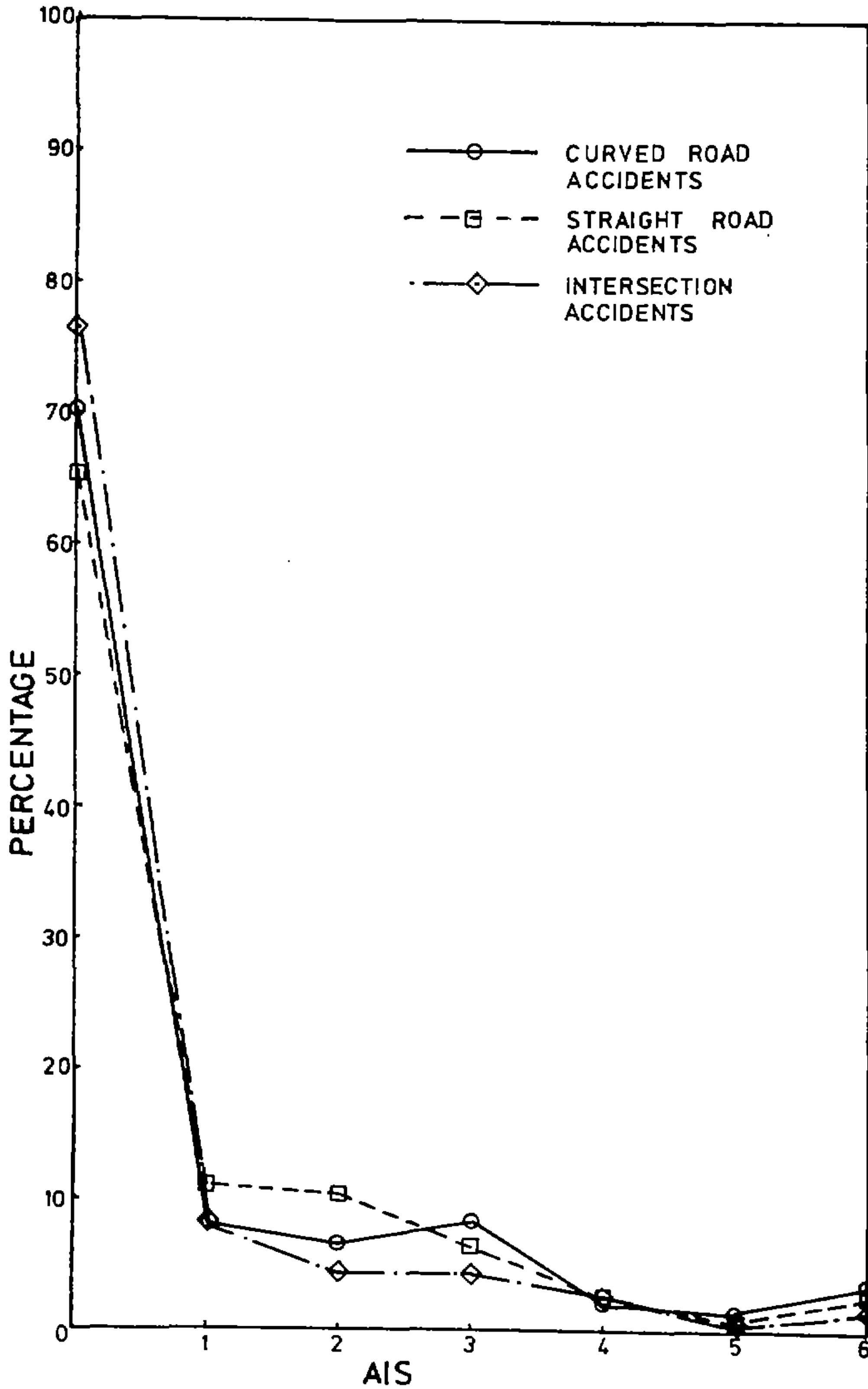


Figure 4.51.Distribution of highest AIS score per accident by pole accident type

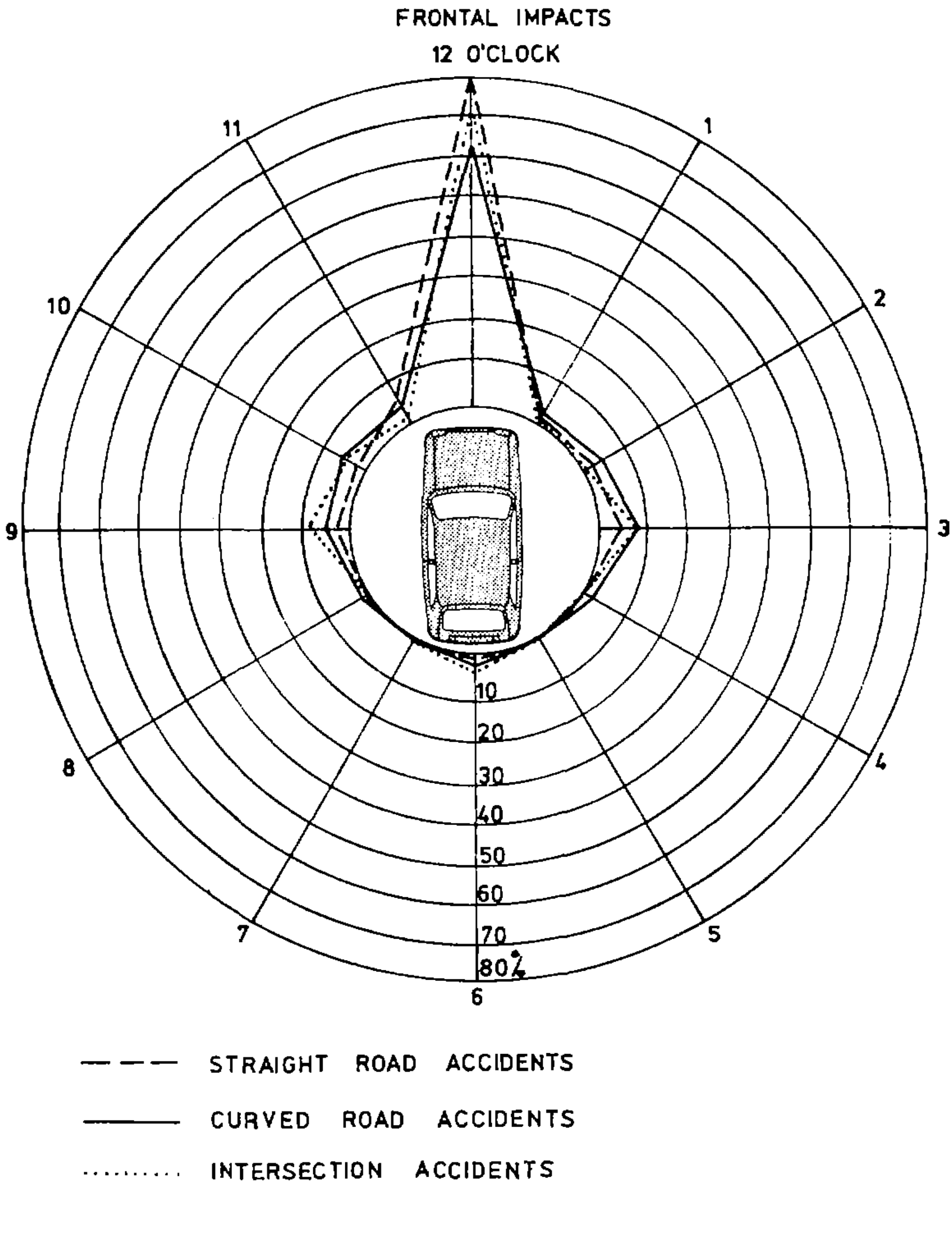


Figure 4.52. Distribution of impact direction by accident type

side impacts was clearly demonstrated in Chapter 3. A similar plot was made for the highest ISS per accident, with the same trends being observed. The injury severity distribution does not appear to be correlated with the level of curvature, given that the road was curved. No other correlations between injury severity and the major site variables were found. Partitioning the data into the data groups defined in Section 4.2 did little to improve the trends observed in the crude, three accident type classification.

4.4.2 Vehicle Damage

The universal quantification of vehicle damage is perhaps best based on the amount of energy absorbed by the vehicle during impact. Because of the varying crush stiffness between vehicles, and its dependence on the direction of impact, estimates of impact energy based on measurements of deformation alone are meaningless. Ideally, impact energy would be estimated by comparing the accident-involved vehicle damage with the damage resulting from controlled vehicle-pole impacts. Unfortunately such data are not available. As the costs of the damage are likely to form the final criterion for remedial action, it was decided to use the cost of pole impact damage as an indicator of vehicle damage severity. The measure used was the proportion of the market value of the vehicle accounted for by the cost of the pole impact damage. Clearly, this is only a crude measure of severity, especially as the level of damage required to 'write-off' a vehicle (pole impact costs proportion equal to unity) depends on the market value of the vehicle. However, given a large enough sample, and assuming that particular vehicle types and vintages are not more prone to any particular accident type, it serves as a basis for comparison between the accident types. Figure 4.53 shows the distribution of pole impact costs proportion for the three accident types. The results observed for occupant injury severity are consistent with those for vehicle damage : the intersection pole accidents result in generally less severe damage to the vehicle than the non-intersection accidents. Very little difference is observed between the straight road and curved road vehicle damage distributions.

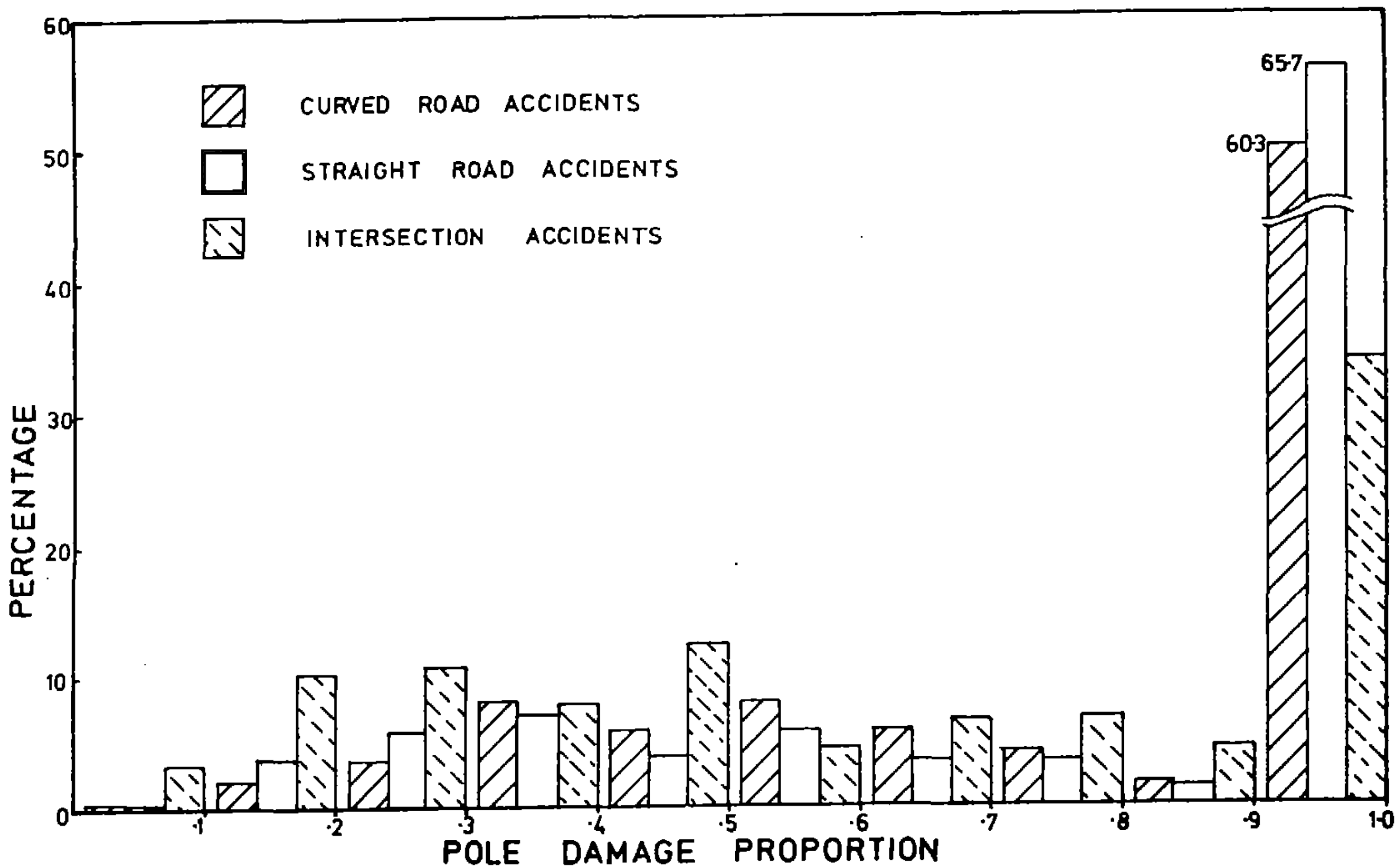


Figure 4.53. Distribution of the proportion of the vehicle market value accounted for by the cost of the vehicle damage resulting from the pole impact

Intersection accidents resulted in thirty-four percent of vehicles being 'written-off' or severely damaged, compared with sixty percent for curved road non-intersection accidents and sixty-five percent for straight road accidents.

4.4.3 Damage to Poles and Utilities

The extent of pole damage (and utility damage) was found to be related to the pole material and pole function, rather than any of the site characteristics. This relationship is discussed in Section 4.6.

4.4.4 Discussion

It appears from this initial analysis, that the accident cost distributions may show some differences between the major accident types. This will be investigated further in Chapter 5.

In summary, intersection accidents seem to be generally less severe than non-intersection accidents ; curved road non-intersection accidents tend to be slightly more severe than straight road accidents. It is possible that these differences are a function of the distribution of vehicle speeds, although it is not possible to investigate this from the data available in this study.

4.5 POLE ACCIDENT OCCURRENCE AND SEVERITY AS RELATED TO VEHICLE CHARACTERISTICS.

4.5.1 Introduction.

Establishing the relationship between pole accident occurrence and vehicle characteristics requires extensive control data for the purposes of comparison with the accident sample. Unfortunately, detailed information relating to the distribution of vehicle characteristics in the population is not available. Consequently, the analysis to follow is restricted to those vehicle characteristics for which control or population data are available. The principal source of published control data is the Australian Bureau of Statistics (ABS) Motor Vehicle Census, for 30 September 1976. Fortuitously, the census date occurred during the accident survey period, although at the time of writing only data relating to the whole of Victoria, rather than just the Melbourne Metropolitan area, was available. This introduces a further degree of uncertainty into the analysis of the related variables.

The most detailed control information was obtained for the vehicle tyres. Details of tyre type and condition were recorded in this study at five locations around Melbourne. The locations chosen were petrol stations, as it was thought that this would reduce the possibility of sample bias, compared with surveys at carparks or sporting venues. The locations were scattered across a variety of socio-economic areas and land use categories, ranging from commercial to residential. The sample size was small (627) compared with the total population of vehicles in Melbourne, but it served to provide estimates of previously non-existent data.

It is noted that while certain vehicle characteristics may be found to be associated with the occurrence of pole accidents, such information is of no consequence to the accident probability at a particular pole site. They do, however, provide further insight to the accident problem as a whole.

4.5.2 General Population Characteristics.

A comparison of ABS data concerning the distribution of vehicles by make, year of manufacture and body style provided a check for gross biases that may have existed in the tyre survey. As has been pointed out, the ABS data covers the whole of Victoria, and may not be directly comparable to the metropolitan population of vehicles. However, given the lack of alternative data, it will serve as a crude check of the tyre sample. The distribution of vehicles by make in the ABS census, the tyre survey, and the accident sample is presented in Table 4.18. Given the size of the two samples collected in the present study in comparison with the ABS population (a sampling fraction of the order of 8.37×10^{-4}!), there do not appear to be any gross biases by vehicle make in the tyre survey. Vehicle make does not appear to be a significant factor in the accident sample when compared with the two control samples. Similarly, the year of manufacture seems to have little effect, as shown by Table 4.20. The distribution of vehicle body style (Table 4.19) shows the largest differences between the accident sample and the ABS due largely to the low rate of motorcycle involvement in pole accidents (only one case recorded during the survey period), and the discrepancies in the number of utilities obtained in the three samples. The difference in the percentage of utilities recorded by the ABS and the percentage in the tyre survey is possibly due to utilities being a common rural vehicle which are included in the ABS figures. Relative risk and standard deviation based for each body style, based on the tyre and accident surveys, are also presented in Table 4.19. It appears that utilities are over-involved in pole accidents, and stationwagons under involved, although when the standard deviation of each relative risk is taken into account, none are markedly different to one.

TABLE 4.18.

DISTRIBUTION OF VEHICLES BY VEHICLE MANUFACTURER (%)

MANUFACTURER	ABS	Tyre Survey	Accident Survey
Austin/Leyland/Morris	6.9	4.9	5.9
BMW	0.2	0.5	0
Chrysler	7.8	6.6	8.3
Datsun	4.7	5.7	3.6
Fiat	0.6	0.8	0.7
Ford	21.5	23.9	26.3
Hillman	1.4	0.6	0.9
Holden	33.4	36.3	37.1
Honda	0.7	0.3	0.9
Jaguar	0.4	0.3	0.9
Mazda	3.5	5.0	1.7
Mercedes	0.8	0.8	0.5
M.G.	0.3	0.2	0.5
Renault	1.0	1.8	0.4
Toyota	6.5	5.0	5.8
Triumph	0.4	0.3	0.4
Volkswagen	3.8	3.6	3.5
Volvo	0.5	0.8	0.1
Other	5.6	2.6	2.7

It appears from the comparisons of the samples, that there are no gross biases in the tyre survey.

TABLE 4.19

DISTRIBUTION OF VEHICLES BY BODY STYLE %

		Present Study			
Body Style	ABS	Tyre Survey	Accident Survey	RR	SD
Motor cars	68.0	76.3	76.7	1.00	0.03
Stationwagons	13.0	15.0	11.5	0.76	0.15
Utilities	5.8	1.9	3.3	1.72	0.60
Panel Vans	2.6	4.2	4.6	1.11	0.27
Trucks, Buses etc	7.7	2.6	3.9	1.52	0.50
Motorcycles	2.9	--	--	--	--

TABLE 4.20

DISTRIBUTION OF VEHICLES BY YEAR OF MANUFACTURE (%)

Year	ABS	Tyre Survey	Accident Survey
-60	4.6	2.0	2.1
1961-64	13.4	10.9	10.6
1965-66	9.4	8.4	7.8
1967-68	11.6	11.6	13.4
1969-70	14.1	13.5	16.4
1971-72	14.5	13.5	17.6
1973-74	17.0	18.0	16.3
1975-76	14.8	21.9	15.9

4.5.3 Vehicle Tyres

The most comprehensive vehicle-related data set collected concerned the vehicle tyres. Details of tyre make, construction, size and condition were recorded for all tyres on the accident and random (tyre) survey vehicles. Details concerning the recommended tyre specifications for the particular make and body style were also incorporated in the coded data. The data items recorded for each of the vehicle tyres were as follows:

(i) Manufacturer

(ii) Size

(iii) Model

(iv) Construction (cross ply, radial or recap)

(v) Inflation pressure

(vi) Tread depth

(vii) Recommended inflation pressure

A number of tyre characteristics were found to have high accident risk. The analysis takes the same form as the pole site analysis: the relative involvement of a tyre characteristic in the accident and random tyre samples being termed 'relative risk'.

Figure 4.54 is a plot of relative risk versus the average tread depth on the front tyres for both wet and dry road accidents. Relative risk rises sharply for tread depths less than 3 mm on wet roads, and to a lesser extent for the dry road cases. The dry road result is somewhat surprising in that reduced tread depth on dry roads generally results in higher side force and braking coefficients. This implies that factors other than tread depth alone are at play. One possible explanation is the correlation found between low tread depths and overdue vehicle maintenance in the accident sample. Low tread depths could also reflect general driver attitudes.

A similar result was obtained for rear tyres, with an average tread depth of 0.5 mm having a 15.5 times higher probability of wet road accident involvement than tyres with a tread depth of 5 mm or greater (Figure 4.55). The dry road risks for these tyres are similar to those observed for the front tyres. They are all very close to unity for tread depths greater than 3 mm.

A similar result, although not as striking, was obtained by The Highway Safety Foundation (1971) -- see Figure 4.56. Mahone (1975) demonstrated a reduction in wet pavement friction for reduced tyre tread depth, a result which is consistent with the rapid increase in relative risk for low tread depths.

In terms of pole site descriptions, low tread depths were found to be weakly correlated with curvature and skid resistance for wet road accidents.

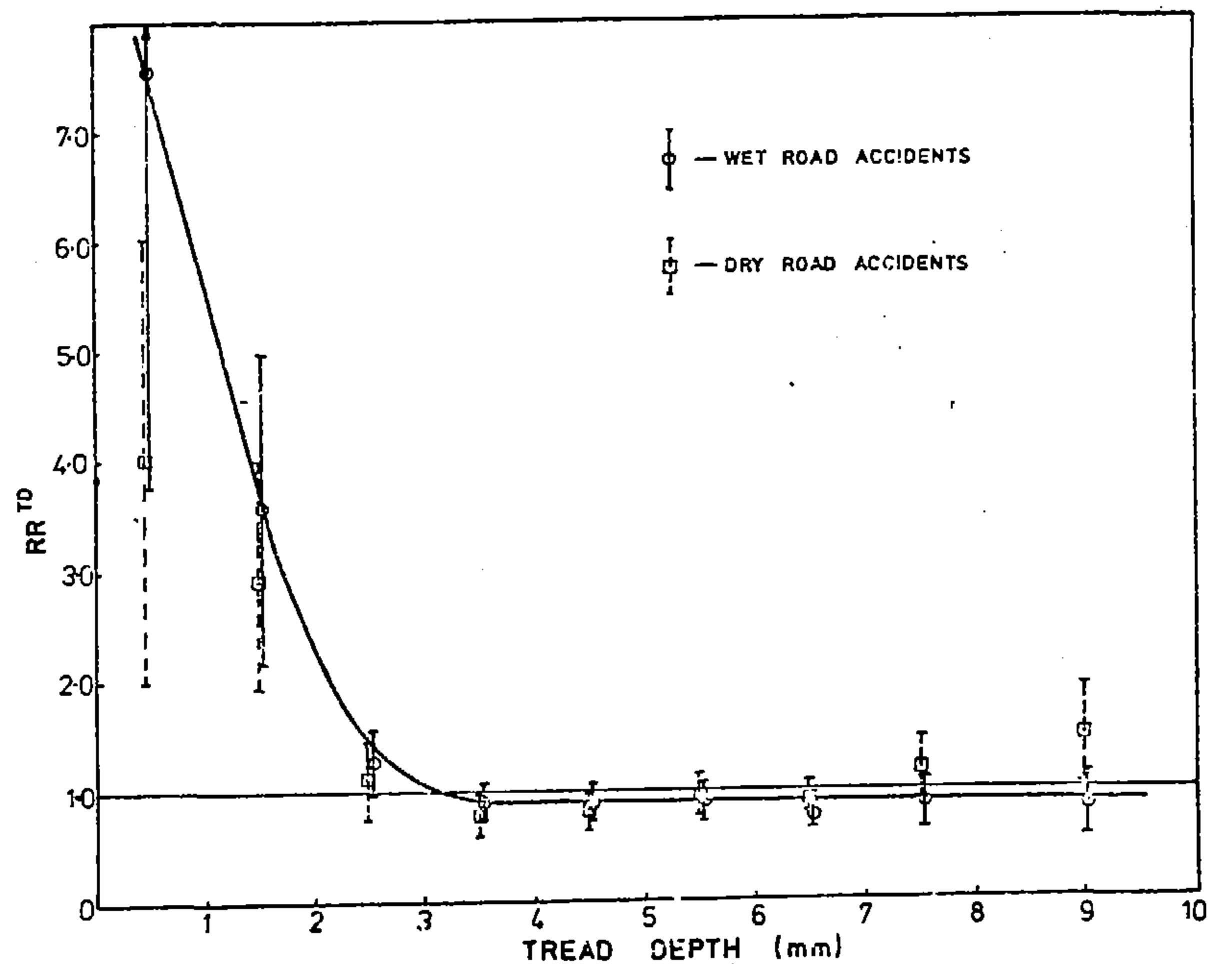


Figure 4.54·Relative risk versus the average front tyre tread depth for wet and dry roads

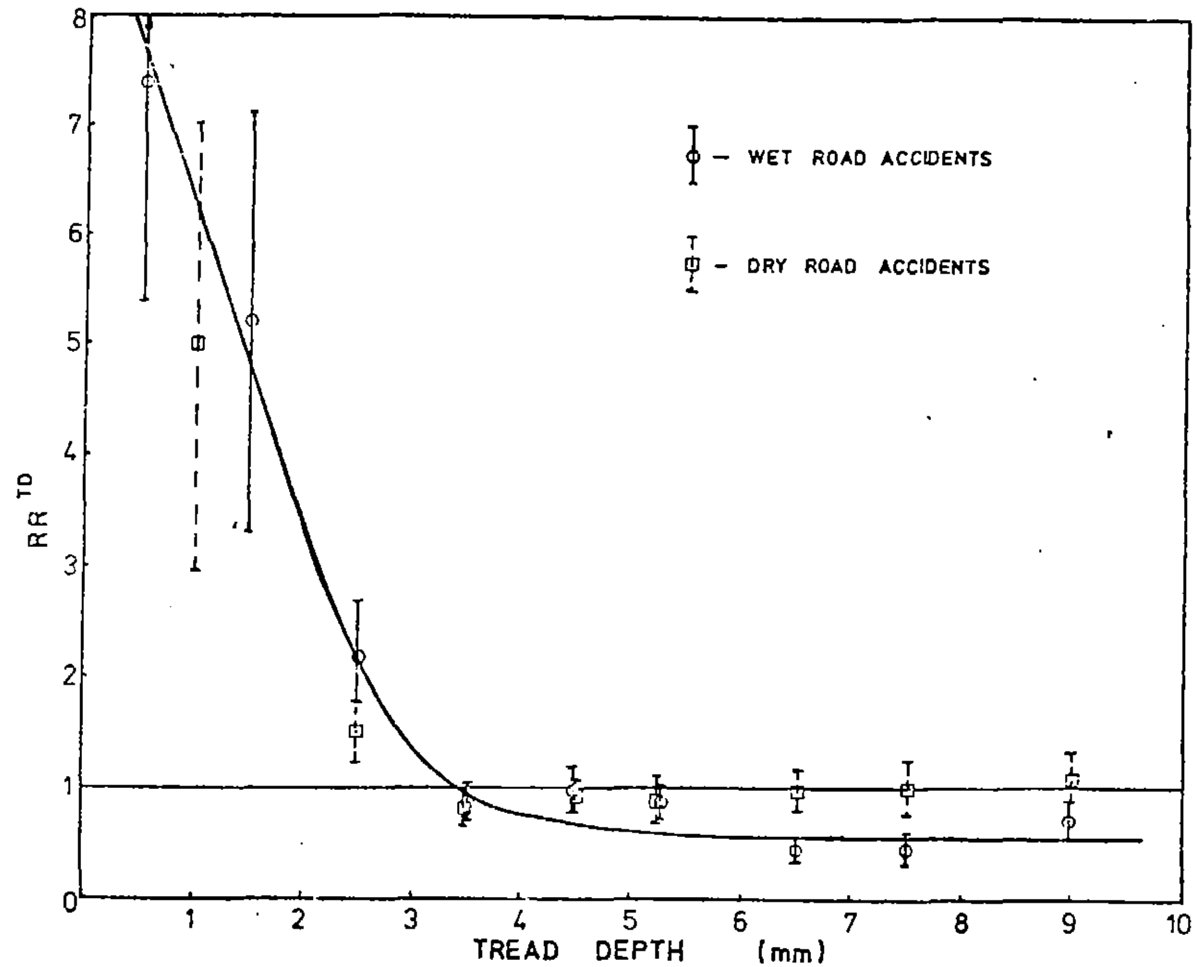


Figure 4.55. Relative risk versus the average rear tyre tread depth for wet and dry roads

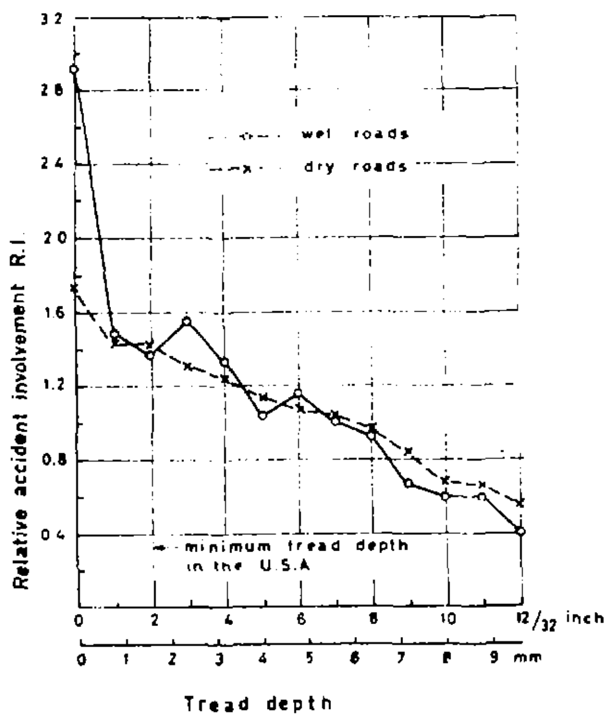


Figure 4.56. Relative accident involvement versus tread depth for wet and dry roads (The Highway Safety Foundation, 1971; taken from Dijks, 1977)

The high risk associated with low tread depths on wet roads seems clear. Another question which is of practical and economic significance is: what proportion of accidents are associated with this vehicle deficiency? Table 4.21 provides the answer.

TABLE 4.21

PERCENTAGES OF VEHICLES HAVING AVERAGE TREAD DEPTH LESS THAN 3 mm

Sample	Front Tyres	Rear Tyres
Random	10.1	18.3
Accident	18.7	28.8

It can be seen that rear tyres are generally in worse condition than front tyres, and that nearly thirty percent of accident-involved vehicles had rear tyres with tread depths which are hazardous on wet roads.

