road is realigned so that HAV is equal to 2 (i.e. 500 m radius) and HDIFF also equal to 2 (e.g. 500 m radius curve and a straight). The change in relative risk is calculated in the following table:

	Before Realignment		After Realignment	
	Value	Relative Risk (from Figure 4)	Value	Relative Risk (from Figure 4)
HAV	3	1.77	2	1.26
HDIFF	4	3.08	2	1.95
Product		5.45		2.46

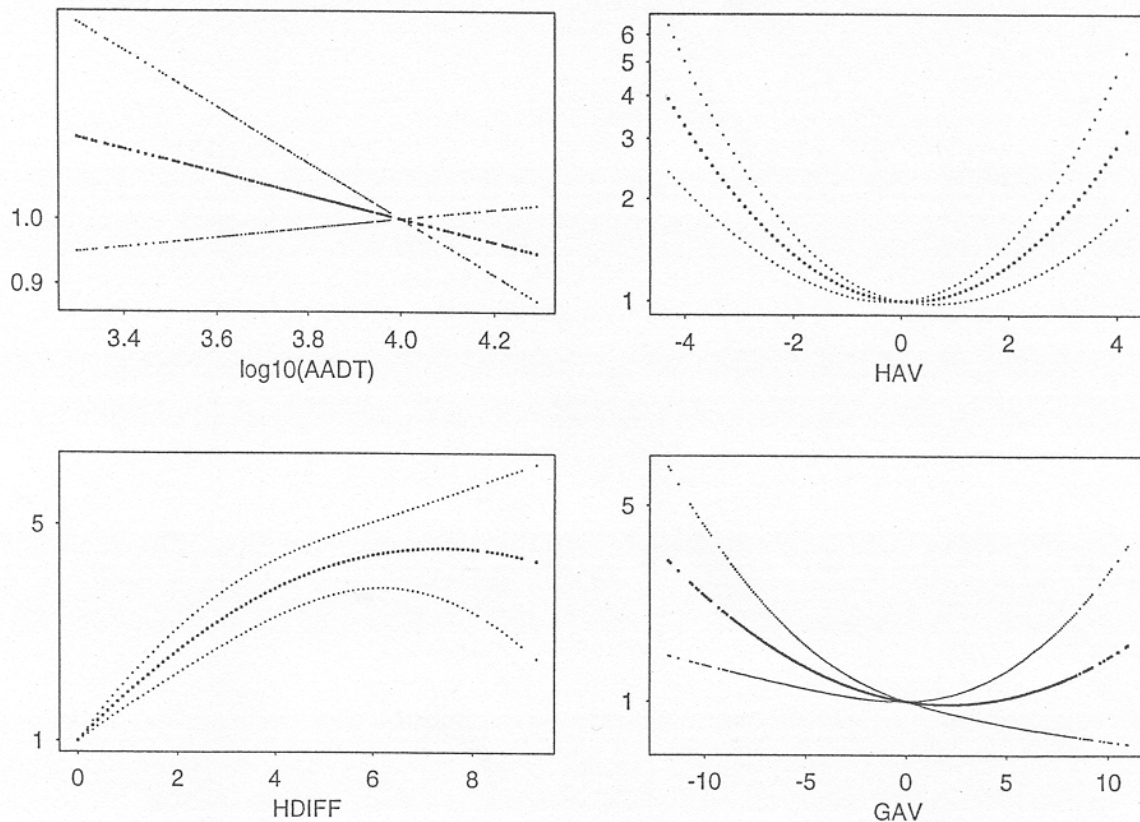


Figure 4: Relative risk versus AADT, HAV, HDIFF and GAV.

Thus the realignment would reduce the risk by a factor of $5.45/2.46 = 2.2$. However, care should be exercised when applying the Poisson model as in

this illustrative example because:

- (a) all the numbers involved are subject to substantial statistical error;
- (b) the relative risk curves are unlikely to be of the exact form fitted;
- (c) the road geometry is typically far more complicated than is captured by the parameters utilised here; and
- (d) it has not been possible to align the accidents exactly with the road segments, resulting in some inevitable smudging of the information.

3.4 Comparison with a Previous New Zealand Study of Accident Curve Geometry Relationships

Matthews and Barnes (1988) constructed a database incorporating all curves on the 2000 km long state highway (State Highway 1) running the length of New Zealand. Also the route positions, angles of turn, direction of turn, lengths of adjacent tangents, traffic volumes and gradients were entered into the database in addition to the total amount of curvature in the 2 km of roadway preceding each curve. Details of accidents were derived from the TAR system over a five year period (1982-1986). The total number of accidents analysed to determine the effect of road and curve geometric elements on curve accidents were 1082 compared with 2365 in the present study.