Tyre inflation pressure was recorded for each tyre as well as the recommended pressure for the particular tyre type and vehicle. Tyre pressure margin was obtained by subtracting the recommended pressure from the observed pressure. Figure 4.57 shows the plot of relative risk against pressure margin. It can be seen that gross under-inflation results in a higher risk of accident involvement compared with correct or over-inflation of the tyres. These results should be viewed with some caution as it is impossible to know that the pressure measured after the accident was the same as the pre-accident pressure. It was found that 11% of vehicles had at least one completely deflated tyre after the accident, so it is not impossible that varying degrees of tyre deflation may have occurred during the accident phase. Tyres with zero or extremely low inflation pressures were eliminated from the analysis. (It should be noted that no information was available as to whether tyre pressure failure occurred prior to any accident.)

To further investigate the role of tyre pressures in pole accidents, the relative risk associated with the difference between the average pressure margin for the front tyres and the average pressure margin for the rear tyres (FRPM) was obtained and plotted in Figure 4.58. A zero difference between front and rear tyre pressure margins means that, although all tyres may not have been at the recommended inflation pressures, the recommended front-rear balance was maintained. A negative value of FRPM meant that compared with

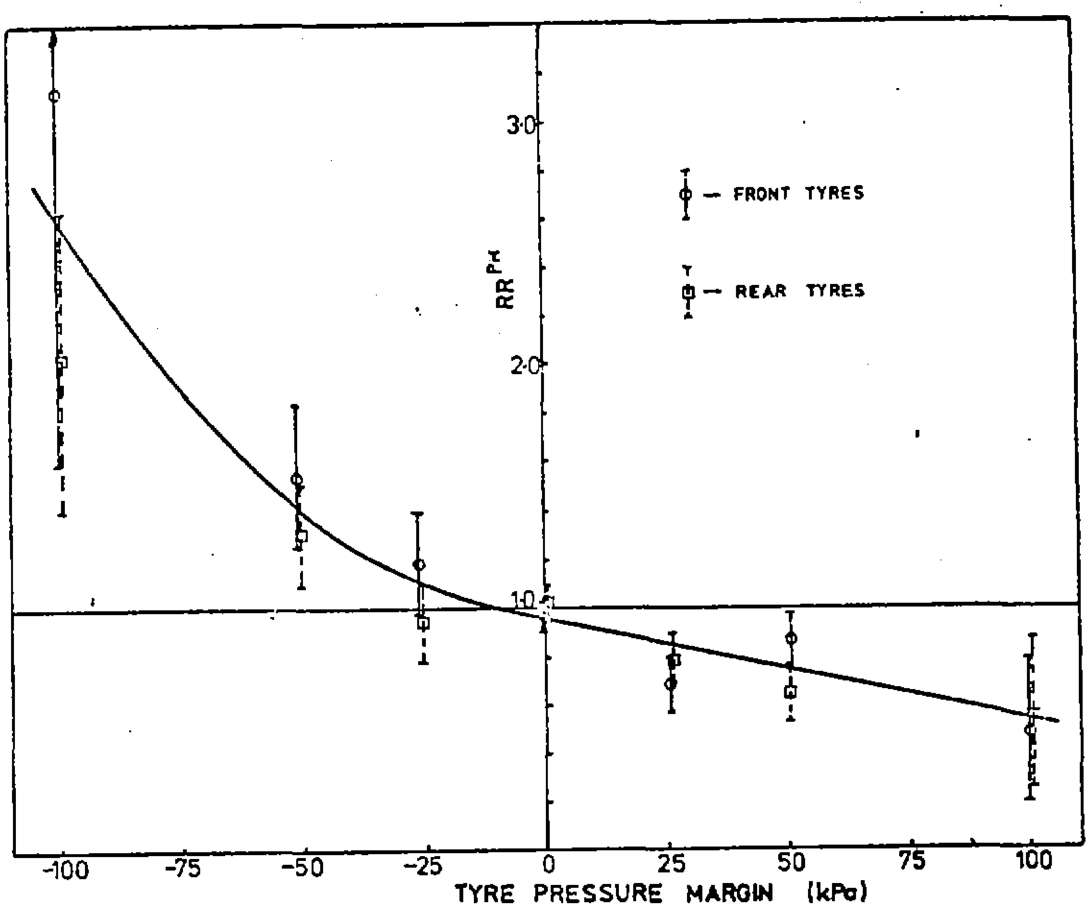


Figure 4.57. Relative risk versus front and rear average tyre pressure margins

specifications, the rear tyres were overinflated relative to the front tyres. Most modern vehicles are designed with inherent under-steer, the front and rear tyre pressures being specified accordingly. (For an understeer vehicle the steering angle required to negotiate a given radius road curve increases as the vehicle speed increases; for an oversteer vehicle the required steer angle decreases. An oversteer vehicle exhibits an instability above a 'critical speed' which is characteristic of the vehicle.) A zero FRPM, then, typically corresponds to a small amount of understeer, and it can be seen in Figure 4.58 that this corresponds to the lower region of relative risk. Larger negative values of FRPM result in increasing understeer characteristics and lead to an increase in relative risk above unity. For the positive direction of FRPM, which produces less understeer and possibly oversteer, the relative risk again rises above unity, apparently at a greater rate than for the increasing understeer direction. Clearly, the front to rear tyre pressure differential is an important factor. The effect of tyre inflation pressures on vehicle 'handling' characterstics has been demonstrated by Hoffman and Joubert (1966), Fancher and Bernard (1975) and others.

It might be expected that this vehicle 'handling' effect would be more pronounced for curved road sites. To investigate this possibility, relative risk plots against FRPM for curved and non-curved sites were produced, as shown in Figure 4.59.

Because of the small numbers in the two samples (accident and random) the 'confidence' intervals are relatively large, and a considerable amount of overlapping occurs. However, the tread in the results is certainly in the expected direction.

For positive values of FRPM (low understeer tending towards oversteer) the relative risk rises sharply for curved road accidents. It might also be expected that the non-curved site group would show a less pronounced handling effect, and in fact all the relative risk points have 'confidence' intervals that overlap a relative risk unity.

Again, the question arises as to what proportion of accident involved vehicles have tyre pressure imbalances which produce hazardous handling characteristics. Table 4.22 shows the proportions of vehicles with various levels of front-rear imbalance in both the random and accident samples.

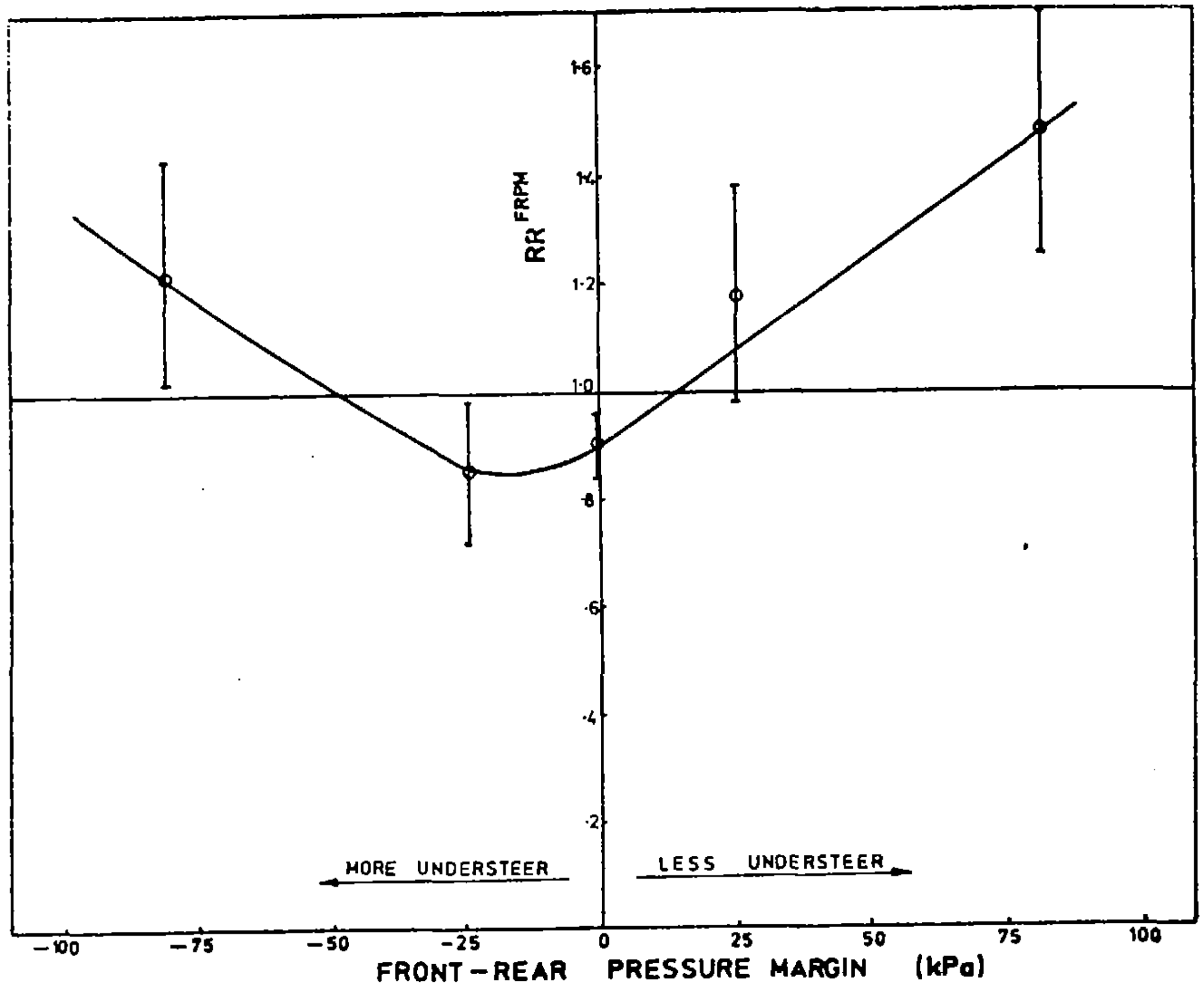


Figure 4.58. Relative risk versus the difference between the average front and rear tyre pressure margins, for all accident cases

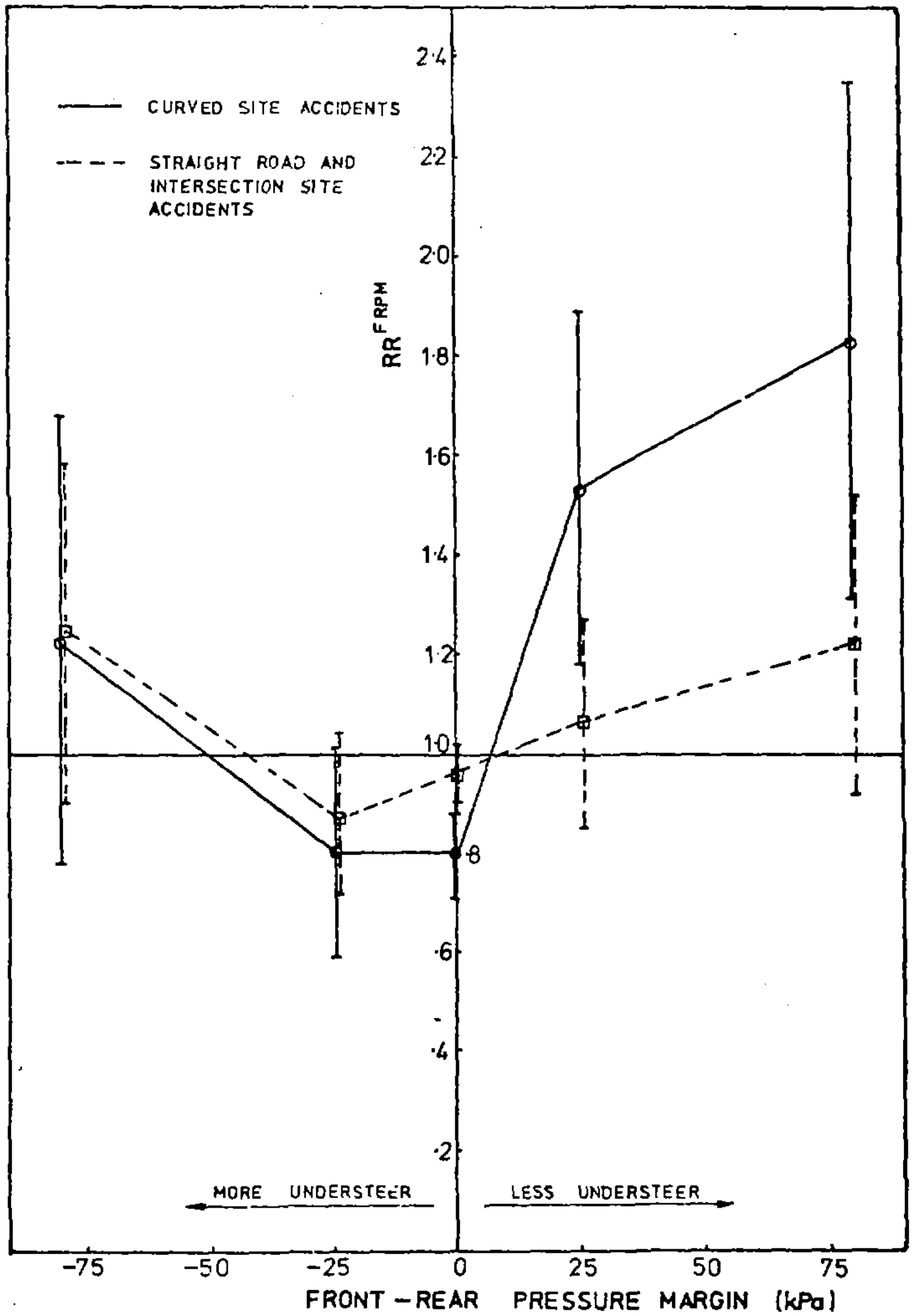


Figure 4.59. Relative risk versus the difference between the average front and rear tyre pressure margins, for curved and non-curved sites

TABLE 4.22

PERCENTAGE OF VEHICLES BY FRONT-REAR PRESSURE MARGIN

FRPM (kPa)	Random Sample	Accident Sample: All accidents	Accident Sample: Curved sites only
Less than -35	6.2	7.6	7.6
Less than -17.5	22.1	21.0	20.3
Within ± 17.5	58.4	53.7	46.6
More than 17.5	19.6	25.3	32.9
More than 35	7.4	10.9	14.3

Thirty-three percent of vehicles in accidents (of all types) had FRPMs associated with relative risks higher than 1.0 in Figure 4.58. Of the vehicles involved in curved site accidents, forty-one percent had 'hazardous' FRPMs, with thirty-three percent of vehicles having FRPMs which tended to reduce understeer.

Another vehicle handling parameter of importance is the response time of the car to steering inputs. Whereas understeer/oversteer is primarily related to the *difference* between the front and rear tyre pressures, the response time is basically a function of the *sum* of the pressures (Hoffmann and Joubert, 1966). As the overall level of tyre pressure decreases (the front-rear balance being maintained), the time lag between steering inputs and vehicle responses increases. Hoffmann and Joubert, and others, have shown that long response times produce a degradation in driver-vehicle performance.

The effect of response time on pole accident occurrence is investigated, by way of the average pressure margin over all four wheels, in Figure 4.60. This plot shows that high average pressure margins, which can be expected to be associated with short response times, are associated with reduced risk. Low pressure margins, and long response times, involve substantially increased risk. Figure 4.61 indicates that it makes little difference whether curved or non-curved accident sites are examined. If anything, the effect of average pressure margin is more pronounced for non-curved sites.

Pressure margins associated with relative risks greater than 1.0 in Figure 4.60 were possessed by 35 percent of accident-involved vehicles, and 23 percent of randomly selected vehicles. Taken together with Table 4.22, these figures indicate that a substantial proportion of accident-involved

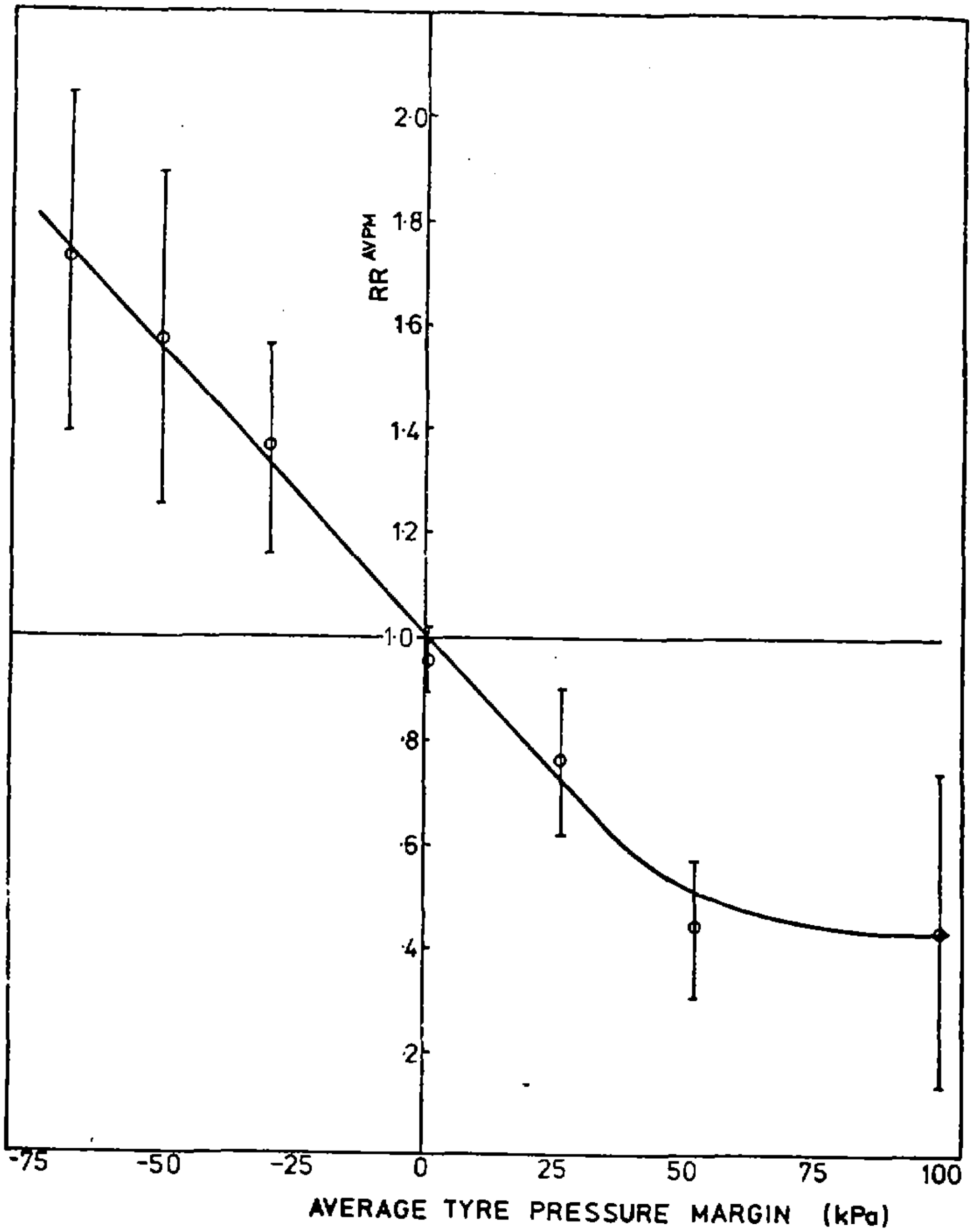


Figure 4.60. Relative risk versus the overall average tyre pressure margin for all accidents

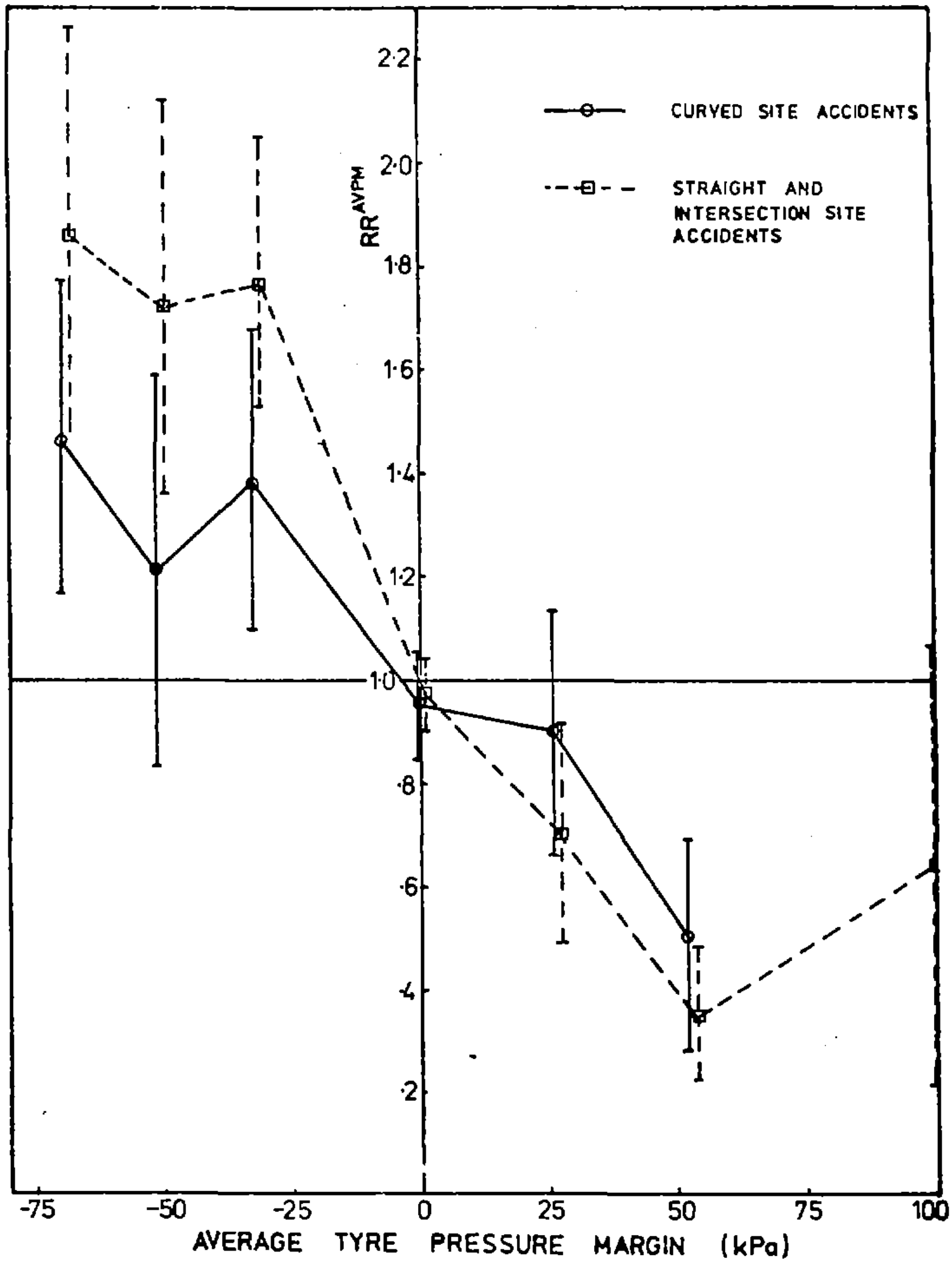


Figure 4.61. Relative risk versus the overall average tyre pressure margin for curved and non-curved sites

vehicles have handling characteristics that have been dangerously degraded through use of improper inflation pressures.

Because of the size of the samples, it was decided that an analysis of the large number of particular tyre models would be rather meaningless. Instead, the tyres were grouped according to their construction:

(a) cross ply
(b) radial ply
(c) recap.

Recapped tyres are not strictly a separate tyre construction group, although it is not realistic to group them with either of categories (a) or (b). It was therefore decided to assign them to a separate category. Table 4.23 details the associated relative risks.

TABLE 4.23

RELATIVE RISK VERSUS TYRE CONSTRUCTION

Tyre Construction	RR	SD
Cross ply	1.21	0.14
Radial ply	0.93	0.06
Recap	0.96	0.12

It appears that tyre construction is a weak effect in the occurrence of pole accidents, particularly in view of the size of the standard deviations of relative risk.

Mixing of tyre makes, construction, and size between axles and on axles was also found to have little effect for the pole accident sample. Extremes in tyre size, that is very wide tyres, were found to have high relative risks. However, the number of such tyres in both samples was extremely small, and probably their high accident involvement reflects driver attitudes and characteristics rather than tyre performance capabilities.

4.5.4 The Effect of Vehicle Weight on Pole Accident Occurrence

The distributions of vehicle mass for motor cars in the accident sample and the ABS census are shown in Table 4.24.

TABLE 4.24

DISTRIBUTION OF VEHICLE MASS FOR MOTOR CARS IN THE ACCIDENT SAMPLE AND THE ABS CENSUS

	Accident Sample		ABS Census	
Vehicle Mass (kg)	No.	%	No.	%
0 - 900	123	20.2	359359	29.5
901 - 1100	87	14.3	253776	20.8
1101 - 1500	371	61.0	573760	47.0
1500 -	27	4.5	33203	2.7
TOTAL	608	100.0	1220098	100.0

The relative risk associated with each category of mass is shown in Table 4.25.

TABLE 4.25

RELATIVE RISK VERSUS VEHICLE MASS FOR MOTOR CARS

Vehicle Mass (kg)	Relative Risk
0 - 900	0.69
901 - 1100	0.69
1101 - 1500	1.30
1501 -	1.63

The results presented apply to motor cars ; the same trends were found for stationwagons. There were insufficient data in the other vehicle categories to enable meaningful analysis.

Some doubt exists concerning the comparability of the two vehicle samples, because of a slight coding difference. In the ABS census, vehicle masses were 'rounded off' to the nearest 50 kg, whereas in the accident survey the precise curb mass from the manufacturers' data, was recorded. Further variability was introduced because in the ABS figures, only one mass associated with the basic vehicle model is coded, for the entire range of model variations within that vehicle make and year. For example, a 'V8' Holden Kingswood is assigned the same mass as a six cylinder Holden Belmont, whereas in fact the V8 model would be about 65 kg heavier. The present survey, on the other hand, took account of the extra mass associated with vehicle model variations. Unfortunately, the boundary between two of the original ABS cells occurs at 1300 kg, which happens to be very close to the mass of the majority of Ford and Holden sedans which make up a large proportion of the population. To reduce the errors resulting from possible mismatching of the two samples at the cell boundaries, it was decided to merge these two cells into one (1100 - 1500 kg).

Given the possible errors associated with the cell boundaries, there still seems to be a significant effect of vehicle mass on relative risk (Table 4.25). Increasing vehicle mass appears to be associated with increasing relative risk. It should be noted though, that the accident numbers in the highest vehicle mass cell are relatively small.

The observed effect of vehicle mass is difficult to explain. Vehicle mass was not found to be correlated with type condition, accident type or driver age. The present findings are, however, in partial agreement with those of Foldvary (1977). He found that the accident rate on Queensland roads (of all types) in 1961 increased with increasing vehicle mass up to a mass of approximately 1100 kg, after which the accident rate declined. Considering the possible shift in the distribution of vehicle mass in the population since the Foldvary data was collected, and the uncertainty surrounding the relative risk associated with 1500 + kg category in the present study, the two sets of results demonstrate similar trends. It is clear, however, that before any definite conclusions can be drawn regarding the effect of vehicle mass, more data are required.

As no control data relating to actual engine brake horsepower (BHP) was available, neither analysis of that variable, nor power/ weight ratio was possible.

4.5.5 Pole Accident Severity as a Function of Vehicle Characteristics

Because of the lack of comparison data on the characteristics of the vehicle population, the analysis of vehicle characteristics in relation to pole accident occurrence was severely restricted. Effects of vehicle engine size and wheelbase in particular had to be excluded. This is not the case in the analysis of their relationship to accident severity because only the data recorded in this study are required.

As in Section 4.4, accident severity is here measured primarily in terms of occupant injury, although the consequences of the accident with regard to vehicle and pole damage are also considered. Perhaps the most informative general vehicle characteristic is vehicle mass, as it also reflects vehicle size and, to a large extent, engine size.

Accident severity was found to increase in terms of occupant injury and vehicle damage with decreasing vehicle mass. Figure 4.62 shows the mean ISS (Injury Severity Score) as a function of vehicle mass. The solid line on the graph represents the mean ISS calculated from the highest ISS per accident, for all accident cases including the no-injury cases. The broken line in Figure 4.62 represents the mean ISS for all injured occupants (including one zero ISS occupant per no-injury case). This treatment of the no-injury cases was necessary because of the number of uninjured occupants was generally not known. The choice

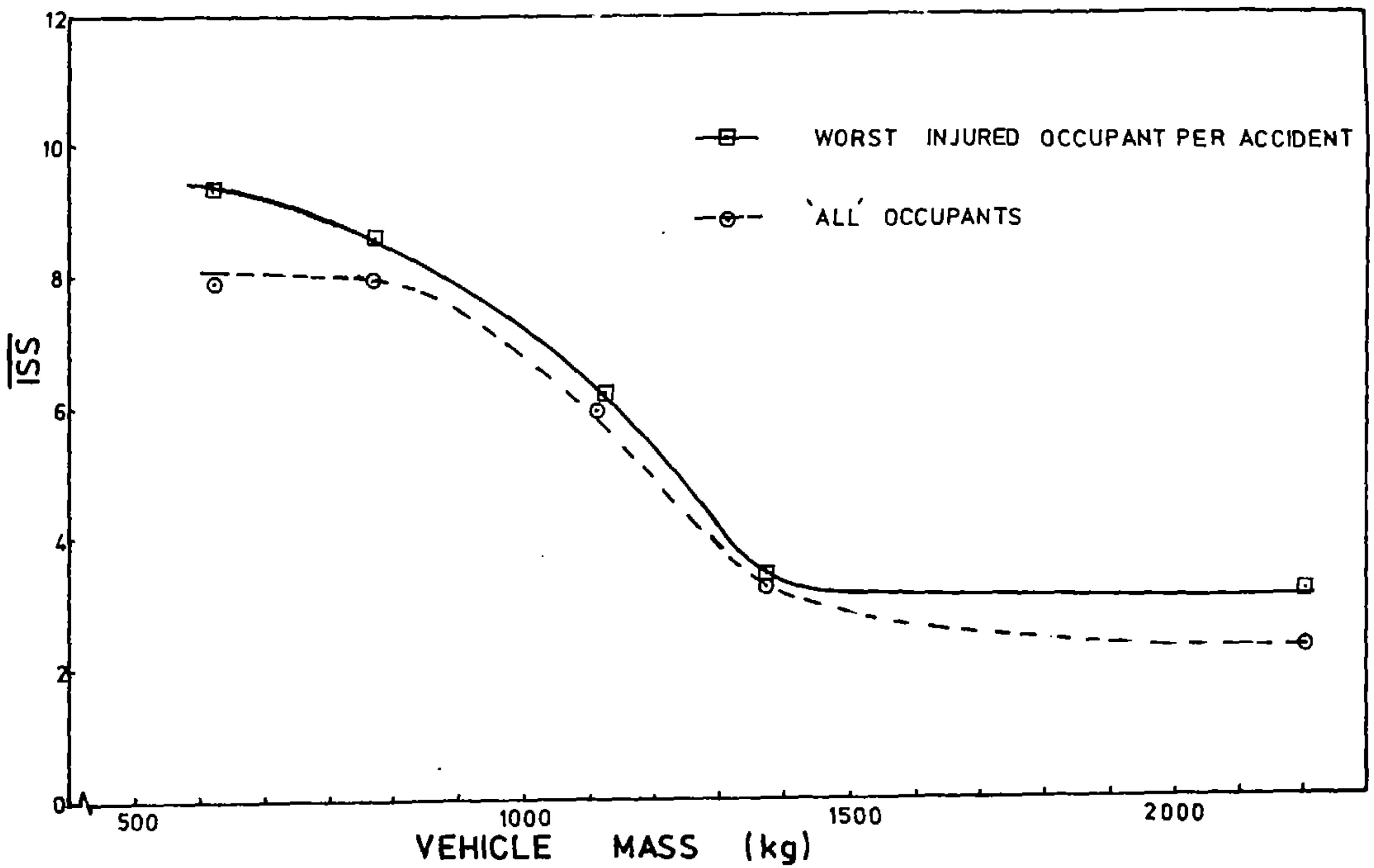


Figure 4.62. Mean Injury Severity Score (ISS) versus vehicle mass

of one uninjured occupant per no-injury accident was considered a conservative approach. It would have the effect of inflating the values of the mean ISS. Nevertheless, the trend is quite clear, with the chances of more severe injuries increasing as the vehicle mass decreases. This finding is somewhat disturbing in view of the current shift towards lighter vehicles in the population. The expected increase in the number and severity of injured occupants may be offset in part if the Section 4.5.4 result relating reduced pole accident occurrence with reduced vehicle mass is in fact true.

As expected, wheelbase and engine horsepower demonstrated similar relationships with injury severity, these two variables being strongly related to vehicle mass. It is also noted that although only the ISS results have been presented here, the same analysis was carried out for the AIS scores, with similar results.

The level of damage to the pole was found to be weakly correlated with vehicle mass, with heavier vehicles tending to cause more pole and utility damage.

Accident severity was not found to be a function of the condition or characteristics of the tyres, or engine orientation and location. It was thought that 'East-West' engines may provide greater occupant protection in frontal impacts. The data do not support this hypothesis, however.

4.6 POLE ACCIDENT SEVERITY AS RELATED TO POLE CHARACTERISTICS

The pole characteristics analysed in this section refer to the pole material and the utilities carried by the pole. Clearly, the occurrence of a pole accident is not affected by the type of pole, unless the type of pole is correlated with some relevant site characteristics. For example, it was found that steel luminaire supports predominate on high traffic volume roads, whereas wooden luminaire supports are used on low traffic volume roads. Traffic lights, as might be expected, were almost exclusively restricted to major road intersection cases. Apart from these two examples, the distribution of poles by material and function did not vary greatly between the accident and random samples (see Chapter 3).

In order to maintain the numbers of cases in each analysis cell at a reasonable level, the poles were classified according to their major function (e.g., cable supporting, luminaire, etc.) with no distinction being made between tram or power cables, or whether or not the pole carried a secondary utility such as a luminaire. Even so, the numbers in the more serious injury categories remained low.

Accident severity in terms of occupant injury was not strongly related to pole classification. Tables 4.26 and 4.27 respectively show the distribution of the highest AIS and ISS per accident by pole classification. Concrete poles have been eliminated from these tabulations because of their small numbers. It appears that there are no gross differences between the injury distributions for each pole type. If anything, on an injury versus no-injury basis, steel luminaire supports result in slightly fewer casualties and wooden ones result in more, although across the range of injury severities the difference is not marked.

TABLE 4.26

DISTRIBUTION (%) OF MAXIMUM AIS PER ACCIDENT BY POLE MATERIAL AND FUNCTION

Pole Material and Function	AIS 0	1 - 2	3 - 4	5 - 6	Total
Steel					
Luminaire	74.4	15.7	6.1	3.7	100.0
Cable-supporting	68.1	20.6	11.1	2.8	100.0
Traffic lights	67.9	21.0	7.4	3.7	100.0
Wood					
Luminaire	63.9	16.7	13.9	5.6	100.0
Cable-supporting	71.1	17.8	8.5	3.6	100.0
Overall	70.2	17.0	9.1	3.6	100.0

TABLE 4.27

DISTRIBUTION (%) OF MAXIMUM ISS PER ACCIDENT BY POLE MATERIAL AND FUNCTION

Pole Material and Function	ISS 0	1 - 5	5 - 20	20 +	Total
Steel					
Luminaire	74.4	12.2	9.8	3.6	100.0
Cable-supporting	68.1	9.7	13.6	8.4	100.0
Traffic lights	67.9	18.7	7.4	5.0	100.0
Wood					
Luminaire	63.9	13.0	17.6	5.6	100.0
Cable-supporting	71.1	13.2	9.9	5.6	100.0
Overall	70.2	13.5	10.8	5.6	100.0

Consistent with the injury findings, the extent of vehicle damage was not found to be correlated with pole type.

The extent of pole and utility damage, however, was found to be related to the pole material and function. Table 4.28 shows the percentage distribution and nature of pole damage (not including utility damage) by pole material and function. Steel cable-supporting poles appear the most 'sturdy' in terms of the rate of complete pole replacement, followed by cable-supporting timber poles. The concrete pole results are once again doubtful because of the small numbers involved (16 accident poles and 14 random poles). Excluding the concrete poles, steel traffic light poles and luminaire supports have the highest replacement rate, followed by timber luminaire poles.

As would be expected, the extent of damage to the pole is reflected in the level of damage to the utilities. Tables 4.29 and 4.30 show the levels of damage to conductors and luminaire assemblies, respectively, by pole classification. The least amount of conductor damage occurs when steel poles are involved, followed by concrete poles and then timber poles. The pattern of luminaire damage follows that for pole damage, with steel luminaire supports generally requiring the most extensive repairs. The 'complete assembly' category in Table 4.30 refers to the lamp, arm, pole and transformer, where fitted.

TABLE 4.28

DISTRIBUTION (%) OF POLE DAMAGE IN THE ACCIDENT SAMPLE BY POLE MATERIAL AND FUNCTION

Pole Function and Material	Pole Damage				Pole Requires Replacement
	No Damage	Deformed	Sheared	Split	
Steel					
Luminaire	37.8	39.0	23.2	0	54.9
Cable-supporting	92.9	4.2	0	0	5.6
Traffic lights	33.3	46.9	19.8	0	59.3
Other	75.0	0	25.0	0	25.0
Concrete					
Luminaire	33.3	0	66.7	0	66.7
Cable-supporting	70.0	20.0	10.0	0	30.0
Wood					
Luminaire	67.5	3.7	24.1	3.7	32.3
Cable-supporting	88.3	1.8	6.3	2.6	10.9
Other	85.7	0	14.3	0	14.3

It is apparent that, with the essentially rigid poles on Melbourne roadsides, the only major effect of pole type on accident 'severity' is in terms of damage to the pole and its utilities. If poles were modified or replaced to make them more yielding in a crash, this would no longer be the case, and the overall costs and benefits associated with changing pole types would involve changes in personal injury and vehicle damage 'severity' measures as well.

TABLE 4.29

PERCENTAGE OF CABLE-SUPPORTING POLES IN THE ACCIDENT SAMPLE WITH DAMAGED CONDUCTORS, BY POLE MATERIAL

Pole Material	Conductor Damage		
	No Damage	Disconnected	Insulator Damage Only
Steel	92.9	7.1	0
Concrete	80.0	20.0	0
Wood	78.4	17.8	3.8

TABLE 4.30

DISTRIBUTION OF LUMINAIRE DAMAGE (%) IN THE ACCIDENT SAMPLE, BY POLE MATERIAL AND FUNCTION

Pole Material and Function	Luminaire Damage			
	No Damage	Lamp Only	Lamp and Arm	Complete Assembly
Steel				
Luminaire	33.3	19.8	16.0	30.9
Cable-supporting	97.8	2.2	0	0
Traffic light	66.7	33.3	0	0
Concrete				
Luminaire	33.3	0	50.0	16.7
Cable-supporting	100.0	0	0	0
Wood				
Luminaire	45.7	27.6	12.4	14.3
Cable-supporting	85.3	7.2	4.4	3.1

4.7 REVIEW

In what follows, the major methods, accomplishments and findings reported in this Chapter are reviewed.

4.7.1 Previous Work

A review of the literature related to accident prediction models revealed little of direct relevance to the present study. The majority of the studies of the relationship between fixed roadside hazard (FRH) accidents and roadway characteristics have concentrated on rural interstate highways. Typically, the statistical models were derived from accident and roadway data for a sample of road segments selected from extensive inventories of the highway system. For the rural interstate road class, it was found that accident rate was related to roadway horizontal alignment, traffic volume, road width, grade and number of intersections.

An analysis of fatal FRH collisions on all classes of road (rural and urban) by Wright and Robertson (1976) was the piece of work most directly comparable with the present study, in that data was collected at a sample of control sites as well as the accident sites. They concluded that combinations of grade and curvature resulted in the highest accident risk.

4.7.2 Site Characteristics Related to Pole Accident Occurrence

(a) Objective

The primary objective of the present study was the development of a statistical model which would allow the identification of variations in accident probability as a function of measurable pole site characteristics. To this end, measurements of roadway, traffic and pole placement variables were made for a sample of sites at which pole accidents had occurred, and at a control group of randomly selected pole sites.

(b) Data groups

To ensure adequate representation of major road and intersection sites in the control group of poles, the random sample was stratified according to road class and broad site description. Accordingly, the analysis of the effects of site characteristics on pole accident occurrence was carried out within the following data groups:

- MNI - Major road non-intersection sites
- MINI - Minor road non-intersection sites
- MJMJ - Intersection of major roads
- MJMI - Intersection of major and minor roads
- MIMI - Intersection of minor roads

(c) Relative risk

The quantification of the effect of a site characteristic on accident occurrence was achieved by the calculation of the associated 'relative risk' (RR). This was defined formally as the ratio of the failure (accident) probability of a 'pole-second' binomial trial to the mean such failure probability for all poles. Relative risk measures the accident involvement of poles with a given site attribute A relative to their numbers in the population of all poles. It was calculated thus:

$$RR^{A} = \frac{\text{Proportion of poles in the accident sample with attribute A}}{\text{proportion of poles in the random sample with attribute A}}$$

The method of maximum likelihood was used to derive estimates of the standard deviations of these point estimates of relative risk. These served as indicators of the magnitude of the confidence intervals for the estimates of RR.

(d) Risk factor models

The inclusion of a site descriptor as a predictor variable in the model for a particular data group was based on a combination of χ^2 tests of independence between the accident and random samples, examination of the consistency and reliability of the relative risk plots and investigations of possible correlations with other variables.

The combined effect on risk of the values of the selected predictor varibales for a given pole was expressed as a 'risk factor' (RF), which is simply the product of the individual relative risks. For example, the risk factor associated with a particular combination of site characteristics, given that the subject pole was in the MNI data group, was calculated as

$$RF_{MNI} = \prod_i RR_{MNI}^{V_i}$$

where $RR_{MNI}^{V_i}$ represents the relative risk associated with the predictor variable V_i given membership of the MNI data group. This calculation of risk factor assumes that the variables have independent effects on the probability of a pole accident.

The descriminatory power of the risk factor models, and the assumption of the independence of the individual relative risks, was tested by regarding the calculated risk factor RF as a site attribute and deriving its associated relative risk RR. Ideally, RR and RF should be the same. Alternative models were evaluated on the basis of the range of RRs produced and how closely they matched the RFs.

(e) Prediction of accident numbers

The total relative risk (TRR) for a pole (relating its hazardousness to the average for all poles in the population) was obtained as the product of its risk factor within a data group and the relative risk associated with membership of that group. For example, for a pole in the MNI data group,

$$TRR = RR^{MNI} \times RF_{MNI}$$

From an estimate of the total number of poles in the study area, the mean 'pole-second' accident probability was deduced. Given this, the TRR for a given site, and the number of pole-second trials in a year, the expected annual number of pole accidents at the site can be calculated. This information can then be used in cost-benefit assessments of possible remedial programs.

(f) Non-intersection models

The site variables shown to make a significant contribution to accident occurrence, and include in the risk factor models for the non-intersection data groups, are as follows:

Variable	Data Group	
	MNI	MINI
Maximum horizontal curvature	o	o
Annual average daily traffic	o	
Pendulum skid test on pavement	o	o
Lateral offset of pole	o	o
Undivided road width	o	o
Distance from curve start	o	
Pavement deficiencies	o	
Superelevation at curve	o	
Pole on inside/outside of bend	o	o
Grade		o

These models were highly successful in discriminating between poles at risk: the range of risks identified was of the order of 1000:1; site characteristics associated with only 10 percent of poles in the relevant population were found in 50 percent of the major road accident sites and 65 percent of the minor road sites. In terms of remedial action, the greatest benefit is likely to accrue from treatment of the high risk poles on major roads, because of the relatively small number of such poles and the large number of associated accidents.

(g) Intersection models

There were insufficient data to allow development of a useful predictor model for the intersection of minor roads. The variables incorporated in the models for the remaining data groups are as follows:

Variable	Data Group	
	MJMJ	MJMI
Roadway 1 AADT	o	o
Intersecting road AADT	o	
Intersecting road width		o
Skid test on roadway 1	o	o
Grade of roadway 1	o	o
Roadway 1 divided / undivided	o	o
Intersecting roadway divided / undivided	o	
Lateral offset of pole	o	o
Radial distance of pole from centre of intersection		o
Intersection type	o	o

Compared with the other data groups, the MJMJ model could not make a strong distinction between poles at risk. Given that poles are adjacent to the intersection of major roads, there seems to be little to distinguish between their accident risks. By contrast, the MJMI model was very successful: Site characteristics associated with only 10 percent of MJMI poles were found in 45 percent of the accident cases.

(h) Users' Manual

To aid application of the models in the identification and quantification of high accident probabilities, a Users' Manual has been prepared. Three fully-worked case studies are included, which cover most of the situations encountered in practice.

4.7.3 Accident Severity as a Function of Site Characteristics

Levels of occupant injury and vehicle damage were compared for the three major site categories:

(i) curved road non-intersection sites
(ii) straight road non-intersection sites
(iii) intersection sites

It was found that accidents on curves were slightly more severe than on straight roads because of an increased number of side impacts on curves. The crashes with poles in both non-intersection categories were considerably more severe than those at intersections. Damage to poles and their associated utilities did not vary between site classifications.

4.7.4 The Effect of Vehicle Characteristics on Accident Occurrence

There is a lack of detailed information on the distribution of vehicle characteristics in the population of vehicles on the road. Because of this lack the analysis of the effect of vehicle characteristics on accidents was somewhat limited. To overcome the deficiency, in part, a random survey of vehicles was made, concentrating on the measurement and recording of tyre variables. The distributions of vehicle make, year of manufacture and body style in the random sample were found to be very similar to those in Australian Bureau of Statistics (ABS) figures for all vehicles on register in Victoria, suggesting that the tyre characteristics measured were representative of the general population.

A number of tyre-related variables had a significant effect on accident occurrence:

(i) Tread depth. Particularly on wet roads, relative accident involvement increased dramatically for tread depths less than 3mm. It was found that a vehicle with a tread of only 0.5mm was about 15 times more likely to be involved in an accident than one with 5mm of tread depth. Substantial proportions of the vehicle population are involved: Approximately 30 percent of the accident vehicles had tread depths less than 3mm.

(ii) Deviations of tyre inflation pressures from specification (pressure margin). The effects of under-and over-inflation of tyres was investigated from the point of view of the influence on vehicle handling characteristics known to be important to driver/vehicle performance. The response time of a car to steering inputs is sensitive to the sum of the front and rear tyre cornering stiffnesses; correspondingly a negative average pressure margin for all four wheels (general under-inflation) would be associated with a longer response time, which is known to degrade the vehicle handling quality. The present data show a strong relationship between average pressure margin and accident occurrence, with negative margins being associated with higher risk, and vice versa. Vehicle understeer/oversteer, on the other hand, is sensitive to the difference between the front and rear tyre cornering stiffnesses and, hence, to the front-rear pressure margin (FRPM). A positive FRPM indicates that, compared with the specified balance between front and rear tyre pressures, the front tyres are over-inflated, leading to a reduction in the amount of understeer or possibly the production of oversteer characteristics. The data showed that deviations in FRPM in both directions caused an increase in accident involvement; the effect of reduced understeer being associated with increased hazard for curved sites was particularly strong. Again, a substantial proportion of the accident vehicles had hazardous deviations of tyre pressures from the specified levels.

(iii) Tyre construction. Compared with other tyre factors the effect of tyre construction on accident risk was relatively weak. Radial ply tyres proved marginally 'safer' than cross ply or recapped tyres.

Increasing vehicle mass was found to be associated with an increase in accident involvement (although a decrease in accident severity). This result should be treated with some caution, however, because of some deficiencies in the ABS data used to provide the vehicle population characteristics.

4.7.5 Accident Severity as a Function of Vehicle Characteristics

The only vehicle characteristic analysed which had a significant effect on accident severity was the vehicle mass. Reduced vehicle mass was associated with higher injury levels and slightly less pole and utility damage.

4.7.6 Accident Severity as a Function of Pole Type

All the poles in the present study were effectively rigid. No difference in accident severity, as measured by injuries and vehicle damage, was detected between poles classified by material or function. The level of damage to the pole and its utilities did vary with pole classification, however.

4.7.7 Conclusion

The objective of discriminating between the characteristics of poles at risk has been realized. A range of relative risks of 1000:1 has been detected. For most of the data groups, measurable site characteristics allow the identification of the 10 percent of poles which experience about 50 percent of the accidents. For the data group most likely to provide cost-effective remedial opportunities, only 4 percent of the poles account for 30 percent of the accidents.

The results obtained relating tyre tread depth to wet road accident occurrence are decisive. The relationships obtained between tyre pressure margins and accidents provide substantial evidence of an effect of vehicle handling qualities on accident production.

CHAPTER 5

THE COST OF POLE ACCIDENTS

5.1 INTRODUCTION

The desire to quantify the decision-making process for 'safety' programs has lead to a number of attempts to assign monetary values to loss of life, limb and property. Estimates of the 'cost' of a fatality in these studies have varied by 8000 percent, the differences resulting from the range of philosophies adopted. Some have even argued that there is no measurable economic loss to society resulting from highway deaths (Dyson, 1975).

Apart from their use in cost-benefit analyses, accident cost estimates have served as measures of accident severity for priority ranking of remedial projects. Alternative ranking methods have been proposed, such as the cost to the project agency per fatality or injury saved (cost-effectiveness) (Weaver, Woods and Post, 1975; Glennon, 1974). The latter method avoids the problems associated with determining the cost of accidents, but does not allow comparisons to be made between accident severities. For example, it is not possible to decide whether or not a program which replaces a small number of serious injury accidents with a large number of minor injury or property-damage-only (PDO) accidents should be adopted on the basis of a cost-effectiveness approach.

The attempt to determine the costs to the community of road accidents seems worthwhile, particularly when government-sponsored remedial programs are envisaged. The allocation of limited funds so as to maximize the total community benefit requires some basis for estimating the improvement in general welfare which will flow from expenditure on various improvement programs.

The estimation of the 'societal cost' of road accidents of different levels of severity is fraught with difficulty and requires numerous assumptions and approximations. There are also several schools of thought as to just what components of cost should properly be charged to road accidents. In this chapter the various philosophical approaches are reviewed, and estimates of the societal costs of pole accidents are made based on three representative cost philosophies, and using cost data collected in this study.

Ultimately, the economic strategy for determining priorities and expenditure levels for remedial programs is the choice of the agency disbursing the funds. It is hoped that the information gathered together in this chapter will prove useful in informing this choice. In any case, it will be used in following chapters to investigate the feasibility of alternative engineering treatments to reduce the losses associated with crashes into poles.

5.2 A REVIEW OF PREVIOUS ACCIDENT COST STUDIES

Studies to determine the societal cost of road accidents have been carried out world-wide since the early 1950's. The cost estimates from these studies, particularly in relation to the 'value' of life, vary widely. The estimates have been largely based on a credit-debit type economic analysis of 'direct' cost components such as property damage, medical expenses, lost income, etc. Indirect costs such as pain and suffering, traffic congestion resulting from the accident, losses to others affected by the accident (e.g., relatives visiting hospital) have also been considered by a few authors ; such costs are, however, extremely difficult to estimate. The acceptance of pain and suffering as a valid cost component is increasing, particularly in the courts, where, for example, an award was made recently to a family on the basis of nervous shock resulting from the death of a member of that family in a road accident.

There are two common approaches to assigning accident costs :

(i) Ex-poste
(ii) Ex-ante.

The ex-poste method is one which reviews the cost elements after the event. The ex-ante approach attempts to assess what society is willing to pay for a given reduction in the probability of an accident. The majority of studies have chosen the ex-poste method ; it was also adopted for the present study.

An alternative to these two methods is to infer the value structure of society from court awards. Payments approaching half-a-million dollars for severe handicaps resulting from car accidents have been made. Whether or not society would place a higher value than this on the loss of life is debatable.

Typically, the studies reviewed arrived at overall average costs for the three main accident severity classes ; fatal, personal injury (PI) and property-damage-only (PDO). In a review of the work in this area up to 1966, Mackay (1966), succinctly described the common classification of cost components in two major groups :

(i) direct costs
(ii) indirect costs.

Direct costs include items that come under two headings :

(a) Use of current resources
(b) Loss of future production.

Current resources consumed as a result of an accident include property damage repairs, medical and hospital treatment, legal charges, insurance costs and police costs. Loss of future production occurs in the case of death or permanent disability.

Indirect costs are defined to include the value of pain and suffering (typically estimated from court settlements), and losses in production by others as a result of the accident (traffic congestion, visiting hospitals, home care, etc.). Much the same sort of classification was adopted by Faigin (1976) in her detailed analysis of road accident costs.

The largest source of variability in the overall cost estimates is the calculation of the value of loss of future production. Some authors choose to omit this cost component altogether and consider only current resource costs ; others include it, but deduct estimated average future consumption. The approaches taken to the societal 'value' of non-working women and children are a further source of variability in overall cost estimates.

The approaches adopted in the majority of studies reviewed fall into three broad groups, depending on the cost components included in the analysis :

CRC	:	Current resource costs only
TCNC	:	Total accident costs (direct and indirect) including loss of future production net of consumption
TC	:	Total accident costs (direct and indirect) including loss of future production.

These approaches are discussed in detail in the following sections.

5.2.1 Current Resource Costs Only (CRC)

The title of this group is not strictly correct, in that the majority of studies so classified included the value of wages lost during convalescence, as well as current resource costs associated with property damage, hospital and medical services, legal costs, etc. (Dunman, 1958 ; Dunman, 1960 ; and Smith and Tamburri, 1968 ; Johnston, 1960 ; Twombly, 1960: Billingsley and Jorgenson, 1963). The value of wages lost during convalescence has been seen as distinct from the costs associated with loss of future production resulting from death or permanent disability. For the purposes of the present study, also, the value of wages lost during convalescence is defined as a current resource cost.

The majority of the studies in this group (Smith and Tamburri ; Dunman, 1958 and 1960 ; Billingsley and Jorgensen) also included the value of court awards and settlements in their calculations, adding further to the variance of cost estimates. Such an inclusion possibly implies the acceptance of some value of pain and suffering, which is common in court awards, although none of the authors made a direct reference to it as a cost component.

The current resource costs approach produces the lower bound of the accident cost estimates, with the societal value of a fatality being put, on average, at$20,000 (1977 Australian dollars). It is noted that although the cost components included in the current resource cost group appear straightforward in nature, their derivation typically involved a number of approximations and assumptions.

It is noted further that the majority of the reports mentioned above were based on accident studies carried out in Massachusetts in 1953, Utah in 1955 and Illinois in 1958. Clearly the uniformity of the average costs presented below results from working from similar or identical data bases.

In summary, the majority of studies included the following items :

- (i) Property damage (vehicle, objects struck)
- (ii) Ambulance costs
- (iii) Doctor and dentist fees
- (iv) Hospital and treatment costs
- (v) Miscellaneous injury costs
- (vi) Loss of use of vehicle costs
- (vii) Value of time lost from work (not including loss of future earnings)
- (viii) Legal and court costs
- (ix) Damage awards in excess of known costs.

Table 5.1 compares the average costs by accident severity, noting that the figures are on a per accident basis, rather than per person. Typically the fatality rate per accident was between 1.3 and 1.6 .

Because of the relative antiquity of the data in Table 5.1, the number of exchange rate changes and inflation rate variations that have occurred since 1960, calculations regarding the present day worth of American data in Australian dollars are relatively meaningless. However, to enable an order of magnitude comparison to be made between the costing philosophies, the value of life based on CRC costs was guestimated at $15,000, present day value.

TABLE 5.1

COMPARISON OF AVERAGE ACCIDENT COST ESTIMATES ($)
BY SEVERITY

Source	Year	Data Base (1)	Average Accident Costs (2)		
			Fatal	Injury	PDO
Dunman	1958	Mass, 1953	5212	860	200
	1960	Mass, 1953	5212	860	200
Twombly	1960	Mass, 1953	5400	880	200
Johnston	1960	Mass, 1953	5400	880	200
		Utah, 1955	3560	1280	300
Billingsley and Jorgensen	1963	Ill, 1958	5150	870	120
Smith and Tamburri	1968	Ill, 1958	9000	2200	400

(1) Mass - Massachusetts
Ill - Illinois

(2) Costs as quoted by each report.

5.2.2 Total Accident Costs (Direct and Indirect) Including Loss of Future Production Net of Average Consumption (TCNC)

As well as including current resource cost components, the studies in this group assessed the value of loss of future production in the event of a fatality or permanent disability. Future lost income was calculated from average earnings figures and discounted to a present worth value using a chosen interest rate (typically between 4 - 10%). Average consumption estimates were calculated from Gross National Expenditure figures and subtracted from the future cost income figures to give the 'net societal' capital loss.

One of the earliest reports to adopt this philosophy was a U.K. study by Reynolds (1956). Later studies to follow this general technique were by Dawson (1967), Troy and Butlin (1971) and Paterson (1973).

In general, weighted average figures for fatal, PI and PDO accidents were derived, taking account of the distribution of casualties and wages between the sexes. The reports varied, however, in their calculation of loss of output resulting from the death of a non-working female, and of the value of pain and suffering. Discount rates also varied from study to study.

Dawson (1967), in his calculation of the net loss of output for female fatalities, arrived at a negative figure - implying a societal gain. In this work the income figures of working women were averaged across all women, with a negative net loss of output resulting from the subtraction of average consumption. Dawson argued that as the community would not wish them dead, the 'gain' foregone must be a minimum estimate of the value placed on keeping them alive. In a later publication Dawson (1971) reworked his cost estimates arguing against the deduction of average consumption from foregone earnings.

Little (1968) also deducted consumption estimates from the income figures in his analysis of accident costs. He also introduced the so-called non-economic losses (pain and suffering) associated with death and injury as parameters, and then observed the effect of the parameter values on the outcome of cost-benefit analyses.

Thorpe (1970) used insurance claim information as his data base, and adopted the method of Reynolds (1956) to calculate loss of earnings for male fatalities without dependents. Loss of earnings for female fatalities without dependents was calculated at the rate of 55 percent of the male figures. Thorpe presented only a total accident cost figure for Victoria for 1966-67 ; 'per accident' costs were not supplied.

Troy and Butlin (1971), in their detailed analysis of accident data for Canberra in the period 1 May 1965 to 30 April 1966, constructed a cost file for each case, covering all the accident cost components listed previously. Pain and suffering was included under the heading of 'residual'. This residual was deduced from court awards, by subtracting current resource costs (medical, vehicle, etc.). Data relevant to the calculation of the cost of fatalities was not presented, and apart from stating that personal consumption was subtracted from the foregone future earnings, the detailed method remains unclear.

Troy and Butlin offered two alternatives in the analysis of fatalities of wives and mothers. The first alternative was to use the price of substitute housekeeping services. The second was to take expected earnings of married women from some other professional or business employment that a fatally injured woman would have expected over her foregone working life. Troy and Butlin used either one of these two, or a combination of both, depending on their assessment of each case.

Paterson (1973) generally followed the approach of Troy and Butlin, but differed in the analysis of female fatalities. Paterson's approach to the value of non-working females was to consider an average statistical household which consumes and produces. Production and consumption was averaged across the adult members of the household. Paterson's 'value of life' estimate was consequently lower than that of Troy and Butlin.

While Troy and Butlin took a case-by-case approach to measuring accident costs, Paterson used an average-cost approach to calculate expenditure and income for representative age groups ; then calculating a weighted average cost based on the relative proportions of males and females involved in accidents.

Joksch (1975) also deducted consumption from foregone earnings to calculate the economic loss of a fatality. Pain and suffering values were estimated for injury cases from court awards. A range of $70 to $13,600 is presented by Joksch for the subjective value of the non-economic loss in traffic injuries.

The majority of studies reviewed in this section estimated the total annual cost of road accidents, but did not provide detailed data of the nature sought. However, from Paterson and Troy and Butlin the value of a fatality was estimated at $40,000, present day value.