Matthews and Barnes showed that the amount of prior curvature had the largest effect followed, in descending order, by gradient, radius, tangent length and direction of turn. Evaluation of the effects of combinations of elements showed that accident risk was particularly high on short radius curves located at the end of long tangents, on steep down gradients, or on relatively straight sections of highway. These findings are consistent with the present study which additionally considered lane width, superelevation, surface type and surface age, and gives confidence in the derived Poisson generalised linear model considering the independence of the studies.

3.5 Possible Further Statistical Analysis

- Repeat the analysis on restricted classes of accidents. For example, where alcohol is or is not involved, or where roads are wet or not wet, or for one or multi-vehicle accidents.
- See if any effect of road surface type and age can be detected.
- Expand the analysis to allow for accidents being assigned to the wrong segment.

- See to what extent accident black spots are explained by the geometry data.

4. OTHER NEW ZEALAND OPERATIONAL AND RESEARCH APPLICATIONS OF RGDAS

4.1 Advisory Speed Signage

The advisory speeds for highway curves are currently determined by recording the maximum reading given by the ball-bank gauge, a vehicle mounted mechanical indicator device which provides a measure of lateral force. A feature of RGDAS is its ability to calculate maximum advisory speeds at intervals of 10 m from the horizontal curvature and cross slope data obtained along with an assumed relation for side friction demand with speed. Mathematical details are given in Rawlinson (1983). Both ball-bank gauge and RGDAS are methods accepted by the Roads and Traffic Authority, New South Wales (RTA) for determining advisory speeds.

During the 1993/94 summer vacation, Transit New Zealand's Napier office employed two students to assess the conformance of existing advisory speed signs with current Transit New Zealand policy, and to identify where additional advisory signs should be installed and revise posted speed levels where appropriate. A study of traffic accident records established that 5% of all run-off-the-road injury accidents could be eliminated through appropriate advisory speed signage. For the Napier region, this amounted to about three injury accidents per year corresponding to an annual community cost of NZ\$2 million. By comparison the cost of the exercise, including the cost of installing 600 or so extra and replacement signs, was conservatively estimated to be NZ\$180,000, yielding a benefit/cost ratio of 103 (25 year analysis period, 10% discount rate, and some traffic growth).

As a result of the success of the Napier initiative, one of the students was again employed during the 1994/95 summer vacation by Transit New Zealand's Christchurch office. For the Christchurch study, use was made of a FORTRAN program⁽³⁾ which allowed the RGDAS files to be divided into more manageable lengths, thereby enabling quicker identification of curve sections of interest.

A survey of seven reference sectors was carried out to compare the RGDAS derived advisory speeds (one pass) with the ball-bank gauge advisory speeds (usually three passes). Of the 221 curves surveyed, 70% had the RGDAS and ball-bank results in agreement. When disagreement occurred, 93% of

⁽³⁾ For more details on either FORTRAN program, contact their author, Dave Wanty, directly.

the RGDAS values were below the ball-bank values (i.e. conservative) and at no time were the differences greater than ± 10 km/h.

4.2 Vertical Curves

A FORTRAN program⁽³⁾ has been developed for Transit New Zealand to examine the average rate of change of vertical curvature from the RGDAS data. Criteria regarding the number of 10 m sections where the rate of change of grade is greater than a specified threshold for a given section length are input and sections meeting the criteria are output. In this manner, sub-standard vertical curves, for example those with $K^{(4)}$ values less than those recommended in Table 7.4 of Rural Road Design (AUSTROADS, 1989) can be highlighted for later inspection to identify whether there is an intersection on the poor vertical curve, etc. This aspect also could have been automated if better use had been made in the 1992 survey of the comment facility available in RGDAS through entering event marks such as intersections, side roads, etc during the survey or post-survey processing.

4.3 Passing Opportunities

TRARR (TRAffic on Rural Roads) is a simulation model developed by the Australian Road Research Board for analysing effects of changes in road and traffic characteristics on rural roads. The model uses a series of speed multipliers, based on road characteristics, and forward sight distances to simulate the movement of individual vehicles along a road segment. TRARR is commonly used in New Zealand for examining the travel time costs and vehicle operating costs of highway routes with various options for improving passing opportunities such as the introduction of climbing lanes and passing lanes. Traditionally, road geometry data required as input to TRARR have been either determined from on-site measurements or from aerial photographs. However, the data are required at 100 m intervals, making data collection and entry an expensive exercise. The latest version of TRARR, Version 4, can now process RGDAS data into TRARR road data format. Once in this format, the data may be used to calculate curve speeds and forward sight distance based on specified eye and object heights and global lateral offsets to left and right. The linking of RGDAS data with TRARR has proven to be very cost effective.

⁽⁴⁾ $K = \text{length required for 1\% change of grade} = \text{length of vertical curve (m)} / \text{change of grade (\%)} = 10 / \text{RGDAS vertical curvature (radians/km)}$.