5.2.3 Total Accident Costs (Direct and Indirect) Including Loss of Future Production (TC)

Societal loss calculations in this group did not adjust the value of lost future production for future consumption. Drake and Kraft (1967) used this approach when they analysed the costs associated with accidents in Washington over a twelve month period. Future cost income was calculated on the basis of age, sex, exployment status and level of disability.

Dawson (1971) made a major change to the method of analysis presented in his 1968 report. In the earlier study the effective loss of output for those killed was calculated by deducting their future consumption from their future production. In 1971, however, Dawson argued that cost estimates are needed in order to measure the benefits of accident prevention. Therefore consumption should not be deducted, as one of the benefits of accident prevention is the fact that the individual is indeed alive and able to enjoy that consumption.

One of the most detailed studies using this approach was by Faigin (1976). A comprehensive analysis of accident cost components for the six levels of the Abbreviated Injury Scale (AIS) was presented. Faigin cautions :

> However, the total of individual cost estimates of accidents should not be interpreted as the value placed on a life or as the total cost of a fatality or injury to society. Neither is it the total amount that society is willing to spend to save a life or to prevent an injury. Rather, the cost components and the total of these components are indicators of the significance of the motor vehicle accident problem.

She employs economic factors as gross estimators of 'societal welfare' - which includes 'levels of health, production of goods and services (both qualitative and quantitative), personal satisfaction and happiness, and physical comfort'.

Average compensations foregone in the market-place were used to estimate non-market production losses (e.g., housewives and children). The derivation of accident costs in the present study was based largely on the work by Faigin. The estimate of the value of life by Faigin was in the vicinity of $230,000.

Flora, Bailey and O'Day (1975) also presented a breakdown of accident costs by AIS levels, although on a comparatively restricted scale.

Several investigations of the cost-effectiveness of automobile safety measures sponsored by the U.S. Government have employed Faigin's cost model, or minor variants. For example, the design specifications for the Ford and Minicars Research Safety Vehicles (Ford Motor Company, 1975 ; Struble et al., 1975 ; Warner, Withers and Petersen, 1975), were worked out using this cost methodology. The National Highway Traffic Safety Administration (NHTSA) used Faigin's model in evaluating the relative benefits of lap belt - air bag and lap-shoulder harness occupant restraint systems (Gates, 1975). For comprehensive discussions of cost-benefit philosophies for safety measures the reader is referred to the Proceedings of The Fourth International Congress on Automobile Safety (NHTSA, 1975).

The National Safety Council (1971-77) also adopted this philosophy in the costing of accidents. Faigin (1975) points out that although the approach may be the same, the resulting fatality cost estimates (of the order of $90,000) indicate that there are significant calculation differences to those which result in fatality estimates of the order of $230,000.

Both Dyson (1975) and Joksch (1975) have submitted that the use of any of the above approaches is erroneous. Rather, they suggest that a study be undertaken of the valuations that people place on their own lives, or more precisely on a reduction in the probability of their death. Joksch described some early work in this area and arrived at a figure of the order of one million dollars per life.

As was stated in the Introduction, the final decision regarding which method to adopt rests with the department or authority contemplating remedial action. The sections which follow present details of the cost data collected during the present study, as well as estimates of total accident costs. These are made using the three costing methods described above, reworked using Australian cost data (where available).

5.3 ACCIDENT COST DATA COLLECTED IN THE PRESENT STUDY

The cost data collected in the present study related to :

(i) Vehicle damage costs and market values
(ii) Pole and utility damage costs
(iii) Hospital and medical costs.

5.3.1 Vehicle Damage Costs

Vehicle damage cost estimates were obtained for each accident case from the repairer or towing firm. The market value of each vehicle was obtained from the Used Car Price Guide ('The Red Book') of National Auto Market Research (1977).

As indicated in Chapter 4, when the cost of repairs exceeded the market value of the vehicle, the damage cost recorded was the market value. Thus, the level of damage required to 'write-off' a vehicle was a function of its market value. However, as the object here is to identify 'societal costs' (not the physical severity of damage), the market value is the relevant cost in the case of a 'write-off'. Figure 5.1 shows the distribution of vehicle damage costs. The overall mean vehicle damage cost per accident is $1,800. The total cost for the accident sample was $1.63 million dollars, with an estimated annual cost of $3.85 million when adjustments are made for the length of the survey (eight months) and the level of accident coverage. (See Section 4.3.4)

5.3.2 Pole and Utility Damage Costs

Individual pole and utility damage costs were not available for the majority of cases studied. Instead, the level of damage to the pole and its utilities was recorded for each case. The value of the damage was then determined from Table 5.2 which was

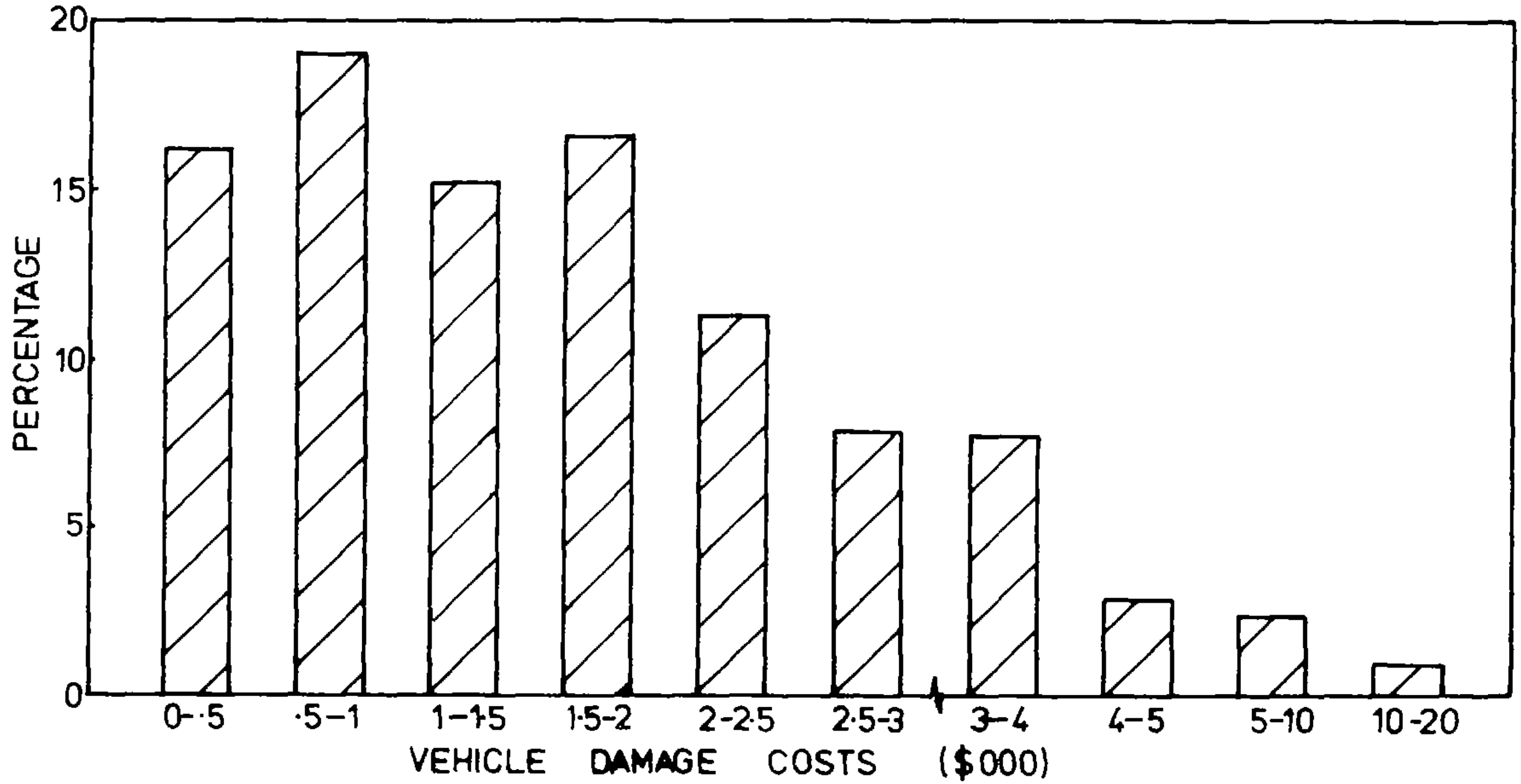


Figure 5.1. Distribution (%) of vehicle damage costs.

Table 5.2

POLE AND UTILITY DAMAGE COSTS ($)

POLE MATERIAL	POLE / UTILITY DAMAGE: I LOW-VOLTAGE CONDUCTOR DAMAGE: POLE HAS MINOR OR NO DAMAGE	I: POLE DEFORMED: NEEDS REPLACEMENT	I: POLE SHEARED	II HIGH-VOLTAGE CONDUCTOR DAMAGE (1): POLE HAS MINOR OR NO DAMAGE	II: POLE DEFORMED: NEEDS REPLACEMENT	II: POLE SHEARED	III LUMINAIRE POLE DAMAGE (2): POLE HAS MINOR OR NO DAMAGE	III: POLE DEFORMED: NEEDS REPLACEMENT	III: POLE SHEARED	TRAFFIC LIGHT DAMAGE: IV CORNER MOUNTED: POLE ONLY NEEDS REPLACEMENT	IV: COMPLETE INSTALL. REPLACEMENT	V GANTRY MOUNTED: POLE ONLY NEEDS REPLACEMENT	V: COMPLETE INSTALL. REPLACEMENT	VI LUMINAIRE DAMAGE (INCREMENTAL COSTS TO THOSE SELECTED IN GROUPS I-V): LAMP ONLY DAMAGED	VI: LUMINAIRE ASSEMBLY REPLACEMENT	TRAFFIC LIGHT DAMAGE WHEN IT IS A SECONDARY UTILITY ON POLE (INCREMENTAL COSTS)	NO UTILITY DAMAGE (5)
WOOD	150	275	450	350	600	900	40	135	135					15	135	425	40
STEEL	150	475	650	350	725	1100	40	(3) 340 / (4) 500	(3) 340 / (4) 500	450	950	800	1250	15	135	425	40
CONCRETE	150	375	550	350	625	1000	40	220	220					15	135	425	40

NOTES: (1) If both LV and HV conductors are damaged, costs for the HV group should be used.

(2) This group refers to costs of pole damage only. Luminaire assembly damage costs (group VI) are added to the costs selected in this group and in groups I, II, IV or V.

(3) Single arm luminaire.

(4) Double arm luminaire.

(5) This cost is incurred if the pole and utilities are inspected, even though there is no damage. It is incorporated in all the other table entries.

constructed from the replies to a questionnaire sent to all of the relevant authorities. The table entries were validated, where possible, against the individual cases for which specific damage costs were available. A number of points regarding Table 5.2 are noted :

(i) All the costs listed include the fixed overhead cost of the initial inspection, whether or not further repairs are necessary.

(ii) The pole sizes were divided into two groups, with low voltage conductor and luminaire poles in one group and high voltage conductor poles in the other. The costs are adjusted accordingly.

(iii) In the case of Telecom service disruption (telephone) \$100 was added to the costs selected in groups I - V. This was because the majority of above-ground Telecom cables are carried by poles not owned by Telecom.

(iv) No case involving damage to a Melbourne Metropolitan Tramways Board steel pole was recorded, (although there were numerous collisions with such poles, of course).

To select the appropriate costs, the primary function of the pole was determined. In the case of a pole which carried two or more utilities, the primary function was selected on the basis of the following order of priority :

(i) Conductors (high voltage having precedence over low voltage)
(ii) Traffic light
(iii) Luminaire.

For example, if a pole carried high and low voltage conductors and a luminaire, and all were damaged, the primary utility selected was the high voltage conductors. In this case, the costs selected in group II would have the costs associated with the luminaire damage (group VI) added to them. In the case of no damage to the pole or its utilities, a fixed 'cover charge' of $40 was assigned to allow for inspection costs. It is also noted that in the case of a luminaire pole, group III in Table 5.2 refers to damage to the pole only, with the incremental costs associated with the luminaire damage being selected from group VI.

The distribution of pole and utility costs in the accident sample is shown in Figure 5.2. As expected, the majority of poles have costs associated with little or no damage. It was seen in Section 4.6 that the level of damage sustained by a pole and its utilities was largely a function of the pole classification. Similarly, the damage costs are a function of the pole classification, as demonstrated by Table 5.3.

TABLE 5.3

MEAN POLE AND UTILITY DAMAGE COSTS ($) PER ACCIDENT BY POLE FUNCTION AND MATERIAL

Pole Function		Mean Damage Costs
(a)	Steel pole	
	Luminaire	280
	Cable-supporting	70
	Traffic lights	450
	Other	40
(b)	Concrete pole	
	Luminaire	220
	Cable-supporting	190
(c)	Timber pole	
	Luminaire	132
	Cable-supporting	134
	Other	40

The overall mean pole and utility damage cost per accident was $180 , the total cost of damage for the eight-month accident sample

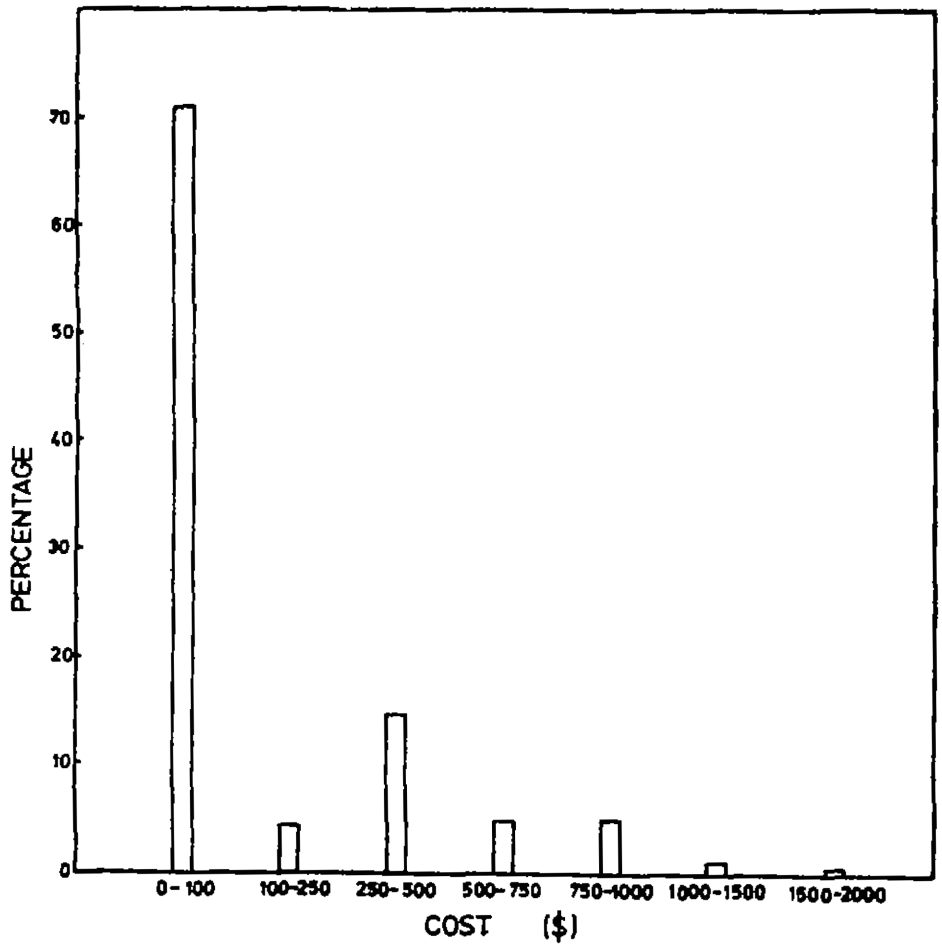


Figure 5.2. Distribution (%) of pole and utility damage costs.

was $155,000 , which is an order of magnitude less than the total cost of vehicle damage. Allowing for sample coverage, etc. the estimated annual cost of damage to poles and utilities is $366,000 .

It can be seen from Table 5.3 that the mean damage costs per accident, in the main, follow the pole replacement rate shown in Table 4.28. Steel cable-supporting poles have a lower mean damage cost than timber cable-supporting poles because of their lower conductor damage and pole replacement rate (Table 4.29). Wooden luminaire poles have a lower mean damage cost than steel luminaires because of the lower incidence of pole replacement for timber poles, and their cheaper replacement costs.

5.3.3 Hospital and Medical Costs

Details of the hospital and medical costs were obtained from the Motor Accidents Board (MAB). The Motor Accidents Board was established in Victoria in 1973 to provide compensation to people injured in road accidents, irrespective of fault. Claims for medical and rehabilitation costs are met, as well as 80% of lost income, to a maximum of $200 per week payable for up to two years. The scheme does not include persons covered by workers' compensation insurance, and loss of income payments are forfeited should a conviction for driving under the influence of alcohol or drugs be recorded.

Because of confidentiality restrictions, costs associated with individual cases were not available. Instead, victims of accidents in this study were grouped according to the location and severity (AIS) of their worst injury. The costs associated with each group were then provided by the MAB (Table 5.4). It can be seen that the data were too sparse for the number of classifications chosen, and it was decided to re-classify the data by severity only, in line with the approach adopted by Faigin (1976). The loss of income figures were also discarded from Table 5.4 because of the very low proportion of cases in which this matter had been resolved, and payments made, at the time the data were obtained. Table 5.5 presents a comparison of the data derived from Table 5.4 and that of Faigin relating to average medical costs by AIS level. Costs are in 1977 Australian dollars.

TABLE 5.4

AVERAGE COSTS ($) BY INJURY ZONE AND SEVERITY

SOURCE : MOTOR ACCIDENT BOARD

Category	Number of Cases	Hospital	Ambulance	Doctor	Total - Less Loss of Income (2)	Number of Loss of Income Payments	Loss of Income Payments (3)
H1 (1)	52	34.70	38.39	51.26	131.79	5	196.63
H2	59	245.72	44.20	71.76	404.14	10	884.93
H3	16	1659.71	43.02	184.80	1889.84	6	947.81
H4	3	3208.64	40.36	594.89	3843.89	1	202.45
H5	2	7275.44	35.42	193.61	7804.47	3	2490.27
H6	9	1633.55	54.48	182.26	1870.24	1	1287.72
T1	21	69.30	36.32	24.72	135.38	4	301.61
T2	10	338.21	41.03	75.70	466.40	2	411.97
T3	17	1236.28	43.78	203.12	1545.68	6	913.34
T4	8	2560.48	44.24	653.97	3326.02	3	3017.67
T5	1	3219.60	50.40	2050.32	6036.23	1	2414.40
T6	11	131.73	48.34	386.62	566.49	1	4825.86
E1	33	37.37	31.52	11.17	75.57	4	622.22
E2	13	471.88	34.65	167.38	680.40	5	636.86
E3	18	1969.20	44.85	358.70	2404.48	8	1621.37
E4	11	2516.51	62.56	530.63	3261.17	5	2061.22

Notes :
(1) H - Head region, T - Torso region, E - Extremities. Numbers refer to the AIS rating of the most severe injury.
(2) Includes pharmacy and other medical costs, but not funeral.
(3) These figures represent the average amount paid per payment, not the average over the total number of cases in each category.

TABLE 5.5

AVERAGE MEDICAL COSTS ($) BY AIS LEVEL

	Doctor		Hospital	
AIS	MAB	Faigin	MAB	Faigin
1	34	61	42	50
2	135	182	293	495
3	252	578	1168	1205
4	584	2376	2626	2475
5	813	6072	5924	6325
6	295	176	807	303

The U.S. costs were adjusted using U.S. consumer price index figures and the monetary exchange rate as at January 1978. While the hospital figures are comparable for the various AIS levels, the higher AIS level doctors' costs are very much greater in the Faigin data. This possibly reflects a different charging structure in the United States. The MAB medical costs are very likely under-estimates of the actual societal costs, as hospital funding is not derived completely from patient charges, and some public ward treatment may have been performed by doctors in an honorary capacity.

Another U.S. study which compiled medical cost data under a similar format was that of Flora, Bailey and O'Day (1975). Their data were limited to AIS levels 1 - 3 and are compared to the relevant MAB and Faigin figures in Table 5.6.

TABLE 5.6

AVERAGE MEDICAL COSTS ($) BY AIS LEVEL

AIS Level	MAB	Flora et al.	Faigin
1	76	101	111
2	428	726	677
3	1420	3826	1783

It appears that the data collected in the present study is at least of the appropriate order of magnitude when compared with the two U.S. studies.

5.4 THE CALCULATION OF OVERALL ACCIDENT COSTS FOR VARYING AIS INJURY SCORES

5.4.1 Introduction

In the review of previous accident cost studies (Section 5.2), three distinct methods or philosophies of costing road accidents emerged. The methods differed in the cost components considered :

(i) Current resource costs only

(ii) Current resource costs, loss of future production, net of future consumption, and indirect accident costs

(iii) The same as (ii) except that the loss of future production component was not net of consumption.

For the purposes of comparison, pole accident costs using each of the three methods above have been estimated. The costs were derived as a function of the AIS injury score, as in Faigin's (1976) work.

Detailed local data which would allow estimates of overall accident costs by injury severity level do not exist. Studies such as those by Troy and Butlin (1971), Paterson (1973) and Thorpe (1970) arrive at estimates of the total annual cost for all accidents, and for a variety of cost components, but provide little detailed information of the type sought. The only study known which contains such detailed costing is Faigin's. For the purposes of establishing order-of-magnitude cost estimates employing the three different groups of cost components listed above, the methodology and data of Faigin were used as the basis of the calculations, with local cost data inserted where possible. It is acknowledged that this application of U.S. data to Australian conditions introduces a degree of uncertainty into the cost estimates. There has also been some debate surrounding some of Faigin's assumptions, (Dyson, 1975 ; Gates, 1975). However, given the desire to make order-of-magnitude comparisons between the three cost philosophies, and the complete lack of detailed local data, such shortcomings are perhaps tolerable.

Since the study by Faigin formed the basis of the cost estimates derived in the present study, readers are referred to her report for detailed discussions of the assumptions and calculations. Only broad outlines of the approach and data are presented here. All costs quoted are in 1977 Australian dollars.

The cost estimates which follow consider only the economic consequences of an accident, and make no attempt to assess the intrinsic value of life or pain and suffering. As such they should provide conservative estimates of the societal costs of pole accidents and how much it is 'worth' spending to reduce them.

5.4.2 Estimation of Current Resource Costs (CRC) by Injury Severity

The items included in the calculations are :

(a) Lost work time (not including loss of future production in the case of permanent disability or death - see Section 5.2.1).

(b) Medical costs.

(c) Legal and court costs.

(d) Insurance administration.

(e) Accident investigation.

(f) Vehicle damage.

(g) Pole and utility damage.

The derivation of the costs associated with each of these items is discussed below, with the results being presented in Table 5.9.

(a) Lost work time

Faigin reported the average number of work days lost for AIS levels 1 - 3. For AIS levels 4 and 5, Faigin calculated loss of future production costs on the basis of percentage disabilities, rather than work days lost during convalescence. It was therefore necessary, for the present purposes, to make some estimate of the work days lost for AIS levels 4 and 5. The estimate was based on the ratio of work days lost to the number of days in hospital. From Faigin's data the ratio was calculated to be approximately equal to 4 for AIS levels 1 to 3. This ratio was applied to the mean-hospital-stay data (from the present survey) for each AIS level to calculate the corresponding work days lost. This was considered to provide a conservative estimate given the increased likelihood of permanent disability, with associated increased rehabilitation and lost work time, for AIS levels 4 and 5 injuries. Australian salary scales obtained from the Australian Bureau of Statistics (ABS) were used to obtain the value of work time lost. No distinction was made on the basis of sex or employment status.

(b) Medical costs

While hospital, medical and ambulance costs were derived from Tables 5.4 and 5.5, rehabilitation costs were taken from Faigin's study, as local data were not available.

(c) Legal and court costs

Costs relating to legal and court services for each AIS level were also taken from Faigin. The weighted average cost per casualty occupant of the legal and court services shown in Table 5.9 ($600) compares favourably with a figure of $550 per casualty occupant estimated from the local data of Troy and Butlin (1971).

(d) Insurance administration

This item was also taken from Faigin. Once again, the overall average cost per casualty occupant is in good agreement with the average cost estimated from Troy and Butlin's data.

(e) Accident investigation

This item refers basically to the cost of police time in recording and investigating the accident. The level of cost was also taken from Faigin. However, given the small amounts involved, and the requirement in Victoria that police be notified of all injury accidents, the cost was set constant for AIS levels 1 to 6.

(f) Vehicle damage

Table 5.7 shows the mean of the vehicle damage costs coded for each level of AIS. It can be seen that despite a general upward trend in the costs with increasing AIS, there is considerable variability in the figures. It is recalled that where the cost of repairs would have exceeded the market value of the vehicle, the damage was assessed as the market value. Thus the level of physical damage to 'write-off' a vehicle depends on its market value. Unless the sample size of each AIS level is sufficiently large, some variability in the mean damage costs would therefore be expected. This is the situation for AIS levels 4, 5 and 6 in particular, where the case numbers are low. To reduce this effect, the cost of the pole impact damage was expressed as a proportion of the market value of the vehicles, as is also shown in Table 5.7. This proportion appears to be a more consistent measure of the extent of vehicle damage. The 'recalculated costs' for each AIS level shown in Table 5.7 were obtained as the product of this proportion with the overall mean vehicle market value ($2,600).

TABLE 5.7

MEAN VEHICLE DAMAGE COSTS ($) BY AIS SCORE

AIS	Cost	Mean Proportion of Market Value	Recalculated Cost
0	1690	0.69	1790
1	1780	0.80	2080
2	2400	0.86	2230
3	2210	0.88	2290
4	1880	0.88	2290
5	1700	0.91	2360
6	2590	0.93	2400

(g) Pole and utility damage

Table 5.8 shows the mean pole and utility damage costs associated with each AIS level. Given the small amount of data for the higher AIS scores, there appears to be little correlation between injury severity and pole damage costs. This result is to be expected from the results of Section 4.6, which showed that pole damage was more strongly related to the pole material and function than to impact severity. Because the mean costs are quite small, and there are insufficient data for the higher AIS levels, the overall mean pole and utility damage cost of $180 was adopted for all AIS levels.

TABLE 5.8

MEAN POLE AND UTILITY DAMAGE COSTS ($) BY AIS SCORE

AIS	Mean Pole and Utility Damage Costs
0	155
1	250
2	220
3	170
4	205
5	40
6	240

Table 5.9 presents the previously discussed estimates of current resource costs resulting from pole accidents, for the various AIS levels. Although the nature of the cost components appear relatively straightforward, their calculation has been seen to involve a number of approximations and estimates. The method seems to grossly understate the relative societal value of a fatality : AIS 3 - 5 injuries have a greater societal cost, based on consumption of current resources only. This result varies from those of other studies which have employed this costing method. In particular, Smith and Tamburri (1968) reported the 'direct' costs associated with three levels of accident severity as follows :

TABLE 5.9

CURRENT RESOURCE COSTS (CRC) FOR POLE ACCIDENTS BY AIS LEVEL ($)

Cost Component	AIS Level 6	5	4	3	2	1	PDO
Lost Work Time	0	4200	2800	1370	740	55	0
Medical							
Hospital	807	5924	2626	1168	293	42	0
Physician	295	813	584	252	135	34	0
Rehabilitation, ambulance etc.	50	4050	2050	45	40	35	0
Legal and Court	2600	2000	1300	900	200	150	10
Insurance Administration	350	350	350	300	250	70	40
Accident Investigation/Follow-up	100	100	100	100	100	100	0
Vehicle Damage	2400	2360	2290	2290	2230	2080	1790
Pole and Utility Damage	180	180	180	180	180	180	180
TOTAL	6872	19977	12280	6245	4168	2746	2020

Fatal	:	\$ 9,000
Injury	:	\$ 2,200
PDO	:	\$ 400 .

Even though these figures are on a per accident basis and are in 1968 U.S. dollars, (the fatal accident cost being roughly equivalent to 15,000 1977 \$ Australian), they are clearly different in terms of relative magnitudes to those presented in Table 5.9. The Smith and Tamburri figures show that a fatal accident has the highest 'direct' societal cost. One cost component included by Smith and Tamburri, which was not considered here, was the cost of court settlements and awards. This item would probably affect the more severe injury and fatal categories, although the current legal position in Australia regarding claims by a driver involved in a single-vehicle accident is doubtful.

5.4.3 Estimation of Total Accident Costs (Direct and Indirect) Including Loss of Future Production Net of Consumption (TCNC), by Injury Severity.

This method of costing includes the cost components used in Section 5.4.2, together with additional components that relate to losses to society (and individuals) as a result of lost production. The additional components are :

(a) Production losses (net of consumption)
- (i) Market
- (ii) Home, community and family

(b) Losses to others (employers, relatives, home care etc.)

(c) Traffic delays.

The resulting accident costs, by AIS level, are presented in Table 5.10. The additional cost components introduced for this grouping are discussed in the following.

TABLE 5.10

TOTAL ACCIDENT COSTS (DIRECT AND INDIRECT) INCLUDING LOSS OF FUTURE PRODUCTION NET OF CONSUMPTION (TCNC) BY AIS LEVEL ($)

	AIS Level						
Cost Component	6	5	4	3	2	1	PDO
Production/Consumption							
Market	84 800	46 640	21 200	780	420	30	0
Home, Family, Community	25 444	14 000	6 360	230	120	10	0
Medical							
Hospital	807	5 924	2 626	1168	293	42	0
Physician	295	813	584	252	135	34	0
Rehabilitation, ambulance	50	4 050	2 050	45	40	35	0
Legal and Court	2 600	2 000	1 300	900	200	150	10
Insurance Administration	350	350	350	300	250	70	40
Accident Investigation/Follow-up	100	100	100	100	100	100	0
Losses to Others	1 400	1 500	700	120	60	10	0
Vehicle Damage	2 400	2 360	2 290	2290	2230	2080	1790
Traffic Delay	100	75	75	200	200	200	200
Pole and Utility Damage	180	180	180	180	180	180	180
TOTAL	118 526	77 992	37 815	6565	4228	2941	2220

based on the percentage disability associated with AIS levels 4 and 5 reported by Faigin. The home, family and community services production losses were estimated as 30 percent of the market production losses for each AIS level, as in Faigin's calculations. Such costs are classified as indirect costs.

(b) Losses to others

The value of 'losses to others' was taken directly from Faigin. The losses refer to the time and money spent by people other than the victims as a result of the accident, such as employer losses (temporary replacement costs), time spent visiting hospitals, home care and time spent in vehicle repair and replacement. This cost element is also classified under indirect costs.

(c) Traffic delay costs

Traffic delay costs are based on estimates of the person-hours lost because of accident-related traffic congestion. Consideration of the average time of day associated with the occurrence of a particular severity level accident is included. Faigin's estimates are based on very crude data, but are adopted for the present study because of the lack of alternative data.

Table 5.10 presents the final estimates for this cost grouping. It can be seen that the societal cost associated with a fatality is now greater than any level of non-fatal injury.

5.4.4 Estimation of Total Accident Costs (Direct and Indirect) Including Loss of Future Production (TC), by Injury Severity

The cost calculations contained in this section are identical to those in the previous section, except that average consumption is not deducted from foregone earnings. The resulting cost estimates, which total to the same order-of-magnitude as those of Faigin, are presented in Table 5.11.

TABLE 5.11

TOTAL ACCIDENT COSTS (DIRECT AND INDIRECT) INCLUDING LOSS OF FUTURE PRODUCTION (TC), BY AIS LEVEL ($)

	AIS Level						
Cost Component	6	5	4	3	2	1	PDO
Production/Consumption							
Market	151 000	83 300	37 900	1370	740	55	0
Home, Family, Community	45 300	24 990	11 370	400	220	15	0
Medical							
Hospital	807	5 924	2 626	1168	293	42	0
Physician	295	813	584	252	135	34	0
Rehabilitation	50	4 050	2 050	45	40	35	0
Legal and Court	2 600	2 000	1 300	900	200	150	10
Insurance Administration	350	350	350	300	250	70	40
Accident Investigation/Follow-up	100	100	100	100	100	100	0
Losses to Others	1 400	1 500	700	120	60	10	0
Vehicle Damage	2 400	2 360	2 290	2290	2230	2080	1790
Traffic Delay	100	75	75	200	200	200	200
Pole and Utility Damage	180	180	180	180	180	180	180
TOTAL	204 582	125 642	59 650	7325	4648	2971	2220

5.4.5 Discussion

Table 5.12 summarizes the accident costs associated with each AIS level using the three different groupings of cost components.

It is reiterated that throughout the foregoing analysis no cost was assigned to the value of pain and suffering experienced as a result of an accident. This item was acknowledged as a valid societal cost component by Faigin but due to the lack of data could not be included.

TABLE 5.12

ACCIDENT COSTS ($) BY AIS LEVEL FOR THE ALTERNATIVE COST COMPONENT GROUPINGS

	Cost Component Grouping		
AIS	CRC	TCNC	TC
0	2 020	2 220	2 220
1	2 746	2 941	2 971
2	4 168	4 228	4 648
3	6 245	6 565	7 325
4	12 280	37 815	59 650
5	19 977	77 992	125 642
6	6 872	118 526	204 582

It can be seen from Table 5.12 that the different approaches result in much the same cost estimates for AIS levels 0 through 3 . Large differences occur, however, for injury scores 4 and higher. Figure 5.3 is a plot of total societal costs by AIS injury level. The graph compares favourably with the results of Struble, Petersen, Wilcox and Friedman (1975) shown in Figure 5.4. Note that the latter results are in 1975 U.S. dollars. The NHSTA data referred to in Figure 5.4 are from a preliminary report by Faigin on the work that has formed the basis of much of the costing carried out in the present study. The Minicars data points were derived by Struble et al., using an approach very similar to Faigin's.

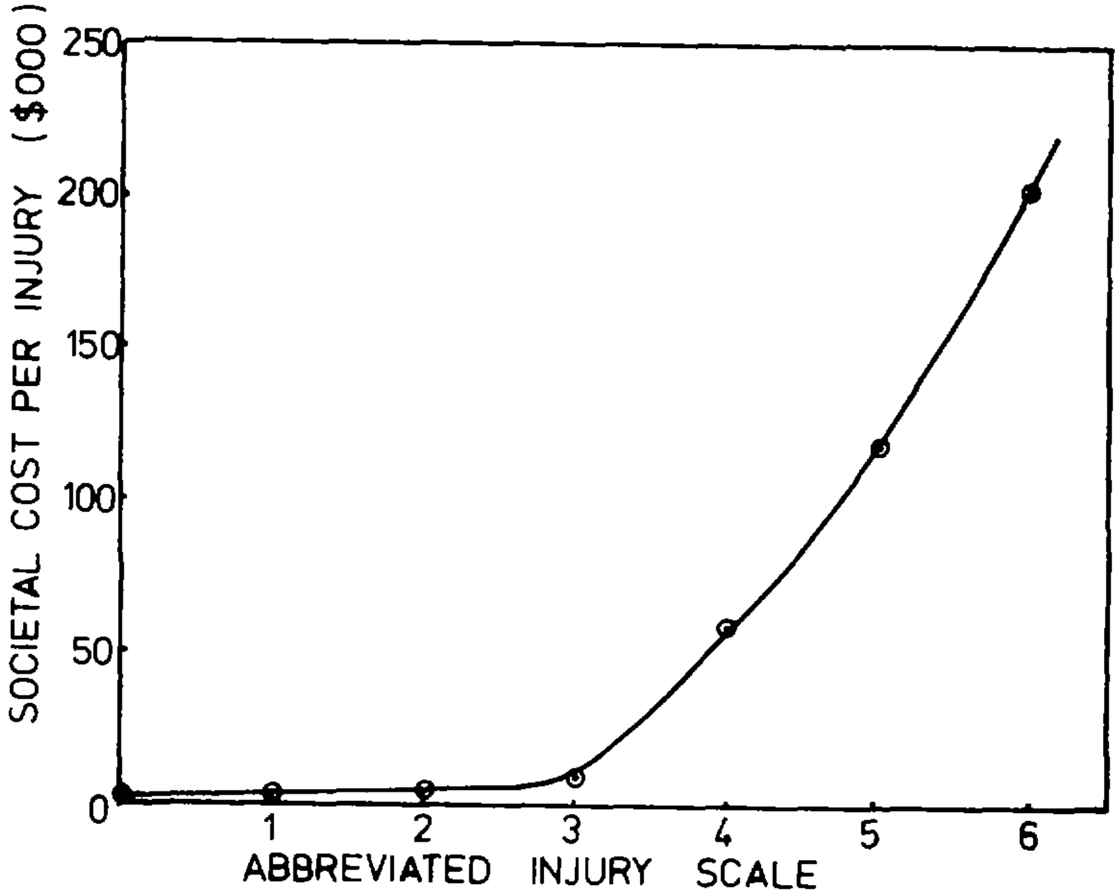


Figure 5.3. Societal cost per injury, based on total accident costs, as a function of injury level.

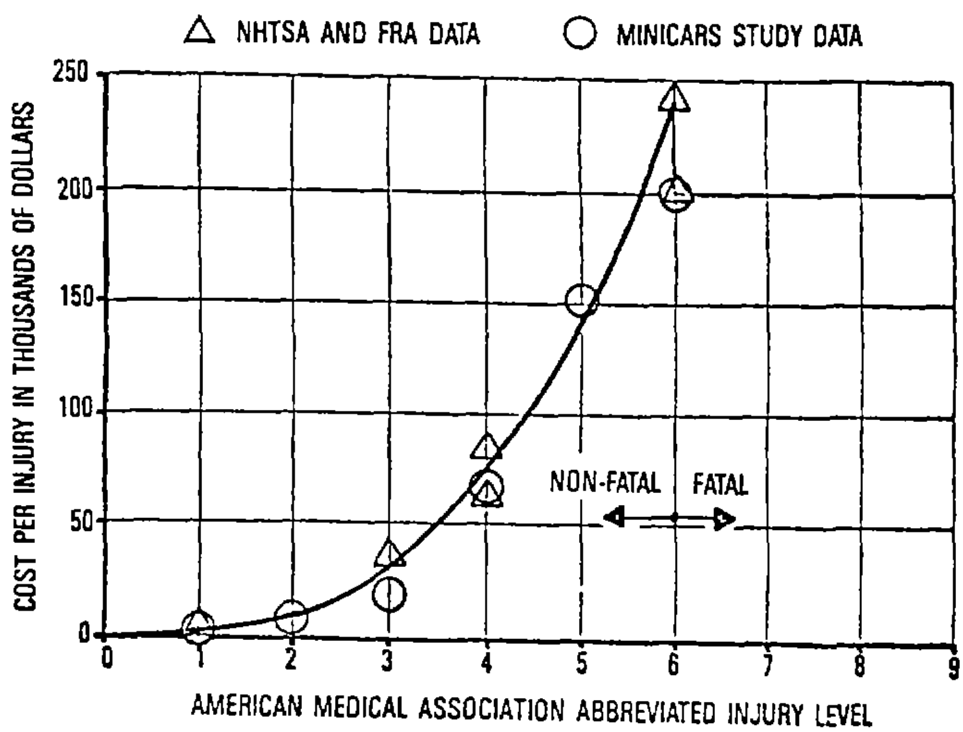


Figure 5.4. Societal cost as a function of injury level (Struble *et al*, 1975).

5.5 TOTAL ACCIDENT COSTS AS A FUNCTION OF THE ACCIDENT CHARACTERISTICS

Societal costs were derived for each individual case in the accident sample, using the estimates in Tables 5.9, 5.10 and 5.11 for the three cost groupings. The total accident cost for each case was calculated as the sum of the costs associated with the injured occupants and the property damage costs. Where the property damage costs were not known mean values were substituted. Thus, in costing an accident using data from Tables 5.9, 5.10 and 5.11, fixed-cost items for the case, such as accident investigation, traffic delay and property damage were subtracted from the total costs for each AIS level, to yield the costs associated with one occupant injury at each level. These occupant-related cost totals were then used to assign costs to each casualty occupant, according to their AIS level. The fixed-cost items were then added to the sum of the injury costs to give a total cost for the accident. This procedure was followed for each of the three cost component groupings resulting in the estimates shown in Table 5.13 .

TABLE 5.13

ESTIMATED ANNUAL COST OF POLE ACCIDENTS FOR THE MELBOURNE METROPOLITAN AREA

Cost Component Grouping	Annual Cost ($ Million)	Average Cost per Accident ($)
Current resource costs	7.0	3 371
Total costs net of consumption	16.9	8 186
Total costs	23.1	11 175

The estimates of the annual cost of pole accidents in the Melbourne metropolitan area shown in Table 5.13 were calculated by scaling up the total cost of the fatal and non-fatal pole accidents by factors of 1.5 and 2.38, respectively. These factors (derived in Section 4.3.4) are required to scale the eight-month study period up to twelve months and incorporate estimates of the survey area coverage and accident reporting rate. The average costs shown in the Table are based on similarly scaled-up accident numbers.

To investigate the effect of accident characteristics on accident costs, Table 5.14 was constructed, showing the mean cost per accident, calculated for each of the following data groups :

CVMA	:	Major road non-intersection case - curved road site
CVMI	:	Minor road non-intersection case - curved road site
STMA	:	Major road non-intersection case - straight road site
STMI	:	Minor road non-intersection case - straight road site
IMAA	:	Intersection of major roads
IMAI	:	Intersection of a major and a minor road
IMII	:	Intersection of minor roads

Here major roads refer to arterial or collector roads (CBR class 6 or 7) and minor roads refer to residential roads (CBR Class 8).

TABLE 5.14

MEAN SOCIETAL COST PER ACCIDENT ($) BY ACCIDENT TYPE FOR THREE COST COMPONENT GROUPINGS

Accident Data Group	Number of Cases	Number of Fatalities	Cost Component Grouping		
			CRC	TCNC	TC
CVMA	197	9	3 907	8 625	13 176
CVMI	58	3	3 095	9 697	13 644
STMA	294	9	3 650	7 812	11 021
STMI	48	4	3 320	10 903	18 786
IMAA	131	3	3 276	7 496	10 674
IMAI	95	3	3 452	8 803	13 138
IMII	56	0	2 266	4 049	4 629

It can be seen from Table 5.14 that the current resource costs are relatively constant across all of the data groups. However, when loss of future production is included, the mean costs per accident become more variable. For the data groups with a small number of cases, the inclusion or non-inclusion of one fatality makes a significant difference to the result. Because of this, little reliance can be placed on the relative costs shown in Table 5.14. However, the intersection of minor roads (IMII) data group has the lowest mean accident cost for all three cost component groupings. There were no fatalities associated with this group.

Because of the uncertainty associated with the results in Table 5.14, the accident sample was reclassified into larger groups, depending on a broad accident description, and neglecting road class. Table 5.15 presents the results.

TABLE 5.15

MEAN SOCIETAL COST PER ACCIDENT ($) BY ACCIDENT DESCRIPTION

	Cost Component Grouping		
Accident Description	CRC	TCNC	TC
Curved road non-intersection	3 723	8 868	13 282
Straight road non-intersection	3 605	8 238	12 090
Intersection	3 149	7 304	10 395

As expected from the injury severity analysis in Section 4.4.1, the curved-road accidents have the highest mean cost per accident, followed by straight road accidents, and lastly intersection accidents. Given the approximations in the accident cost derivations (Section 5.4), and the small differences shown in Table 5.15, it seems reasonable to assign a mean accident cost to curved road and straight road accidents, for the purposes of cost-benefit analysis. The intersection accident costs, however, are significantly lower than the non-intersection costs. This distinction is therefore maintained in the final selection of accident costs presented in Table 5.16.

TABLE 5.16

MEAN SOCIETAL COST PER ACCIDENT ($) ADOPTED FOR COST-BENEFIT ANALYSIS, BY ACCIDENT TYPE

	Cost Component Grouping		
Accident Type	CRC	TCNC	TC
Non-intersection	3 700	8 500	12 500
Intersection	3 100	7 300	10 400

Tables 5.17 and 5.18 show the estimated total annual cost of pole accidents for the Melbourne metropolitan area for each of the three cost component groupings. Table 5.17 presents a breakdown by data group, and Table 5.18 by accident description.

TABLE 5.17

ESTIMATED TOTAL ANNUAL COST ($ MILLION) OF POLE ACCIDENTS FOR THE MELBOURNE METROPOLITAN AREA BY ACCIDENT GROUP

	Cost Component Grouping		
Accident Group	CRC	TCNC	TC
Non-Intersection			
Major roads	4.1	9.5	12.9
Minor roads	0.8	2.6	3.7
Intersection			
Major roads only	1.0	2.3	3.2
Major and minor roads	0.8	2.0	2.7
Minor roads only	0.3	0.5	0.6
TOTAL	7.0	16.9	23.1

TABLE 5.18

ESTIMATED TOTAL ANNUAL COST ($ MILLION) OF POLE ACCIDENTS FOR THE MELBOURNE METROPOLITAN AREA BY ACCIDENT DESCRIPTION

	Cost Component Grouping		
Accident Description	CRC	TCNC	TC
Curved road	2.2	5.4	7.5
Straight road	2.8	6.7	9.2
Intersection	2.0	4.8	6.4
TOTAL	7.0	16.9	23.1

It is evident from these two tables, and the estimates of pole numbers in each category (Section 4.3.2), that cost-effective remedial treatments are most likely to be possible with poles adjacent to major roads, particularly on curves.

5.6 SOCIETAL COSTS BY IMPACT DIRECTION

It was seen in Chapter 3 that oblique and side impacts with poles are generally associated with more severe injuries than frontal or rear pole impacts. Also, frontal impacts occur approximately four times more often than side impacts. As a guide to where vehicle crashworthiness improvements might best be sought, on a cost-benefit basis, total societal costs were calculated as a function of impact direction relative to the vehicle. Three sets of cost figures, corresponding to the three cost component groupings referred to throughout this Chapter, were generated.

Figures 5.5 and 5.6 show costs based on current resource cost components. Note that all total costs in this section refer to the Melbourne metropolitan area. For this cost component group, the mean accident cost (Figure 5.5) hardly varies with impact direction.

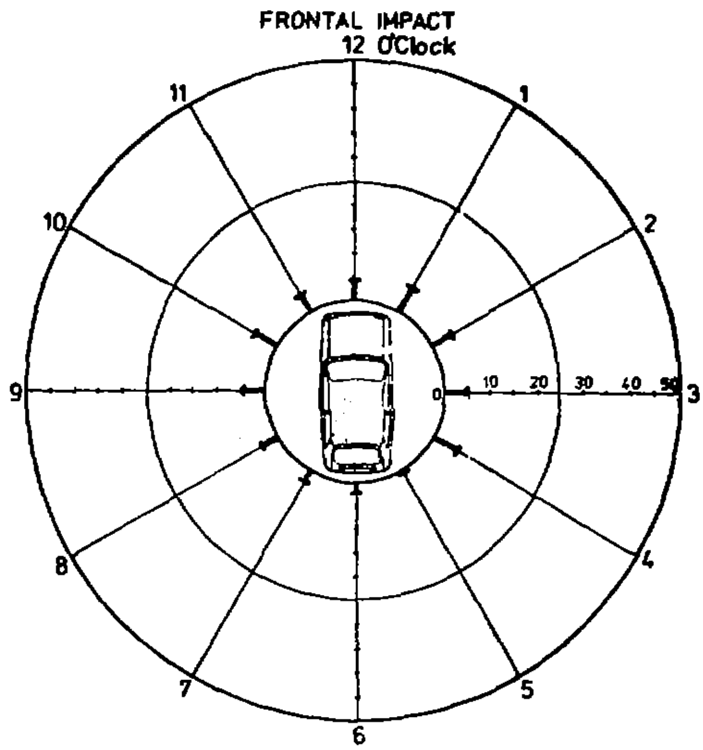


Figure 5.5. Mean cost ($'000) per accident, based on current resource components, by direction of impact.

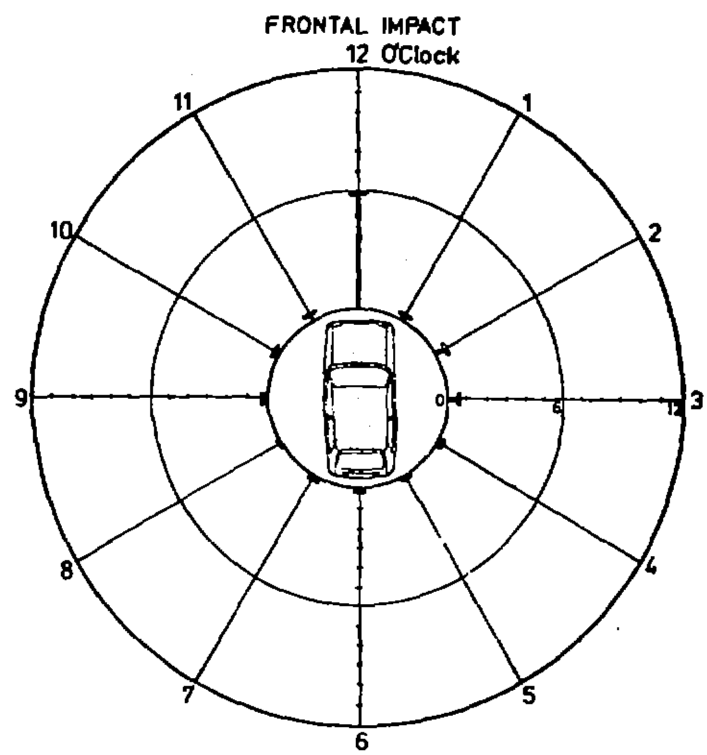


Figure 5.6. Estimated annual cost ($ million), based on current resource cost components by direction of impact.

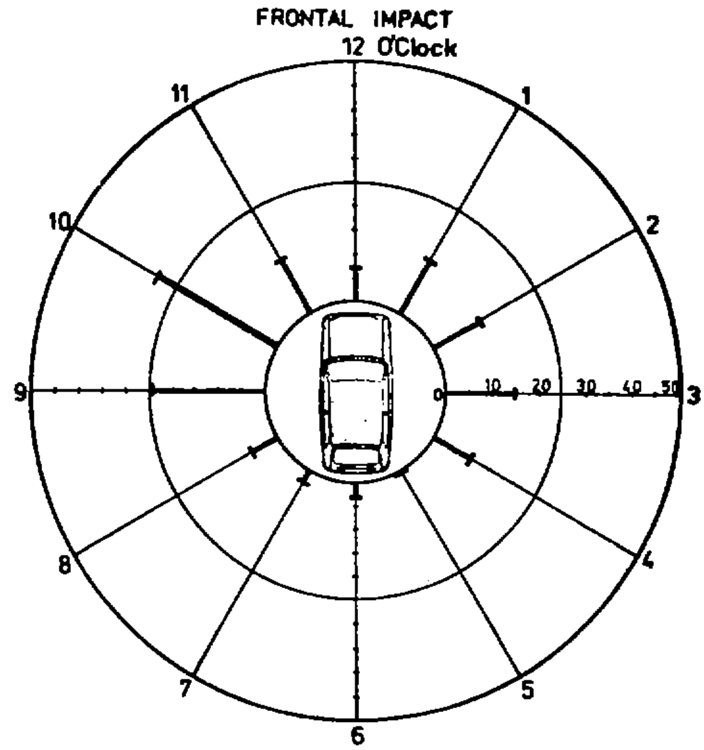


Figure 5.7. Mean cost ($000) per accident, based on total accident cost components net of consumption by impact direction.

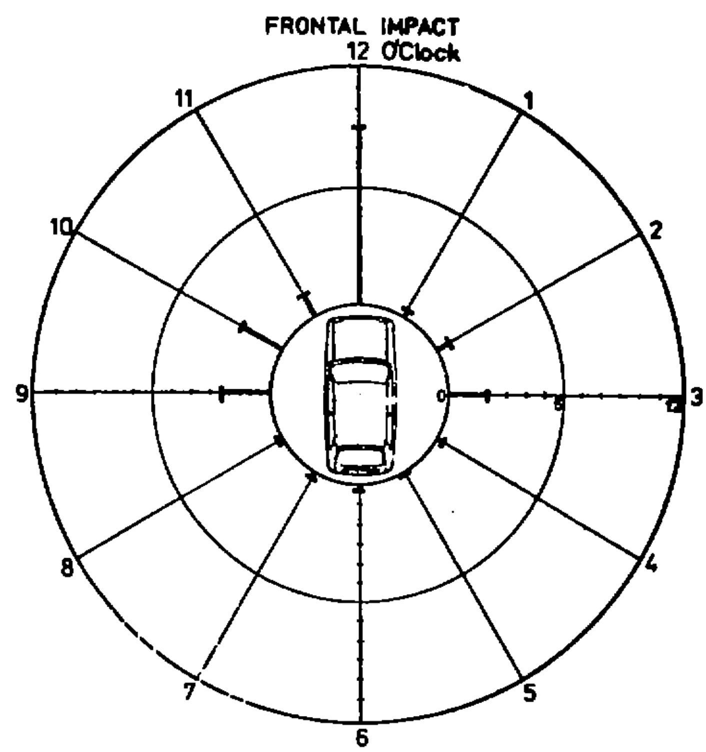


Figure 5.8. Estimated annual cost ($ million), based on total accident cost components net of consumption, by impact direction.

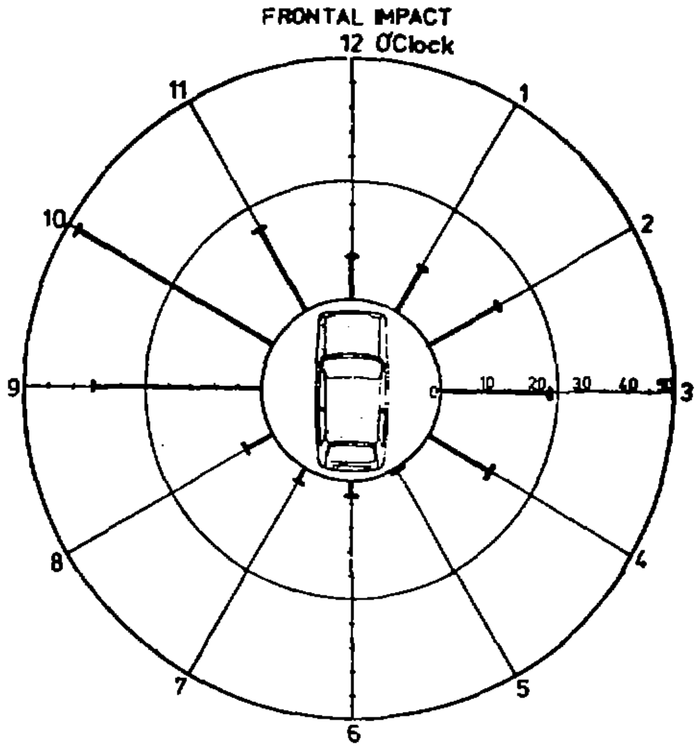


Figure 5.9. Mean cost ($'000) per accident, based on total accident cost components, by impact direction.

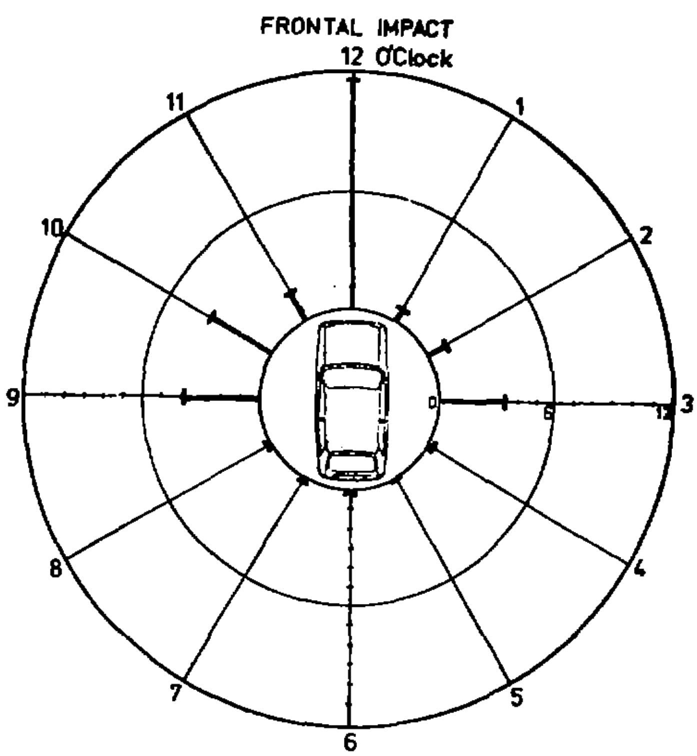


Figure 5.10. Estimated annual cost ($ million), based on total accident cost components, by impact direction.

The value of lost future production is not included in these calculations, so that average injury costs are of the same order of magnitude as property damage costs. Thus, the more severe injuries associated with side impacts are not reflected in the distribution of mean accident costs using this approach. As would be expected, the bulk of the estimated annual costs (Figure 5.6) are associated with frontal impacts.

The second cost component group includes estimates of loss of future production net of consumption, thereby placing more weight on the injury costs relative to property damage costs. Figure 5.7, which shows the mean accident cost by impact direction, is markedly different in form from Figure 5.5. Side and oblique impacts now have higher mean costs than frontal impacts. The distribution of costs by impact direction is very similar to the distribution of injury severity by impact direction shown in Chapter 3. Despite the higher mean accident cost associated with side and oblique impacts, frontal impacts still account for the majority of the estimated annual costs, because of their greater frequency, (Figure 5.8).

As expected the total cost component group results (Figures 5.9 and 5.10) are almost identical in form to those of the previous cost component group. It is apparent that, although significant gains could be achieved by improving frontal impact crashworthiness, side impact crashworthiness improvements are also worthy of further investigation.

5.7 SUMMARY AND CONCLUSIONS

(i) A review of the available literature revealed a wide range of accident cost estimates, particularly with regard to assigning a value to the loss of life.

(ii) Despite much criticism, the costing of road accidents in terms of lost resources and damage costs provides a very useful basis for informing rational decisions regarding the allocation of limited funds to alternative remedial programs.

(iii) The approaches to the costing of road accidents vary according to the particular cost components included in the analysis. Three basic cost component groupings emerged :

CRC : Current resource costs only ; for example, property damage costs, hospital and medical bills, etc.

TCNC : Current resource costs together with the value of lost future production net of consumption, for both the victims and others affected by the accident ; e.g., relatives and employer.

TC : The same as TCNC but without deductions for consumption.

The TC approach has been fairly widely used in the U.S.A. to investigate the cost-effectiveness of safety measures.

(iv) Calculations of societal cost for each level of the Abbreviated Injury Scale were performed for the three cost component groupings, largely based on the work of Faigin (1975). Local data were inserted into Faigin's model for the following items :

(a) Age and sex distribution of road accident casualties.
(b) Wage distribution by age and sex.
(c) Vehicle damage costs.
(d) Pole and utility damage costs.
(e) Hospital and medical costs.

The resultant mean societal cost of a fatality estimated for the three cost component groupings was :

CRC : $ 6 870
TCNC : $ 118 530
TC : $ 204 580

(v) The estimated total societal cost per annum of pole accidents in the Melbourne metropolitan area for the TC grouping (which does not attempt to account for pain and suffering) was \$23.1 million, with an average cost per accident of \$11.175.

(vi) Non-intersection pole accidents have a higher average societal cost than intersection pole accidents. Curved-road sites appear to have a slightly higher average cost than straight-road sites. However, given the approximate nature of the estimates, and the small difference between them, the costs of curved- and straight-road sites have been set equal for cost-benefit analyses. For costing based on the TC group, the average cost per accident was :

(a) Non-intersection \$ 12 500

(b) Intersection \$ 10 400.

(vii) Considering the effect of impact direction on the vehicle on societal costs, it was found that :

(a) Side and oblique impacts have a higher mean cost per accident than frontal impacts if the value of lost production is accounted for.

(b) Because of their greater frequency, the bulk of the societal costs result from frontal impacts. However, there are significant gains to be made from side impact crashworthiness improvements as well.