4.4 Estimation of Vehicle Performance

Grade and cornering forces acting on vehicles can be derived from RGDAS measures of grade and horizontal curvature and cross slope respectively. The availability of accurate three dimensional road geometry data therefore enables measured vehicle performance on actual highways to be directly compared with the predicted performance.

Two current research projects are making use of the RGDAS data in this regard. The first involves using the concept of route severity, in which theoretically derived longitudinal and lateral vehicle forces are integrated with respect to distance to calculate the total energy expended by a vehicle in making a journey, to assess the effects of road design on vehicle operating costs such as fuel and tyres (Cenek et al, 1993). The second is being performed by Industrial Research Ltd and is concerned with expanding their heavy vehicle simulation capability from "flat roads at constant forward speed" to real New Zealand highways and speed control included in the driver model so that stability characteristics of heavy vehicles under actual operating conditions can be better assessed.

4.5 Curve Accident Investigations

With the availability of the GripTester, a low cost trailer based constant slip friction tester manufactured by the Scottish firm Findlay Irvine Ltd, it is now possible in New Zealand to determine site specific friction-speed characteristics of the road surface. This information, when combined with RGDAS measures of horizontal curvature and cross slope, allows accurate determination of the speed at which a vehicle will skid while traversing a specific curve (Stewart and Cenek, 1995). By comparing this "critical" speed with the 85th percentile curve speed, reliable estimates of friction safety margins can be obtained.

5. FUTURE APPLICATIONS

Two planned future applications of RGDAS data related to maintenance practice are briefly outlined in this section.

5.1 Relationship Between Shape Correction and Curve Accidents

Superelevation is important for safe travel on rural road curves. Because the road surface may be periodically shape corrected to reduce its roughness, a critical issue requiring investigation is whether current construction practices produce significant departures from the design superelevation, either by decreasing the superelevation or by introducing abrupt changes in the superelevation through inadequate cross slope control. Such poor shape correction practices, if left unrectified, in some

situations may cause a sharp increase in the friction demand by a vehicle travelling at the design speed as it enters the curve in question. While we can show that the friction value may be within the normal range drivers use, a sudden change in friction demand will lead to a sudden change in steering attitude of a vehicle negotiating the curve, and hence increased risk of run-off-road and head-on accidents. A study is presently being undertaken to assess whether inadequate superelevation or too great a rate of rotation are causative factors in accidents occurring on shape corrected curves. Raw 8 m RGDAS curve geometry data are being utilised so rate of rotation values can be calculated as part of the study and compared with recommendations given in Rural Road Design (AUSTROADS, 1989).

5.2 Identification of Sub-Standard Road Sections

A programme of research is being formulated which will seek to relate both road geometry and surface characteristics (microtexture, macrotexture, and longitudinal and transverse roughness) to accident risk so that there can be more effective allocation of maintenance funding. The necessary information will be provided by surveys of the entire state highway network performed with the sideway force routine investigation machine (SCRIM) which gives a measure of skid resistance, and ARRB's new multi laser profilometer (MLP), a vehicle mounted, laser based system that continuously measures pavement macrotexture, longitudinal surface shape and transverse shape. If the MLP is installed with GipsiTrac, ARRB's road alignment data and digital mapping system replacing RGDAS, water ponding areas can be calculated from the measures of transverse shape, grade, and cross slope, thereby highlighting potential aquaplaning sites. Therefore by combining the resulting SCRIM and MLP databases with existing TAR and RAMM databases, it will be possible to identify critical combinations of road geometry and surface texture features which are likely to significantly contribute to traffic accidents.

6. CONCLUSIONS

- (1) A common question posed by highway engineers is "What will happen to the number of accidents if such and such a change is made?" The Poisson generalised linear model presented in this paper goes some way to providing a rational method for evaluating the accident risk reduction associated with common engineering treatments for typical two lane rural roads. However, it requires validation and expansion to include effects of other road features shown by overseas studies to influence accident rates such as sight distance, pavement texture characteristics, and delineation.
- (2) While the New Zealand Land Transport Safety Authority has a system for monitoring the effectiveness of remedial measures undertaken at

problem sites, no systematic mechanism presently exists for linking road geometry, surface characteristics, road condition and traffic data to the TAR accident database. Such a database is essential for deriving road construction and maintenance policies effective in reducing traffic accidents. However, our experience highlighted the need to locate road alignment data to the same level of accuracy traffic accidents are recorded, estimated to be about ± 20 m. The incorporation of differential GPS in vehicle based data collection systems such as RGDAS may be a cost effective way of determining spatial coordinates to such accuracy.

- (3) Road geometry data obtained with ARRB's RGDAS system was shown to have a number of safety related applications ranging from locating advisory speed signs to assessing heavy vehicle configurations for particular routes.

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