CHAPTER 6

PERFORMANCE OF ALTERNATIVE LOSS REDUCTION MEASURES

6.1 INTRODUCTION

The term 'loss reduction' is taken here to refer to a lowering of the societal cost of pole accidents, the emphasis being on societal costs rather than costs to specific groups or individuals. The evaluation of remedial programs from the viewpoint of individuals or individual groups will often lead to different conclusions to those reached on the basis of costs to the community at large. (See, for example, Edwards _et_ _al_., 1969)

Figure 6.1 shows a 'loss reduction' measure adopted by a Brisbane local council at a high-risk pole accident site. It consists of the installation of a second pole, the sole function of which is to act as a barrier for the utility pole behind. The barrier pole was rather callously described in the press as an example of the council's cost cutting activity. Undoubtedly, from the point of view of the council, the elimination of pole and utility repair costs at that site is a cost saving. There is arguably even a small net societal gain, assuming that there is no change in vehicle damage or occupant injury levels. However such savings are orders of magnitude less than the societal costs arising from accidents where there are casualties involved. Clearly, to minimize societal costs, alternative solutions should be sought at such an acknowledged 'black spot'. This example also serves to demonstrate the institutional problems involved in promoting remedial programs (e.g., pole removal or modification) when the group bearing the cost of the program, the council in this case, is not the group to directly receive the benefits.

It is a reasonable argument that, if remedial measures are to be instituted to improve total societal welfare, the community as a whole should bear the cost of such measures, through the framework of government and taxation. On the other hand, it may be preferable for society to influence roadway and roadside design

Figure 6.1. Barrier pole installed as a 'loss-reduction' device (Photograph courtesy of the Brisbane Telegraph).

practices towards minimum societal cost solutions through the use of legal processes, such as damage and compensation awards, against authorities employing inappropriate practices. Epstein (1977) has explored some of the legal implications of fixed roadside hazards. It is beyond the scope of this study to comment further on the institutional mechanisms for introducing loss reduction programs. The efforts in this study are directed at identifying the measures that are available, and the net societal benefits which could be expected from their implementation.

Loss reductions can be achieved both through changes in (a) the frequency and (b) the severity of pole accidents. This study is addressed primarily at the engineering aspects of the collision event, thus avoiding the controversy and uncertainty surrounding programs directed at 'non-engineering' aspects such as driver training or alcohol involvement (see Section 1.4). This does not mean that there are no gains to be made in the 'non-engineering' areas. However, the engineering solutions are better defined, in that the costs can be estimated relatively accurately and the benefits can be predicted with some confidence.

The engineering options available can be classified as follows :

(a) Accident attenuation

- (i) Crash barriers/attenuators
- (ii) Alternative pole designs
- (iii) Vehicle crashworthiness.

(b) Accident probability reduction

- (i) Roadside layout
- (ii) Roadway characteristics
- (iii) Vehicle characteristics.

The sections which follow discuss the available technology and the relative loss-reduction merits of these options.

Installation and maintenance costs are not considered here, as these form part of the cost-benefit analysis of Chapter 7. Loss reduction is assessed in the accident attenuation section on a per-collision basis.

6.2 ACCIDENT ATTENUATION

6.2.1 Crash Barriers and Attenuators

Crash barriers (such as guard rail, bridge rail and concrete barriers) are designed to redirect errant vehicles away from road-side hazards, while typically absorbing only a small proportion of the vehicle's kinetic energy. Crash attenuators, on the other hand, function primarily by bringing the errant vehicle to rest. The majority of the collision energy is absorbed by the attenuator and the vehicle deceleration must fall within prescribed limits. Attenuators typically take the form of arrays of steel barrels or containers filled with water or sand. For glancing impacts along the side of the attenuator, barrier performance criteria apply, with the vehicle being redirected rather than arrested.

Crash barriers and attenuators are in fact hazards, in their own right, and their installation is warranted only if the average accident severity associated with them is less than for the road-side hazard, taking account of any differences in collision probability between the protected and unprotected site. The installation of barriers, particularly, increases the probability of an accident occurring, by exposing a larger area to the errant vehicle, and usually closer to the roadway, than the hazard being 'protected'. In fact, the U.S. Department of Transportation recommends the installation of crash barriers and attenuators only at those locations where it is not possible to remove the hazard, (Lawrence and Hatton, 1975).

Troutbeck (1976) has made a detailed review of the specifications and performance of various attenuator and barrier types. A brief survey only will be presented here.

(a) Crash barriers

The three common types of barrier currently in use throughout the world are :

(i) Rigid barriers
(ii) Semi-rigid barriers
(iii) Flexible barriers.

The majority of work on crash barriers has been focussed on highway applications with impact velocities in the region of 100 km/h . Similarly, literature dealing with the warrants for barrier installation has concentrated on highway applications. As has been previously discussed, the predominant road class encountered in the present study was urban arterial and collector roads, which typically involve lower traffic speeds than highways. This suggests that the installation of barriers and attenuators has, in the past, only appeared justifiable on high speed roads, where accident severities would generally be higher.

Rigid barriers are predominantly constructed from concrete and do not deform under impact. Figure 6.2 shows a New Jersey rigid barrier which is typical of most of the in-service rigid barriers. Ideally, the vehicle is redirected by 'riding up' the lower banked section of the barrier, and then back onto the roadway with minimal vehicle damage or deceleration. However, typically the vehicle is redirected by an impact with the barrier, particularly for approach angles of 15° or more. The crash energy is then dissipated mainly by vehicle deformation. Troutbeck and Post et al.(1973) recommended that such barriers should only be installed at locations where there is little probability of the impact angle being greater than 15° . For greater angles the transverse deceleration levels become intolerable. For the urban road system impact angles in the vicinity of 15° are more than likely. On this basis, the installation of rigid barriers is not recommended. A further disadvantage of this type of barrier is its tendency to induce vehicle rollover. Studies which have investigated the performance of this barrier type include Nordlin and Field (1968), Michie and Bronstad (1971), Nordlin et al. (1971c), Post, Hirsch and Nixon (1973).

Semi-rigid barriers, usually referred to as guard rails, are the most commonly installed barrier type. They typically consist

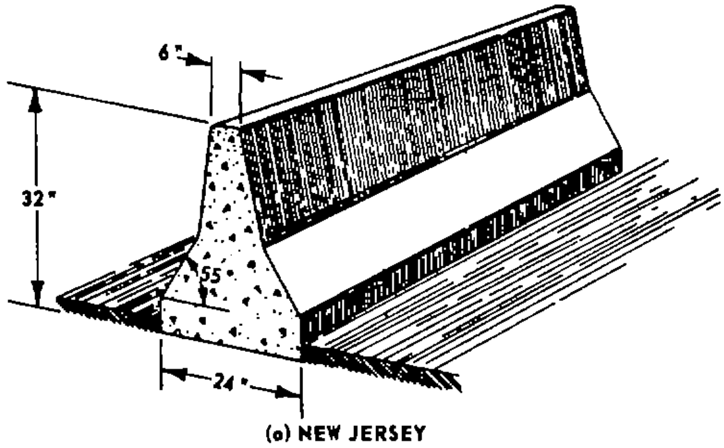


Figure 6.2. New Jersey rigid barrier (Deleys and McHenry 1967).

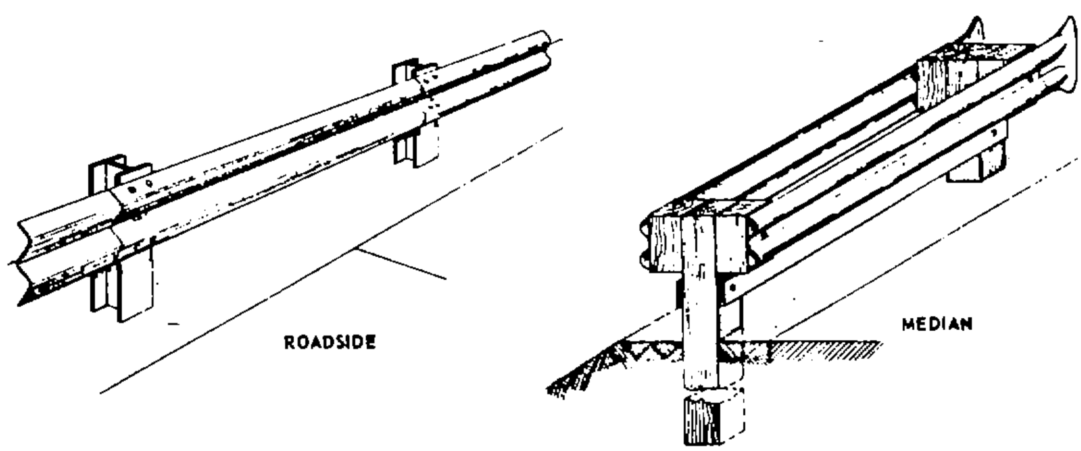


Figure 6.3. W-section semi-rigid barrier (Deleys and McHenry, 1967).

of steel or aluminium beams, of a variety of sections, mounted on timber, concrete or steel posts. On impact, the beam flexes until the supporting posts fail, at which stage the system redirects the vehicle, with the beam behaving like a cable in tension. To function effectively, guard rails must therefore be installed in fairly long lengths and be securely anchored at each end. Figure 6.3 shows W-section beam guard rail in both a roadside (house side) application and a median strip application. The performance and installation warrants for highway applications have been investigated by a number of authors (e.g., Deleys and McHenry, 1967 ; Michie and Calcote, 1968 ; Michie, Calcote and Bronstad, 1971 ; Michie and Bronstad, 1971 ; Michie and Bronstad, 1972 ; Bronstad and Burket, 1971 ; Paar, 1973). As is the case with rigid barriers, collisions with semi-rigid barriers can be quite severe.

In order to establish the relative collision severity of semi-rigid barriers (guard rails), when compared with object types, and in particular utility poles, information was sought from the Traffic Accident Research Unit (TARU) of the Department of Motor Transport, New South Wales. In response, TARU (1978 a) generated the data table contained in Appendix C from their 1977 accident file for New South Wales. The data were restricted to 60 km/h speed limit zones, so that they refer essentially to urban areas. Table 6.1 , derived from the data contained in Appendix C , is for collisions in which only one object was struck. In terms of the casualty figures shown, crashes into guard rail (referred to by TARU as safety fence) are, on average, about half as severe as utility pole collisions. It is noted that the category 'safety fence' in the TARU accident file does include other barrier types apart from guard rail. However, for the majority of cases in the urban area, 'safety fence' refers to guard rail barriers.

The calculation of the average accident costs for each object type in Table 6.1 was based on the cost data presented in Tables 5.9, 5.10 and 5.11, and the relevant single impact data from Appendix C . Since the TARU accident data do not include specific details of injury severity, a mean non-fatal injury cost was determined for each of the three cost groupings (CRC, TCNC and TC), based on the distribution of injury severities in pole accidents

TABLE 6.1

ACCIDENT SEVERITY AND AVERAGE COST BY TYPE

OF OBJECT STRUCK

Object Struck	Percent Casualty Acc.	Casualties per 100 Acc.	Average Accident Cost ($)		
			CRC	TCNC	TC
Pole	54	75.4	4400	9200	13430
Tree	53	73.2	4340	9060	13040
Boulder/Embankment	33	44.7	3430	5430	7120
Bridge/Tunnel	32	42.5	1050	5470	7200
Guide Post	27	27.3	3030	5570	7560
Safety Fence	28	37.4	3650	5060	6240
Boundary Fence	22	23.3	2240	3850	4590
House-Fence/House	20	24.4	3310	4460	5360
Curb/Island/Mound	32	37.8	3250	5360	7080
Sign Post/Traffic Light	30	36.6	3210	5760	7820

Notes :

(1) This table was derived from Tables C.1, 5.9, 5.10 and 5.11.

(2) The average accident costs include the following repair costs :
Utility Pole - $ 180
Safety Fence - $ 450
Boundary Fence - $1000
House Fence/House - $ 500

(3) This table refers to single impacts only and was derived from the TARU data contained in Appendix C.

(4) The three cost categories are described in detail in Section 5.2.

reported in Chapter 3. This assumes that the distribution of injury severities is the same for all object types. The average cost was then calculated, for each object type, by obtaining the sum of (i) the costs associated with the number of fatalities and non-fatal injuries recorded against the object type, and (ii) the fixed accident costs (vehicle damage, legal costs, etc.) associated with the recorded number of casualty accidents, and with the number of property damage only (PDO) accidents. This total cost was then divided by the total number of accidents for the given object type. This procedure further assumes that the fixed costs associated with casualty accidents, and with PDO accidents, are the same for all object types. The results show that for the TC cost group, a guard rail accident has approximately half the average accident cost of a utility pole collision.

It should be noted that, as utility pole collisions tend to result in the highest accident severity, the use in Table 6.1 of a mean non-fatal injury cost based on the distribution of injury severities in pole accident casualties would tend to inflate the average costs associated with 'less dangerous' object types. The use of the PDO costs derived for pole accidents in Chapter 5 would have a similar effect. Thus, the use of Table 6.1 to compare the relative costs of crashes with objects other than poles is likely to underestimate the benefits of pole removal or modification. By way of comparison, Table 6.2 presents the relative collision severity associated with collisions with four common fixed-object types, for a variety of road types.

Because the studies listed in Table 6.2 all used different severity measures (such as the proportion of casualty accidents, casualties per 100 accidents, casualty accidents per 100 accidents, etc.), the results were normalized by dividing the accident severity associated with each object type by that associated with utility poles. This gave the average severity for each object type relative to utility poles. For the studies in which two or more severity measures were reported, there was little difference between the normalized results obtained using the different measures. Table 6.2 clearly indicates that, while guard rail represents a less hazardous obstacle to the errant vehicle than utility poles, the average accident severity remains quite severe.

TABLE 6.2

RELATIVE ACCIDENT SEVERITY BY TYPE
OF FIXED OBJECT STRUCK

	Study					
Object Hit	(a)	(b)	(c)	(d)	(e)	(f)
Utility Pole	1.00	1.00	1.00	1.00	1.00	1.00
Tree	0.98	1.32	1.08	1.09	1.17	0.98
Fence, wall, building	0.41	0.75	0.57	0.88	-	0.37
Guard rail	0.65	0.69	0.73	0.89	0.93	0.52

(a) Good and Joubert (1973) - all road types
(b) Jorgensen (1966) - primary highways
(c) Hunter, Council and Dutt (1977) - all road types
(d) Newcomb and Negri (1971) - all road types
(e) Glennon (1974) - rural and interstate highways
(f) TARU (Table 6.1) - urban roads.

The discussion thus far has considered only the relative collision severities of guard rails and other roadside objects. However the installation of guard rails significantly alters the probability of a collision occurring. For example, consider a site at which there are three poles, spaced at 40 m intervals, which are to be shielded. For guard rail to be effective it would need to be continuous over at least a 90 m length. Typically, on the urban road system, it would need to be installed at the road edge. This means that an errant vehicle leaving the road in this 90 m segment is certain to collide with the barrier. On the other hand, if the barrier were not installed there is approximately a one-in-three chance of a collision with one of the poles. This probability is based on a pole spacing of 40 m , a vehicle width of 1.8 m , and the formula reported by Deleys and McHenry (1967) which relates the maximum angle ψ at which a vehicle can leave the roadway to vehicle speed V, the coefficient of friction between the tyres and road surface μ, and the initial lateral distance y between the vehicle and the obstacle

$$\psi = \cos^{-1}\left[1 - gy(\mu + \phi)\ V^2 \right]$$

where

ϕ = road camber or superelevation

g = acceleration of gravity .

The relationship assumes that the vehicle is initially travelling parallel to the road edge, and then performs a limit turn towards the edge of the road. It therefore defines the minimum probability of a collision. For the present example, the initial velocity was assumed to be 60 km/h , and both wet and dry roads were investigated with $\mu_{wet} = 0.3$ and $\mu_{dry} = 0.8$. The probability of one in three represents the mean value. This means that in about two out of three cases the errant vehicle would not collide with a pole in the section under consideration. At worst, if evasive manoeuvres were unsuccessful, it would go on to collide with an object behind the line of poles, typically a house fence. It can be seen from Table 6.1 that the average collision severity associated with house fences is far less than that for either utility poles or guard rails. It is clear that, despite the reduction in accident severity afforded by semi-rigid barriers relative to utility poles, the increased accident probability resulting from its installation negates the benefits associated with such a reduction. This was also the conclusion reached by Glennon and Tamburri (1967).

Two other points regarding the installation of semi-rigid barriers on urban roads should be noted :

(i) Approximately 1.2 m is required between the guard rail and the obstacle behind to allow for the deformation of the beam on impact (Delibert, 1977). This would involve moving the pole in the majority of hazardous locations : Figure 6.4 shows that 60 percent of the poles on major roads are within 1.2 m of the road edge. Of the poles involved in accidents,

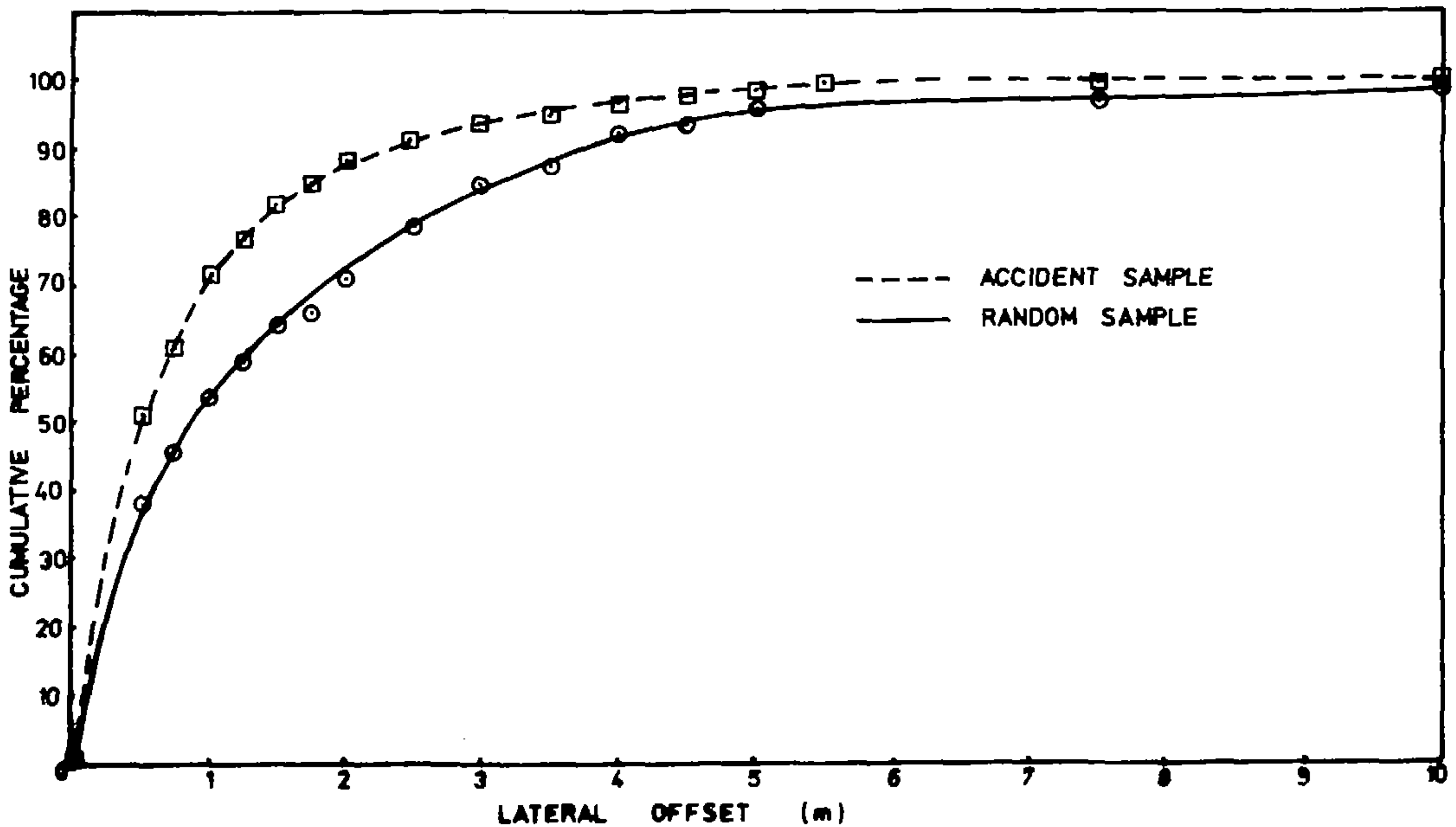


Figure 6.4. Cumulative distribution of pole lateral offset for the random sample of sites on major roads (CBR class 6 or 7).

75 percent are within 1.2 m of the road edge. The latter group is representative of those poles most likely to require some remedial treatment.

(ii) In the urban environment, access requirements to abutting properties would preclude installation of guard rail in sufficient lengths for it to function effectively. Also, the numerous guard rail terminations which would be required (and which are the most lethal part of the installation) would raise the average severity of crashes with the guard rail far beyond that shown in Table 6.1.

Flexible barriers consist of cables attached to steel or wooden posts, and redirect the vehicle by the tensile forces developed in the cable. They can only be used in locations where large barrier deflections can be tolerated, a characteristic that makes them unsuitable for the urban road system. The studies which have investigated the performance of flexible barriers include Basso, Pinkney and McCaffrey (1970), McCaffrey (1972), and Pinkney, Basso and Fraser (1972).

(b) Crash attenuators

Rather than redirecting errant vehicles, crash attenuators are designed primarily for locations in which frontal impacts with the obstacle are most likely. They function by bringing the errant vehicle to rest in a less violent manner than would the obstacle. The impact energy is largely dissipated by plastic deformation of the attenuator. Performance specifications, typically based on a 60 mph (26.8 m/s) head-on impact velocity, require that the vehicle be brought to rest such that its average deceleration, calculated from the impact velocity and stopping distance, is limited to 12 g. For oblique impacts, the attenuator is required to function like a barrier, with the vehicle being redirected (Michie and Bronstad, 1971).

The design of crash attenuators has varied from an array of steel barriers or sand- or water-filled containers, to dragnets and vermiculite concrete cells, Figures 6.5 - 6.8 show four attenuator types in service in the United States. Extensive development and testing of crash attenuators has been carried out in the U.S. for highway applications (Hirsch and Ivey, 1969 ; Hayes, Hirsch and Ivey, 1970 ; Ivey, Buth and Hirsch, 1970 ; Tamanini and Viner, 1970 ; Hayes, Ivey and Hirsch, 1971 ; Nordlin, Woodstrom and Doty, 1971a and 1971b ; Tamanini, 1971 ; Jain and Kudzia, 1973 ; Viner and Tamanini, 1973 ; Lawrence and Hatton, 1975).

Early in-service experience of attenuators, located primarily in freeway off-ramp gore areas, has indicated their effectiveness in reducing accident severity : The proportion of accidents resulting in casualties is approximately 20 percent (Fitzgerald, 1973 ; Jain and Kudzia, 1973 ; Kruger, 1973 ; Viner and Tamanini, 1973). This figure compares favourably with those in Table 6.1.

Attenuators range in length from 2 m to 8 m , depending on the design impact velocity and the attenuator characteristics. It can be seen from Figures 6.5 - 6.8 that they are designed to be struck from one direction only. Snagging of the vehicle is likely to occur if the attenuator is impacted from the opposite direction to that intended. This aspect of their design, eliminates them from consideration for use on two-way roads.

Typically, attenuators are between 2 m and 3 m wide at the base. In the majority of cases, therefore, the pole would have to be relocated to accommodate the attenuator. If relocation well away from the road edge is possible, this could well be an adequate solution in itself, and no attenuator would be required.

As with crash barriers, the installation of attenuators increases the probability of a collision occurring, while still presenting a hazard to errant vehicles.

It appears from the foregoing review that the installation of crash barriers or attenuators adjacent to poles in the urban road system is unlikely to be effective in terms of societal loss reduction.

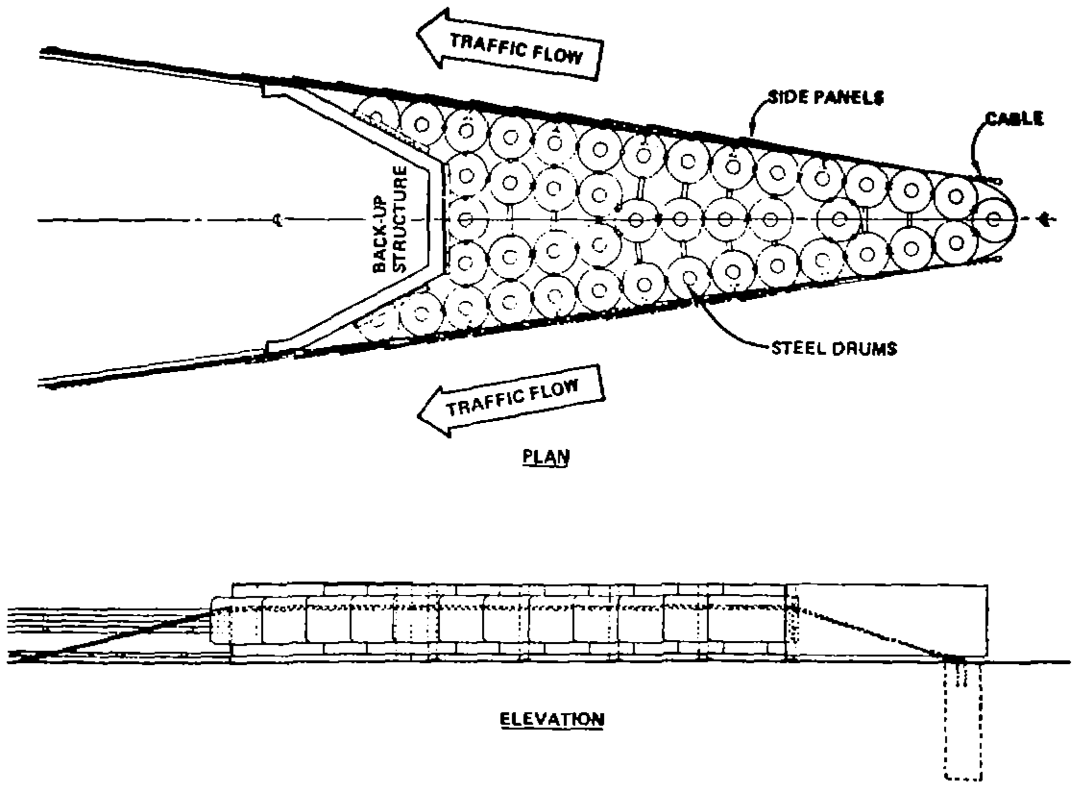


Figure 6.5. Typical steel drum crash attenuator (Lawrence and Hatton, 1975).

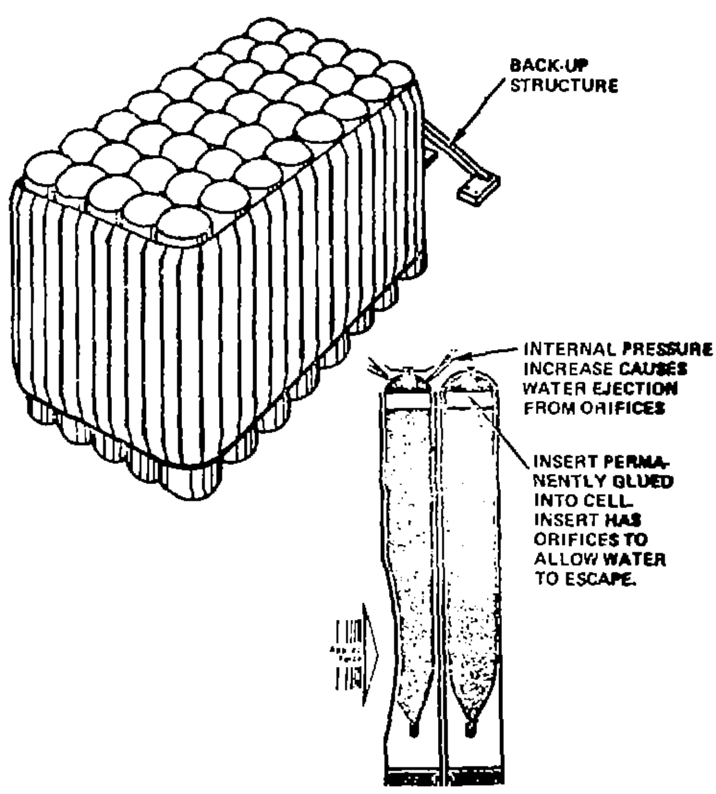


Figure 6.6. Hi-Dro (water-filled) cell cluster crash attenuator (Lawrence and Hatton, 1975).

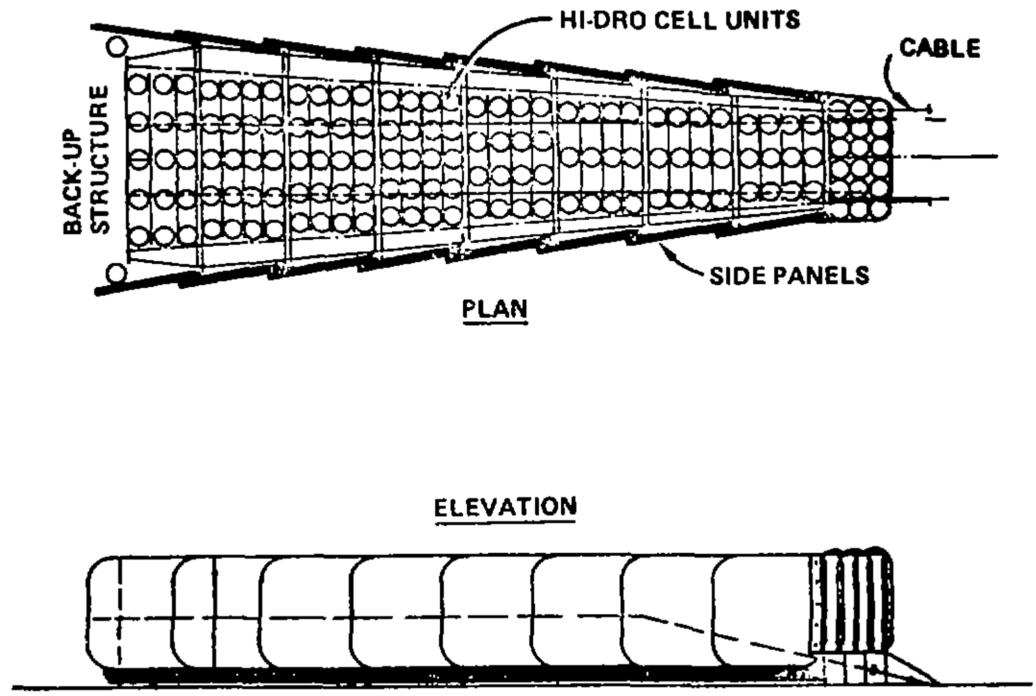


Figure 6.7. Hi-Dro (water-filled) cell sandwich crash attenuator (Lawrence and Hatton, 1975).

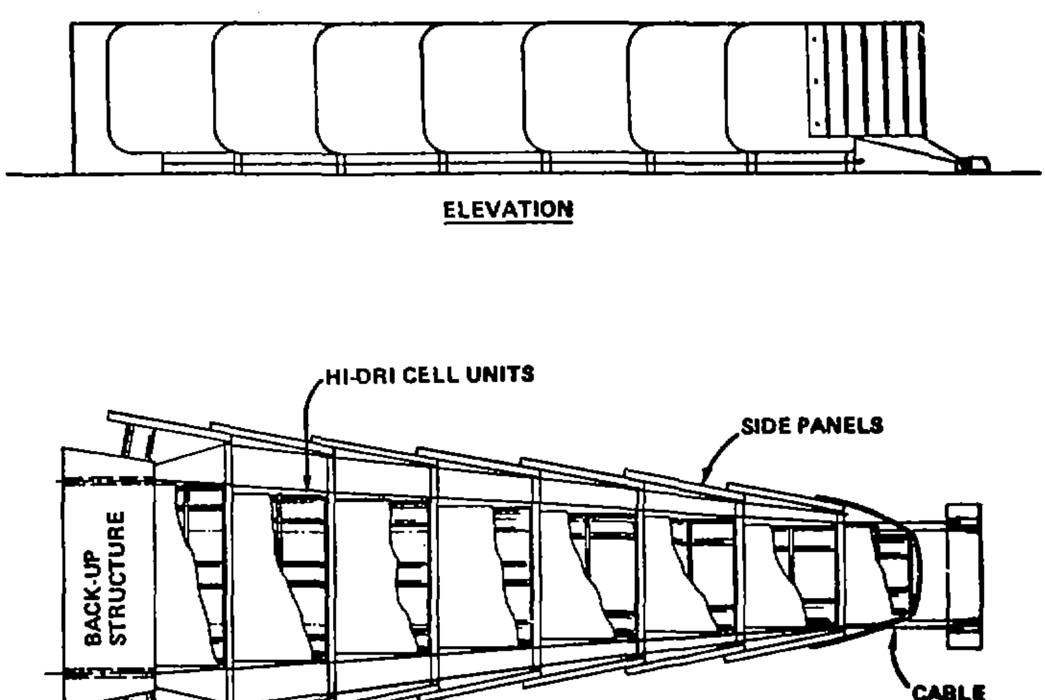


Figure 6.8. Vermiculite concrete cell sandwich crash attenuator (Lawrence and Hatton, 1975).

6.2.2 Alternative Pole Designs

The reduction of pole accident severity through the use of poles that collapse or break away on impact has been the subject of extensive research and development. Such poles present a lower shear strength zone to the errant vehicle while satisfying the in-service bending, shear and compressive strength requirements. Work in this area has concentrated on luminaire and sign supports, although some preliminary investigations for cable-supporting poles have been made.

(a) Luminaire poles

The initial research into collapsible luminaire poles (lighting columns) was carried out in the late 1950s and early 1960s at the Road Research Laboratory in England. This work led to the development and patenting of the Cambridge slip-base shown in Figure 6.9. The shaft of the pole is attached to the foundation stub by clamping bolts placed in four V-slots. The bolts are held in place by a thin steel sheet and tab washers on the flanges. The shear strength of the base is determined by the clamping force between the two plates and the nature of the plate surfaces. Consistent performance of the slip base depends on the preparation of the surfaces and the degree of tightening of the bolts. On impact the pole slides across the fixed flange, tearing the retaining sheet and pushing the bolts out of the slots. The electrical wiring is disconnected by means of a plug that pulls out as the pole separates from the fixed stub base.

Highnett (1967) reports the results of a test in which a 2400 lb (1090 kg) vehicle impacted a 40 ft (12.2 m) lighting column fitted with a Cambridge slip base at 62 mph (100 km/h). Figure 6.10 shows the resultant vehicle deceleration trace and the final resting position of the pole. The impact resulted in a maximum vehicle deceleration of 4.8 g and a velocity change of 2 mph (3.2 km/h). Vehicle damage was slight and it is highly unlikely that any occupant injury would have resulted from such a collision. For this high-speed collision, the pole fell to the ground along the path of the vehicle, with the arm of the support coming to

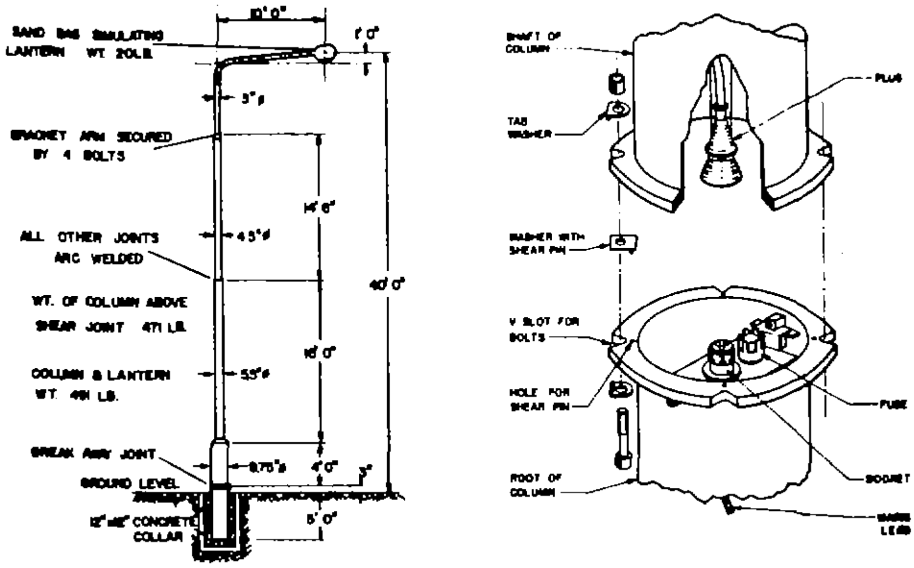


Figure 6.9. Cambridge slip-base (Highnett, 1967).

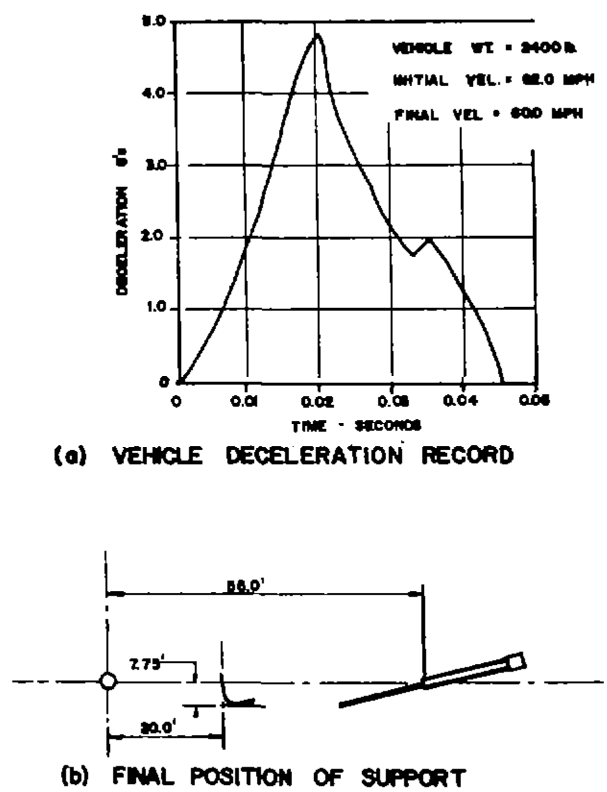


Figure 6.10. Results of a test on a Cambridge slip base.

rest 20 feet (6.1 m) from the base. This suggests that, for the lower speed urban environment and given an initial offset from the kerb of the order of 1.5 m, and approach angles of about 15°, a struck pole would finally encroach only slightly on the roadway if at all (Edwards et al., (1969) in their detailed testing program of break-away poles present plots of roadway encroachment against impact velocity).

A side-impact test into a 40 feet (12.2 m) break-away lighting column was also conducted (Highnett, 1969), with an impact velocity of 47 mph (76 km/h) and using a 2400 lb (1089 kg) vehicle. The column behaved in much the same way as in the frontal test, with peak decelerations of 13 g transversely and 3.8 g longitudinally being recorded.

Development of the slip-base concept was taken up by the Texas Transportation Institute (Rowan and Edwards, 1968 ; Edwards et al. 1969) and by the California Division of Highways (Nordlin, Ames and Field, 1968). As well as developing and evaluating a new slip-base design (Figure 6.11), a series of tests was also conducted on frangible bases. Frangible bases involve the failure of a component at the pole base, usually in the form of an aluminium transformer housing. Readers are referred to Edwards et al., and Nordlin, Ames and Field for detailed descriptions of the bases tested and the results. It suffices to say that the slip-base design was found to offer the least impact resistance for both low and high speed tests. The majority of the frangible base designs exhibited comparable impact performance to the slip-base for high speed impacts. However, for impact velocities less than 20 mph (32 km/h), their impact resistance increased sharply, with a correspondingly increased deceleration level and probability of a secondary collision of the separated pole with the vehicle roof. It is the superior low-speed performance of the slip-base design that makes it more suitable for the urban arterial road system.

A combination of an aluminium luminaire pole and an aluminium break-away coupling has been found to give excellent high and low speed impact performance in terms of both vehicle and pole

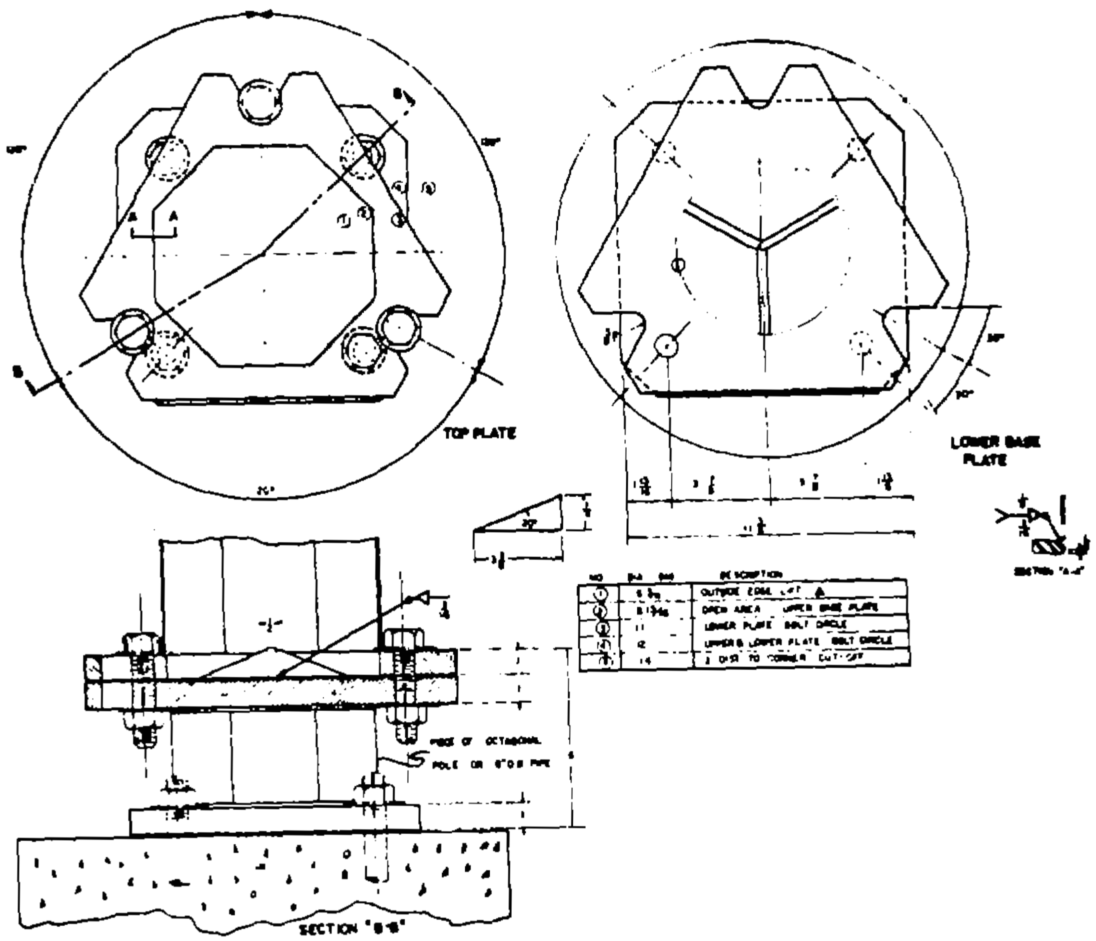


Figure 6.11. Texas triangular slip-base coupling
(Johnson amd Messer, 1970).

damage (Aluminium Company of America, 1977). The coupling consists of four longitudinally-grooved aluminium cylinders placed between the base of the pole and the concrete pad, forming a 'four-legged' stand. These cylinders fail in shear on impact, yet are quite strong in tension and compression to withstand in-service wind-loads.

Other studies which have investigated the performance of frangible and slip-base luminaire poles include those by Chisholm and Viner (1973), Walton, Hirsch and Rowan (1973), Prodoehl, Dusel, and Stoker (1976) and Owings, Adair and Rudd (1976).

The final choice of the type of pole and break-away coupling must be made by the installing authority on the basis of installation costs, performance criteria and availability. In terms of impact severity, the slip-base and the aluminium break-away coupling are equivalent.

The South Australian Highways Department has adopted the policy of installing slip-base luminaire poles in the road system under its control (Highways Department, South Australia, 1977). Table 6.3 details the accident history of tubular steel luminaire poles under its jurisdiction, for a variety of base configurations, in the period August 1969 to March 1977. The 'buried base' pole has its lower 1.7 m buried in the ground. The 'rigid base' consists of a square steel plate set in a concrete footing, to which the pole is attached by means of a matching steel plate and four bolts. The 'slip-base' footing employs a three-bolt configuration similar to the Texas slip-base. The condition of the pole after the collision is noted in Table 6.3 : 'no salvage' refers to the complete scrapping of the pole ; 'some salvage' means that the damaged sections are replaced on-site and the pole re-erected ; 're-erected' implies minor damage only, such as dents which can be repaired on-site. Table 6.3 shows that none of the buried base poles could be re-erected, compared with 7 percent of rigid base poles and 40 percent of slip-base poles.

The repair costs shown were those incurred by the Highways Department. They include labour, material and machinery costs

TABLE 6.3

COLLISIONS WITH TUBULAR STEEL LIGHTING COLUMNS IN THE PERIOD

AUGUST 1969 TO MARCH 1977 AS RECORDED BY THE SOUTH AUSTRALIAN HIGHWAYS DEPARTMENT

Base Type	Condition of the Pole	Number of Accidents	Total Repair Cost ($)	Average Repair Cost ($)
Buried	No salvage	11	3591	326
	Some salvage	0	0	0
	Re-erect	0	0	0
Sub-total		11	3591	326
Rigid	No salvage	23	6099	265
	Some salvage	4	414	103
	Re-erect	2	120	60
Sub-total		29	6633	229
Slip-base	No salvage	68	18105	266
	Some salvage	12	2488	207
	Re-erect	54	4833	90
Sub-total		134	25426	190

and the cost of seeking restitution from vehicle drivers. The Table indicates that the slip-base configuration has the lowest average repair cost of the three base types installed. If the reported rate of recovery of costs from drivers is taken into account (50% for buried and rigid base poles and 14% for slip-base poles), the average repair cost to the Highways Department for the three base types is as follows :

buried base	-	$ 163
rigid base	-	$ 115
slip base	-	$ 163 .

In terms of occupant injury, over the period covered by Table 6.3 rigid base pole collisions resulted in one fatality and seven personal injuries, buried base pole collisions resulted in one personal injury, and slip-base pole collisions produced three minor injuries. Walker (1974) reports similar in-service experience for Cambridge slip-base poles, with three slight injuries resulting from 32 collisions.

From a detailed analysis of the crash performance of various pole types, and typical U.S. cost data, Edwards et al., (1969) concluded that :

> ...if only those costs which the highway department generally assumes (i.e., initial and maintenance costs) are considered, the rigidly mounted steel pole is the best choice. On the other hand, if accident costs are included in the total cost this configuration is the worst choice. When accident costs are considered, the slip-base used in conjunction with the steel or aluminium pole appears to be the optimum configuration. Note that for a small percentage increase in "direct" costs (highway department costs) a much larger percentage decrease in "direct plus indirect" costs (includes accident costs) is realized.

It is clear that the installation of slip-base luminaire poles dramatically reduces the societal cost of pole collisions in terms of pole repair costs, vehicle repair costs (the majority of vehicles drive away) and occupant injuries.

An objection sometimes raised against the installation of slip-base or breakaway poles is the possibility of the falling pole causing a second collision or injuring a pedestrian. However, no such occurrence has been reported by either the South Australian Highways Department or Walker. It was noted earlier that the chances of a vehicle colliding with a pole when it leaves the roadway in the urban area are of the order of 1 in 3. Thus, in the majority of cases, errant vehicles leaving the roadway to the left will strike objects other than a pole - typically a house fence. Poles, therefore, cannot be regarded as providing reliable 'protection' for pedestrians. Accident statistics relating to pedestrian casualties (Australian Bureau of Statistics, 1978) reveal that of the 211 pedestrian fatalities in Victoria during 1977, only one involved a pedestrian not on the carriageway. Similarly, of the 2055 pedestrians injured, only 47 were not on the carriageway. By way of comparison primary pole accidents in Victoria annually account for 55 fatalities and 810 injured persons. These figures show clearly that the level of societal loss associated with off-carriageway pedestrian casualties is minor compared with that associated with pole accidents. If the problem of pedestrian death and injury resulting from vehicles leaving the roadway was of sufficient magnitude to warrant remedial action, installing rigid poles as barriers would hardly be the solution. It is noted further that the data reported in Chapter 3 show that pole accidents are most likely to occur at times of the day (and under the weather conditions) when pedestrian traffic is lightest.

Secondary collisions between following or oncoming vehicles and the fallen pole can also be discounted as a significant hazard. Field tests have shown that for typical impact angles (15° to the curb) the trajectory of the sheared pole is such that encroachment on the roadway is likely to be slight (Edwards et al., 1969). Walton, Hirsch and Rowan (1973) have shown that even if a vehicle does encounter a fallen luminaire pole, no loss of vehicle control occurs, and the resultant vehicle damage is slight or non-existant. As with the alleged danger to pedestrians, the distribution of pole accidents, with time of day and associated traffic volumes, make secondary collisions unlikely : the data of Figure 3.7 show that over half (53%) of all pole accidents occur during times which account for only 21% of total daily traffic.

Highnett and Walker (1971) investigated the possibility of employing a cable to support a sheared slip-base pole between adjacent poles on narrow medians. The tests were only partially successful in that for a 4 m wide median, some encroachment of the traffic lanes occurred.

A further question that is raised in relation to breakaway poles concerns the post-impact trajectory of the vehicle. In the majority of cases in the accident sample of this study in which the vehicle ran off to the left (house-side), the vehicle would have struck a house-fence had the pole not been there (assuming that control of the vehicle would not have been regained). Thus, if a second object were to be struck by the vehicle after colliding with a breakaway pole, for house-side encroachments it would most likely be a house-fence. It was seen in Table 6.1 that boundary and house-fences result in the least severe of all roadside object collisions : In terms of casualty percentages they are 3 times less severe than pole accidents.

For breakaway poles located in a median, the question of a secondary collision involving an on-coming vehicle is raised. As previously remarked, the majority of vehicles that leave the road do not strike poles. It is unlikely therefore that the installation of breakaway poles would markedly alter the number of cross-median, head-on collisions on urban divided roads. It is again noted that pole accidents are most likely to occur at times when traffic volumes are lowest, further decreasing the probability that vehicles colliding with breakaway median poles would substantially increase the number of cross-median, head-on collisions. As an indication of the current level of such crashes, the cross-median, head-on crash rate, for the Sydney metropolitan area in 1977, represented only one percent of road accident fatalities, 0.2 percent of personal injuries and 0.07 percent of all casualty and tow-away accidents. By way of comparison, the pole accident rate for the same period and area was 8.1 percent of fatalities, 6.7 percent of personal injuries and 4.4 percent of all accidents (TARU, 1978 b).

Many of the questions concerning the in-service performance of slip-base and other breakaway pole types should be answered by the results of a study currently being conducted for the U.S. Department of Transportation under Contract No. DOT-HS-5-01266.

A Swedish company has developed an alternative to the breakaway luminaire poles which reduces the probability of a secondary collision. Called the ESV lighting column, it wraps around the vehicle on impact, rather than shearing, bringing the vehicle gradually to rest. The column consists of steel rods spot-welded to a thin sheet steel skin. While able to withstand design wind loads, on impact the spot welds fail and the rods and skin act as independent, weaker structures which deform as the vehicle is brought to rest. Impact velocities of 35 - 75 km/h resulted in average vehicle deceleration levels of 5 g , with peak decelerations ranging from 7 g to 13 g . (ESV - Konsultab, 1978 ; Doulton Insulators Australia, 1978). Figure 6.12 shows the results of a 76 km/h impact with an ESV pole. Peak deceleration was 12 g , with an average deceleration of 4 g over a stopping distance of 5.3 m .

Compared with breakaway lighting columns the ESV column has the advantage of trapping the errant vehicle and reducing the probability of a secondary collision. However, this means that the column is destroyed by each collision, whereas for the breakaway type a pole retrieval rate of 40 percent has been observed (Table 6.3). The two pole types (ESV and slip-base) are of comparable price : $500 for an installed, 10 m single-arm pole. Although the vehicle damage is possibly more severe with an ESV column collision (occupant injury is unlikely to occur with either pole), the potential for damage from secondary collisions following house-side breakaway pole impacts may compensate for this. The ESV pole brings a vehicle travelling at 75 km/h to rest in less than 5 m . Thus, for an impact angle of 15° , neither the vehicle nor the pole are likely to strike the house-fence, or encroach greatly into adjacent running lanes. It is noted that the performance of the column in trapping the vehicle for offset frontal collisions and side or oblique collisions has not been reported. More than 3500 ESV columns have been installed throughout 50 lighting systems in Sweden and Norway in urban areas as well as on highways and

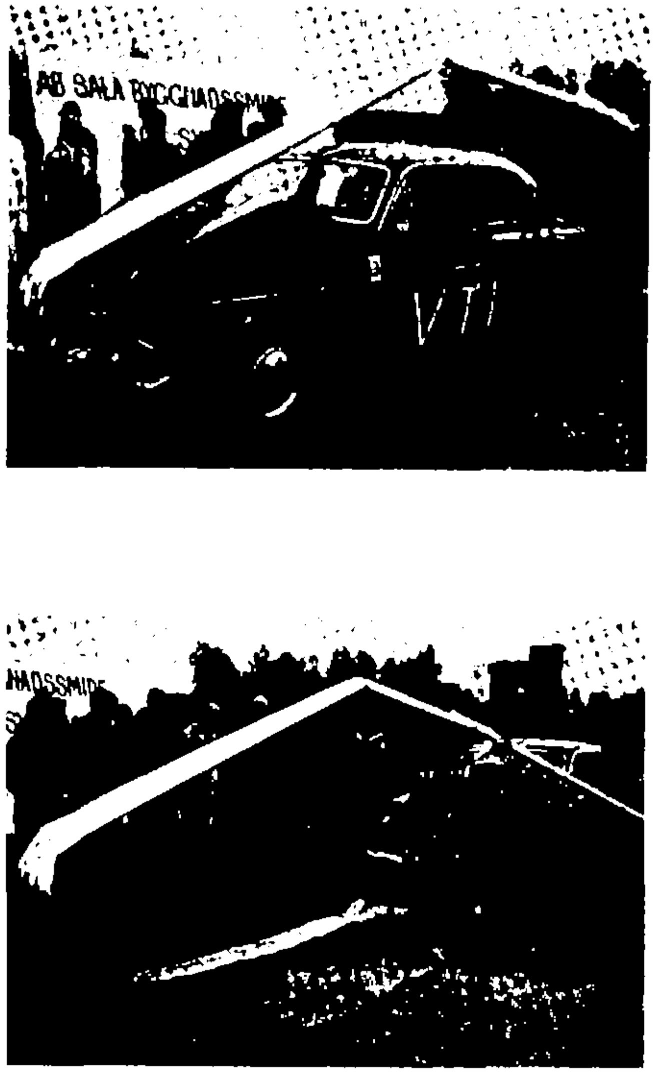


Figure 6.12. Results of a 76 km/h impact test with a ESV lighting column (ESV-Konsultab, 1978).

super-highways.

Luminaire poles constructed from fibreglass are also in service in various countries around the world, and give comparable performance in terms of accident severity reduction to the other breakaway poles. Out of 563 fibreglass luminaire poles installed in New Zealand, 40 were destroyed by vehicle impacts without injury in the period 1970-74 (McLeod, 1974). Although the capital cost of fibreglass poles is comparable with other pole types, a disadvantage of these columns is that completely new poles usually have to be installed after a collision.

From this review of the available technology for safer luminaire poles it is apparent that there are a number of breakaway or frangible pole designs with the potential for substantial societal loss reduction.

The choice between the various concepts becomes a policy decision. The breakaway poles offer the lowest cost to the pole owners, although in terms of societal cost the consequences of the secondary collision for house-side installations suggest that the ESV 'wrap around' pole may be desirable. For median poles, the slip-base pole is preferable both on the basis of societal cost and cost to the authority. Table 6.4 summarises these results. Although this Table incorporates a number of assumptions and estimates, it clearly demonstrates the societal gains that could be made, with little additional cost to the authority which owns the poles. It is noted that luminaire pole collisions in the accident sample were fairly evenly divided between house-side and median locations.

(b) Cable-supporting poles

While breakaway pole designs are well established for luminaire and sign supports, this is not the case for cable-supporting poles. The objection to breakaway cable-supporting poles (hereafter referred to as utility poles) has been the danger of bringing down 'live' conductors. It was seen in Chapters 3 and 4 that the majority of urban cable-supporting poles are timber. This discussion therefore concentrated on timber poles.

TABLE 6.4

COSTS ASSOCIATED WITH LUMINAIRE POLE COLLISIONS ($)
BY TYPE OF POLE

Pole Type	Societal Cost per Collision (1) House-side	Societal Cost per Collision (1) Median	Cost to the Authority per Collision
Slip-base steel (2)	5700 (3)	340 (4)	190
ESV (5)	2000	2000	500
Rigid base steel (6)	10500	10500	280
Rigid base timber (6)	13100	13100	130

(1) Based on the Total Cost component group described in Chapter 5.

(2) Includes $150 vehicle damage costs.

(3) Assumes that a secondary collision with a house-fence occurs. Costs are based on Table 6.1

(4) Assumes that a secondary collision with oncoming traffic does not occur.

(5) Includes $1500 vehicle damage and assumes that the vehicle is successfully trapped.

(6) Costs are based on the injury severity distribution and pole damage costs by pole type reported in Chapters 4 and 5.

Blamey (1962) carried out one of the first controlled experiments comparing the impact performance of timber poles with sheet steel poles for use as luminaire supports. Predictably, he recommended the use of sheet steel poles.

Wolfe, Bronstad, Michie and Wong (1974) were the first to propose modifying existing timber utility poles in such a way that, on impact, the centre section of the pole 'pops' out, leaving only the top section of the pole and the cross-arms suspended by the conductor cables. The modifications consist of drilling holes through the pole, in much the same way that timber sign supports are now commonly modified. For utility poles, two sets of holes are drilled, one near ground level and the other just below the cross-arms. The amount of pole material which can be removed through drilling is dictated by the in-service strength requirements. The modifications are possible because :

(i) The shear strength in the impact zone can be markedly reduced without a proportional reduction in ability to withstand in-service bending loads, and

(ii) poles are oversize with respect to their strength requirements, not so much for their above-ground performance, but to increase the service life of the below-ground portion of the pole.

Wolfe et al., conducted a series of pendulum tests which demonstrated the feasibility of the concept. A further series of pendulum tests has been carried out at Southwest Research Institute in the U.S.A., using several alternative pole modification techniques (Chisholm, 1978). At the time of writing, however, no results have been published.

The preliminary scale model tests using Australian pole timbers and dimensions, reported by Fox et al (1978), demonstrate that this breakaway concept is feasible for Australian conditions. The results are very preliminary, and considerable development and testing are required before a practical design solution is achieved. However, for the purposes of illustration it will be assumed here that such a solution will be found, and an attempt is made to predict accident costs for modified poles.

The accident attenuation afforded by such modifications, as estimated from the scale model tests of 75 km/h impacts, was such as to decrease the proportion of casualty accidents from 90 percent to 54 percent. The accident statistics for New South Wales presented in Table 6.1 , however, show a casualty accident rate of 54 percent for unmodified pole collisions*. This implies that

* The TARU data for pole crashes are used, rather than those from the present study, for consistency in severity estimates with other fixed object types.

impact velocities are typically less than 75 km/h . To obtain a comparable estimate of the in-service performance of modified poles, it was decided, therefore, to scale the modified pole casualty accident rate down by the factor 54 ÷ 90 to 32 percent. The scale model tests also indicated that the probability of a fatality arising from a collision with a modified pole was extremely small. In estimating collision costs, therefore, the average non-fatal collision cost used in the construction of Table 6.1 was applied to this (estimated) casualty accident rate. Adding the PDO accident costs results in the following estimates of the cost of a collision with a modified utility pole for the three cost component groupings described in Chapter 5 :

CRC	-	\$ 3330
TCNC	-	\$ 4860
TC	-	\$ 6170

The predicted velocity change in a 75 km/h impact with a modified utility pole is of the order of 25 km/h . A secondary impact with a house-fence (utility poles are typically in house-side locations) will therefore be less severe than primary house-fence impacts. It is unlikely that very much more vehicle damage or occupant injury than has already resulted from the pole impact will occur in the house-fence collision. (For breakaway luminaire poles on the other hand, impact with the pole results in very little vehicle velocity change, which means that a secondary impact involving a house-fence will be of equivalent severity to a primary impact.)

To allow for secondary collision costs, an additional \$2000 was added to the primary impact costs to compensate for house-fence damage, additional vehicle damage and occupant injury, and for the re-erection of the pole. The final cost estimates for collisions with modified timber utility poles are :

CRC	-	\$ 5330
TCNC	-	\$ 6860
TC	-	\$ 8170

When these cost estimates are compared with those for rigid poles in Table 6.4, it can be seen that, even given the uncertainty associated with the cost estimates, the breakaway utility pole has the potential for significant societal gains.

(c) Traffic light poles

Although traffic light poles are typically amongst the smallest poles installed, their average impact severity remains severe (Chapter 4). No published information on the feasibility or development of breakaway or wrap-around traffic light poles was found. Although the electrical circuitry associated with traffic lights is more complex than for luminaires, there appears to be no technical reason why such poles could not be made breakaway or wrap-around. The previous arguments refuting supposed increased hazards due to secondary collisions with breakaway poles apply to these poles also, despite the fact that they are most frequently located at intersections. It was seen in Chapter 4 that it is difficult to discriminate between the accident risks of poles at major road intersections. It may be that this factor would economically rule out pole modifications, rather than reasons of technical feasibility. However it suffices to say that the breakaway or wrap-around technology has not yet been applied to these poles. Remedial programs related to traffic lights are otherwise restricted to a reduction in pole numbers and/or relocation.

6.2.3 Vehicle Crashworthiness

Most research on vehicle crashworthiness has been concerned with vehicle-to-vehicle collisions. However, the original Experimental Safety Vehicle (ESV) specifications included a number of requirements for pole collision crashworthiness (Slechter, 1971). These were that the vehicle should be able to withstand a 50 mph (80 km/h) frontal pole impact and a 15 mph (24 km/h) side impact without exceeding the vehicle frame deceleration limits shown in Figure 6.13, or an occupant space intrusion limit of 3 inches (7.6 cm). All of the ESV program participants encountered extreme difficulty in achieving the pole impact performance requirements while meeting the target vehicle mass of 4000 lb (1816 kg).

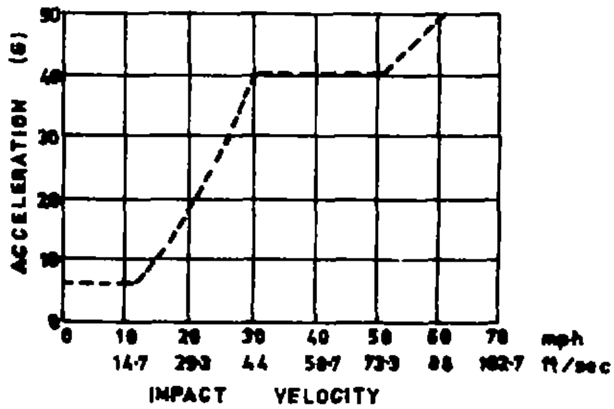


Figure 6.13 Maximum permissible acceleration versus pole impact velocity for Experimental Safety Vehicles (Slechter , 1971).

The occupant space intrusion limit was particularly difficult to meet for such a concentrated impact, although some were able to satisfy the deceleration limits. The strong relationship between occupant space intrusion and occupant injury in pole crashes was clearly brought out in the results of Chapter 3.

The specified impact velocity for ESV frontal impacts was reduced to 30 mph (48 km/h) in 1973, although at the same time the target vehicle mass was reduced to 3000 lb (1362 kg) (Scott, 1973). By 1974 the emphasis had changed from stringent crashworthiness requirements (at the cost of increased vehicle weight, material usage and running costs) to determining what crashworthiness specifications could be justified in terms of societal costs in the context of smaller vehicles and the need for conservation of materials and fuel. The ESV program participants concluded that the only way to solve the pole impact problem within these modified guidelines was to treat the roadside rather than the vehicle (Rodger, 1972 ; Esposito, 1974). In a study of vehicle side impact performance, Hartemann et al., (1976) also concluded that it was prohibitively difficult to protect against fixed objects and that a re-arrangement of the roadside was more likely to be beneficial. In terms of societal gain, Warner (1976) recommends the removal of roadside trees and poles, rather than the installation of crash attenuator devices. This conclusion was based, in part, on predicted improvements in vehicle crashworthiness.

Despite the ESV experience, Miller, Ryder and Shoemaker (1974) have reported good results from crashworthiness modifications to standard sub-compact cars. For a 57 mph (92 km/h) frontal impact with a modified vehicle they found little occupant space intrusion and a deceleration level near 40 g's throughout much of the crash event. By contrast, an unmodified vehicle underwent generally higher deceleration levels and severe occupant space distortion.

In summary, it appears that currently achievable crashworthiness improvements are unlikely to prevent severe injury or death in pole collisions, particularly for side impacts. It is possible that frontal crashworthiness improvements may become available in the future with only a small increase in vehicle mass. However, it would seem that the greatest potential for loss reduction lies in the area of roadside modifications.

6.3 ACCIDENT PROBABILITY REDUCTION

The probability of a pole accident can be reduced by modifying the roadside layout in such a way that pole numbers are reduced or offsets are increased. Reductions can also be achieved through modifications to the roadway, particularly in relation to horizontal curvature and pavement skid resistance. The accident-avoidance capabilities of vehicles could also be improved. The sections which follow analyse the benefits associated with both roadway and roadside modifications. Brief mention is also made of the difficulties currently associated with vehicle-related remedial programs.

6.3.1 Roadside layout

Modification of the roadside layout to reduce the probability of pole accidents requires relocation or removal of poles. It was seen in Chapter 4 that the distance between the pole and the road edge (lateral offset) is a strong discriminator of accident risk for all pole accident types and road classes. (Figures 4.14, 4.31, 4.37, 4.44). All of these Figures demonstrate a 'levelling-off' of accident risk (probability) for higher lateral offsets. For example, for major-road, non-intersection sites (Figure 4.14), there is little additional reduction in risk for lateral offsets greater than 3 m.

Assume, for the moment, that a particular pole experiences (on average) one collision per year. Then the loss reduction associated with relocating the pole (by increasing its lateral offset) is determined by the following steps :

(1) Calculate the factor by which the accident probability is reduced by dividing the relative risk associated with the current lateral offset by that associated with the proposed lateral offset. For example, the relocation of a major-road, non-intersection pole from the road

edge to a lateral offset of 3.5 m reduces the accident probability by a factor of 0.3 (Figure 4.14).

(2) Multiply the expected annual accident rate (1.0 in this case) by the probability reduction factor (0.3) and the average MNI accident cost ($12500 for the TC cost component group - Section 5.5) to give the expected societal cost per annum of the relocated pole ($3750).

(3) Subtract the expected societal cost per annum of the relocated pole ($3750) from that for the original location ($12500) to give the net societal gain per annum of the site damage ($8750).

This calculation utilizes the finding that average accident severity is not related to lateral offset (Section 4.4.1), for the example chosen the calculation indicates that there may be significant gains to be made by relocating the pole, once the cost of relocation is accounted for.

The obvious way to reduce the number of pole accidents is to reduce the number of poles. Although this is not always possible for luminaire and traffic light poles, cable-supporting poles may certainly be eliminated by under-grounding the conductors. Pole removal, of course, means that an errant vehicle may strike another object if vehicle control is not regained in the now pole-free zone. The majority of cable-supporting poles installed are house-side poles. For 70 percent of sites in the accident sample a house-fence was the next object in the vehicle path after the pole. However, the greater lateral offset of the fence compared with the pole results in a much lower collision probability. Taken together with the reduced average accident severity for fence collisions, this shows that pole removal would result in a sizeable reduction in societal accident costs.

For example, if a curb-side pole involved in one collision per year is removed from a verge between a house-fence and a major roadway, the potential savings are calculated by the following steps :

(1) Establish what object is likely to be struck by an errant vehicle if the pole is removed (a house-fence 4 m from the curb in this example).

(2) For the lateral offset of this 'replacement' object (the fence) calculate the collision probability reduction factor (0.30 , from Figure 4.14).

(3) From Table 6.1, select the average accident cost associated with a 'replacement' object collision (TC = $5360).

(4) Calculate the expected annual societal cost from the 'replacement collision' as the product of the expected annual pole accident rate (1.0), the probability reduction factor (0.30) and the average replacement accident cost ($5360) : $1600 in this example.

(5) Calculate the expected annual savings as the difference between the annual cost of pole accidents at that site (expected accident rate by the average cost of pole collisions for that site classification) and the annual 'replacement collision' cost calculated in (4). ($12500 - $1600 = $10900)

In practice, the expected accident rate should be determined by the predictor model developed in Chapter 4. It is likely also that a string of poles, rather than just one, will warrant treatment. This should be assessed by applying the model and above calculations to each in turn.

The assessment of benefits associated with pole removal have been based on the economic 'values' of life and limb and property damage. No allowance for the aesthetic benefits flowing from such a program has been made ; the derived benefits could therefore be considered conservative.

Although the above examples have dealt with non-intersection cases, the same approach applies to intersection sites. Intersections of major roads, which are largely controlled by traffic lights, are candidates for treatment by reducing the number of poles. This could be achieved by installing traffic light poles which have displays in more than one direction.

From the examples discussed above it would appear that significant societal savings could be achieved at high risk locations by the removal or relocation of poles. The conditions under which savings outweigh the costs are examined in Chapter 7.

6.3.2 Roadway Characteristics

As in the previous section, the quantification of the potential for societal loss reduction through modifications to the roadway is based on the relative risk curves presented in Chapter 4. The principal roadway characteristics which were identified in Chapter 4 as significantly affecting accident probability, and which are also readily amenable to change, were road surface skid resistance and horizontal curvature. Other factors which would probably be corrected at the same time are pavement surface deficiencies and inappropriate superelevation.

Significant reductions in the expected accident rate for sites with low skid resistance or high horizontal curvature or both are possible. For example, for the major road, non-intersection group (MNI), Figure 4.9 shows relative risk versus maximum horizontal curvature upstream of the pole. A reduction in the value of maximum curvature from $0.015\,m^{-1}$ or higher to $0.01\,m^{-1}$ or less results in a reduction of accident probability by a factor of at least 2.7. If the curvature of $0.015\,m^{-1}$ could be eliminated altogether the accident probability would be reduced by a factor of 10.6. The economic value of savings accruing per annum from a re-alignment of the roadway is simply the difference between the old and new expected accident rates multiplied by the average accident cost.

Similarly, the savings associated with pavement skid resistance improvements can be determined from the appropriate relative risk plots contained in Chapter 4. While the corrective action and its effectiveness with regard to horizontal curvature of the roadway are clear cut, this is not entirely the case for pavement skid resistance.

Tyre - road interaction is a very complex mechanism and the relative roles of tyre characteristics and pavement material and profile on skid resistance has been the subject of extensive research. Sweatman and Joubert (1976) present a comprehensive review of the work to date in this field. They also discuss a number of available road surface treatments. It is the latter topic that is of particular relevance here.

The majority of techniques for improving skid resistance involve a complete resurfacing of the roadway, the methods and results varying with the materials used. One method that does not require resurfacing initially is to cut grooves into the road surface. Hatcher (1974) reports a significant reduction in the wet road accident rate for sites modified by road grooving.

For concrete pavements, Bonnot and Ray (1976) report an initial increase in side force friction coefficient of 70 percent. Grooving of the roadway is not entirely suitable for bituminous surfaces because of the tendency for the grooves to close up under the action of traffic. A further disadvantage is the increase in traffic noise associated with grooved pavements (Salt, 1976).

The disadvantage of many resurfacing treatments is the cost associated with relocating the curbs to accommodate the new surface height, or with removing the old pavement. Both also result in significant traffic disruption. A method which largely avoids these problems, and provides a hardwearing, high skid-resistance surface, involves the laying over the existing roadway of an epoxy resin binder embedded with a synthetic aggregate called super-calcined bauxite. Its thickness is such that curbs usually do not need to be relocated and it can be laid over-night. The surface, known locally as Shellgrip, has been in service in many locations around London since the late 'sixties and early 'seventies. One of the attractive features of the surface is its apparent ability to maintain high skid-resistance values over a number of years. Figure 6.14, from Lamb (1976), shows the performance of

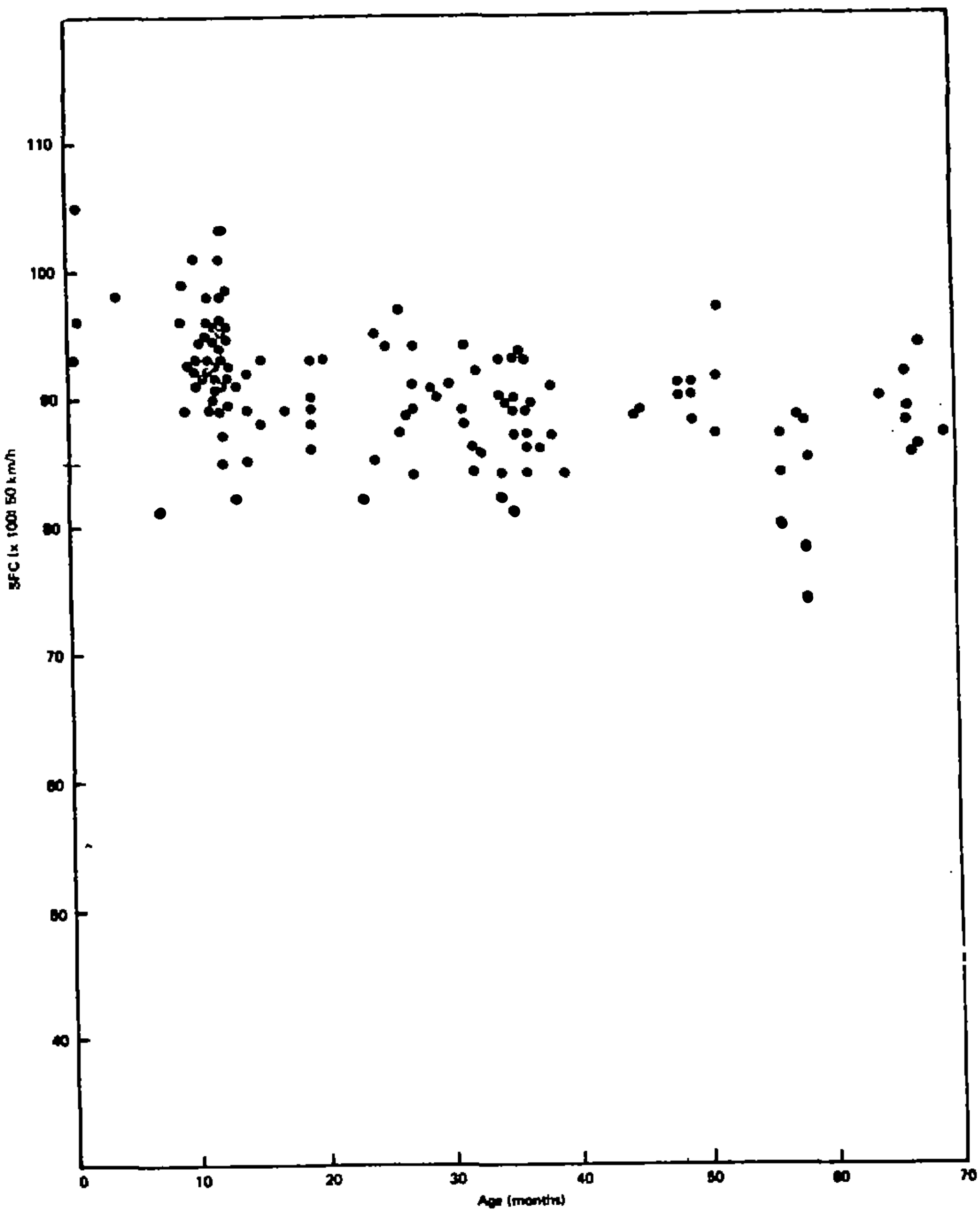


Figure 6.14. Skid resistance of Shellgrip at road junctions as a function of time since laying (Lamb, 1976).

CATEGORY	ROAD SITUATION	MINIMUM SFC	TEST SPEED
A	Approaches to traffic signals, pedestrian crossings and similar hazards on main urban roads.	0.55	50 km/h
B	(i) Urban arterial roads. (ii) Urban freeways.	0.45 0.45	50 km/h 80 km/h
C	State highways, rural freeways, and rural main roads carrying more than 2000 vpd.	0.40	80 km/h
D	Main roads carrying less than 2000 vpd and unclassified roads.	0.35	80 km/h

Figure 6.15. Desirable levels of skid resistance used by the Country Roads Board of Victoria (Sweatman and Joubert, 1976).

Shellgrip at road junctions over a period of nearly six years. The side force coefficient plotted (approximately comparable to the British Pendulum Skid Test for low speeds) declined on average only 10 percent over that period. Lamb reports that the surface has been effective in providing a high skid-resistance at the most heavily trafficked sites for a period of at least 8 years. Similar service lives have also been reported by Poulson and Wood (1976) and Hatherly and Young (1976).

Sutton (1970) reports the installation of a small test strip of Shellgrip in Melbourne in 1969. The skid-resistance value six months after laying was 63 , as measured by a pendulum tester, falling to 59 twelve months after laying. It was thought that this more rapid deterioration in skid-resistance relative to overseas experience was due to the inferior quality of the calcined bauxite used. In any case, both these values exceed the 'critical' value of 50 apparent in Figure 4.11 for the MNI group. It is interesting to compare this critical value with the skid-resistance values recommended by the Country Roads Board of Victoria and shown in Figure 6.15 . For Category A sites (the most hazardous), the recommended minimum side force coefficient of 55 is very close to the unity relative risk crossover value shown in Figure 4.11 (although it is noted that the two skid-resistance measurements are only approximately comparable). It seems clear from the literature that the Shellgrip system is very well suited to spot improvement of hazardous, low skid-resistance sites, and that it maintains pendulum skid test levels in excess of the 'critical' value of 50 over a long service life.

6.3.3 Vehicle Characteristics

In the somewhat limited study of the relationship between vehicle characteristics and pole accident occurrence presented in Section 4.5 it was revealed that the 'handling' characteristics of the vehicle (as determined by the tyre inflation balance) were related to pole accident probability. It was also shown that tyre tread depth was a significant factor in the accident process, particularly on wet roads.

Remedial programs aimed at the reduction of 'accident-prone' vehicle characteristics require the definition of acceptable standards. While this is relatively simple for tyre construction and tread depth, it is not currently the case for vehicle handling characteristics. Good (1977) concluded from his state-of-the-art review that the relationship between driver-vehicle performance and objectively measurable vehicle characteristics is not sufficiently well-defined to allow the framing of Standards. Further work is required to define the relationship between vehicle design characteristics and accidents.

The role of vehicle defects in accident causation appears to be quite small. Treat and Joscelyn (1974) report that such factors account for no more than 5 percent of accidents. According to the New South Wales Accident Statistics for 1977, which are based on police reports, vehicle defects were involved in one percent of fatal crashes, and two percent of injury crashes (TARU, 1978c). Vehicle defects were defined to include brakes, steering, tyres, lights, suspension etc. In the present study, 30 percent of accident vehicles had tyre conditions with above-average risk of accident involvement.

Foldvary (1973) comprehensively reviewed vehicle inspection programs and their effectiveness. He found that there was insufficient knowledge to judge the effectiveness of such programs. Recommendations for further research and a format for a cost-benefit analysis were also presented. Periodic checks should ensure satisfactory condition of these items inspected for at least a short time after the inspection. However it would seem that a sustained education campaign aimed at drivers and garage attendants regarding tyre condition and correct inflation pressures etc. would be required to maintain these in appropriate condition. The present results suggest that such a campaign has the potential for significant benefits. Before it could be embarked on, however, it is clear that the preliminary results obtained here need to be confirmed and extended.

6.4 SUMMARY AND CONCLUSIONS

(i) The installation of crash barriers or attenuators would not be an effective loss-reduction measure for pole accidents in the urban road system.

(ii) Crashes with breakaway or wrap-around luminaire poles produce significantly lower societal costs than those with rigid luminaire poles. It has been the South Australian Highways Department's experience that such savings can be achieved at little or no extra cost to the authority owning and installing the poles.

(iii) The arguments sometimes advanced against breakaway poles suggesting that they would involve unacceptably hazardous secondary collisions, danger to pedestrians, or increased cross-median collisions, have been shown to be unfounded. Such effects, if any, would be insignificant compared with the reduction in the severity and cost of pole accidents.

(iv) The development of breakaway or wrap-around traffic light poles should be investigated.

(v) Based on the results of preliminary scale model tests, a scheme for modifying timber, cable-supporting, utility poles has a significant potential for loss reduction.

(vi) Substantial improvements in vehicle crashworthiness in pole impacts do not appear feasible at current levels of technology, and within societal constraints on cost and consumption of material and fuel resources.

(vii) The most effective method of loss reduction in relation to pole accidents is pole removal. As with other methods, the benefits must be weighed against the costs (as is done in Chapter 7).

(viii) Resurfacing and re-aligning the road can also provide societal returns for high-risk locations. The 'Shellgrip' resurfacing technique appears to provide an accident-reducing treatment which maintains its effectiveness over a long service life.

(ix) Although vehicle 'handling' characteristics appear, from the present study results, to be related to pole accident occurrence, it is not yet possible to define mandatory standards for vehicle design. However, an education campaign directed at drivers and garage attendants, on the importance of maintaining tyre inflation pressures at manufacturers' recommended levels, is worthy of consideration. Further work is required to define the relationship between vehicle characteristics and accident causation.

CHAPTER 7

THE EVALUATION OF SELECTED LOSS REDUCTION PROGRAMS

7.1 INTRODUCTION

Because there are only limited funds available for the financing of remedial programs, there is a need for a system of priority ranking of alternative projects. A number of approaches to such a ranking system have been proposed in the past, most of which involve the assessment of project costs against project benefits. In order that the costs and benefits can be compared, the assessment of benefits (a reduction in the frequency and severity of accidents) inevitably involves the assigning of monetary values to loss of life, personal injury and property damage (Chapter 5).

In an attempt to avoid the problems associated with measuring project benefits in monetary terms, a number of authors have proposed the use of cost-effectiveness ratios (Glennon, 1974 ; Weaver, Woods and Post, 1975 ; Laughland et al., 1975). A cost-effectiveness ratio is usually defined as the cost of the project to the authority implementing the change divided by the expected reduction in the number of casualty accidents. While this method enables the ranking of alternative projects to a certain extent, it does not provide the means to evaluate a project which, say, replaces one severe injury per year with a greater number of minor or moderate injury accidents. Furthermore, it does not provide any information as to whether the projects are in fact economically warranted at all. This method simply postpones the problem of assessing the loss reductions in monetary terms.

It is fair to say that there is still considerable controversy surrounding the validity of cost-benefit analyses, largely because of the conceptual and philosophical problems associated with the costing of benefits (O'Neill, Kelley and Wong, 1975 ; O'Neill and Kelley, 1974 ; Joksch, 1975). However, the benefit-cost approach has been adopted for the present study, so that the expenditure of funds on remedial programs can be argued for on an economic basis which, at worst, understates the benefits available by failing to account for intangibles such as reduced pain and suffering or aesthetic improvement of the urban landscape. The calculation of accident costs, as detailed in Chapter 5, excluded such intangible items, not because of lack of validity or relative merit, but rather because of lack of data. Analyses based on these derived costs should therefore be considered conservative from the point of view of recommending change. On the other hand, a possible disbenefit of pole remedial programs which has not been accounted for would be a change of driver behaviour in response to an apparently safer roadside, such as to increase the level of risk associated with other types of accident. O'Neill (1977) has proposed a decision-theory model of danger compensation which attempts to predict such effects. However, the theory is not sufficiently well established to allow its use in practical situations, and no relevant empirical data are known of.

The ranking of alternative projects and the assessment of their societal worth can only be based partly on benefit-cost calculations, and must also include consideration of the non-economic factors associated with social well-being and environmental quality. This Chapter presents only the analytical, monetary aspects of project evaluation.

7.2 BENEFIT-COST EVALUATION

The benefit-cost evaluation of alternative site treatments presented in this section is based largely on the Net Present Worth or Net Discounted Present Value (NDPV) technique reported by Hunter, Council and Dutt (1977). Two other measures employed in the analysis are the Annualized Net Benefit (i.e., the average annual excess of benefits over costs during the life-span of the improvement) and the Benefit-Cost Ratio. The Benefit-Cost Ratio can be calculated as the ratio of the discounted present worth of the benefits to the discounted present worth of the costs or, equivalently, as the ratio of the annualized benefits to the annualized costs. For a review of these and other commonly adopted measures, readers are referred to Laughland et. al., (1975).

For the purposes of the present study, the following definitions of benefits and costs were adopted :

> Benefits are defined as the savings accruing from the reduction in the number and/or severity of accidents which could be attributed to the site improvement.
>
> Costs are defined as the capital outlay required for the construction of the improvement, as well as the expenditure on maintenance (not including crash damage) over the whole service life. Crash damage costs are defined as negative benefits and are deducted from the accident reduction benefits.

The NDPV is calculated as the difference between the discounted present value of the benefits which accrue throughout the improvement's service life and the discounted present value of the costs. If no maintenance costs are incurred the latter is equal to the capital outlay. The present value of benefits obtained in a given year after the improvement has been made is obtained by multiplying the annual benefit by the Present Worth Factor for that year (which depends on the selected interest rate see Appendix D). The present value of benefits for the life of the improvement is then the sum of each of the annual amounts. The present value of costs is the sum of the initial capital investment and the cumulative value of the annual maintenance costs multiplied by the present worth factor for each year over the service life.

The Annualized Net Benefit is calculated to enable the comparison of alternative investments (projects) with different service lives. It is obtained by multiplying the NDPV by the appropriate capital recovery factor (Appendix D). The Annualized Net Benefit represents the annual dividend which would result from an investment of the NDPV at the selected interest rate.

The capital recovery factor CR based on an interest rate r and a service life T (years) is calculated as follows (Jorgensen and Associates, 1966) :

$$CR_T^r = r\,(1+r)^T/((1+r)^T - 1)$$

where

r = interest rate (per annum)

T = service life (years) .

Values of CR for a range of interest rates and service lives are tabulated in Appendix D, Table D.2 .

The present worth factor PW for year n at interest (discount) rate r is :

$$PW_n^r = 1/(1+r)^n$$

Values of PW for a range of interest rates and years are tabulated in Appendix D, Table D.1 .

The NDPV is then given by :

$$\text{NDPV} = \left(\sum_{n=1}^{T} (\text{Annual Benefits}) \times PW_n^r\right) - \left(I + \sum_{n=1}^{T} (\text{Annual Costs}) \times PW_n^r\right)$$

where I = initial capital investment.

The Annualized Net Benefit ANB is :

$$\text{ANB} = CR_T^r \times \text{NDPV} .$$

Finally, a benefit-cost ratio B/C can be calculated as follows :

$$B/C = \frac{\sum_{n=1}^{T} (\text{Annual Benefits}) \times PW_n^r}{I + \sum_{n=1}^{T} (\text{Annual Costs}) \times PW_n^r}$$

A number of assumptions concerning the derivation and use of the above equations were made :

(i) At the end of the service life of the improvement, a zero salvage value was assumed.

(ii) As recommended by Laughland et al., (1975) a zero inflation rate was chosen.

(iii) Similarly, an accident growth rate of zero was assumed.

The ranking of alternative projects is based on the following guidelines :

(i) The project with the highest NDPV receives the highest priority.

(ii) If alternative projects have different service lives, the Annualized Net Benefit (ANB) should be used as the measure of priority.

(iii) If a number of projects have equal or near-equal merit on the basis of their NDPV, the benefit-cost ratio can be used to discriminate between them.

(iv) If the NDPV of any project is negative (costs greater than benefits) then, on an economic basis, the project should be discarded.

The use of the NDPV as the primary ranking measure is also recommended by Fleischer and Jones (1975) and Struble et al., (1975).

7.3 THE EVALUATION OF A NUMBER OF REMEDIAL ALTERNATIVES

7.3.1 Introduction

Ideally, perhaps, every alternative loss-reduction measure should be evaluated for every roadside pole. Even if automated, such a task would require an enormously detailed and comprehensive pole and roadway inventory. At first glance, also, the identification of only those poles most likely to warrant treatment, out of the estimated 553,000 poles in Metropolitan Melbourne (see section 4.3.2) presents a daunting task. However, the accident predictor models derived in Chapter 4 provide a means by which this task can be reduced to a manageable size.

Estimates of pole numbers and annual accident rates associated with each data group were presented in Chapter 4. It was on the basis of these estimates that the calculation of the relative risk associated with 'membership' of a particular data group was calculated (Section 4.3.1). From the results in Figure 4.50 it can be seen that the intersection-of-major-roads data group (MJMJ) has the highest 'between groups' relative risk, followed by the major-road, non-intersection group (MNI). This means that, on average, poles classified as members of either of these two groups have higher accident probabilities than poles in any of the three remaining data groups.

It was also found in Chapter 4 that, whereas the MNI data group predictor model was able to assign a wide range of accident probabilities to poles within the group (Section 4.2.4), the model associated with the MJMJ data group was a relatively poor discriminator of risk (Section 4.2.6). (It is noted that because of pole-density correlation problems encountered in the derivation of the MJMJ model, only a limited version of the final model could be tested for discriminatory power.)

It was suggested in Chapter 4 that, on the basis of the accident numbers, the pole numbers and the discriminatory power of the model the data group most likely to yield poles which would warrant treatment is the MNI data group. This is rather crudely confirmed by Table 7.1, which lists the minimum number of poles in each data group that would require treatment to have some effect on 100 accidents per year. The calculation of these numbers takes into account the number of poles in the population associated with each data group, the relative annual accident rates and the discriminatory power of the predictor model for each data group. The level of discrimination for the MNI group can be seen in Figure 7.1, which shows the cumulative percentage distribution of risk factor (RF) for both the accident and random samples of poles. The data for this Figure are identical to those in Figure 4.27.

TABLE 7.1

ESTIMATE OF THE MINIMUM NUMBER OF POLES REQUIRING TREATMENT TO AFFECT 100 ACCIDENTS PER ANNUM WITHIN EACH DATA GROUP

Data Group (1)	Annual Accidents (2)	Accidents Affected		Poles Requiring Treatment (3)	
		No.	%	%	No.
MNI	1155	100	8.6	0.5	380
MINI	250	100	40.0	2.0	4 340
MJMJ	310	100	32.3	20.0	2 390
MJMI	225	100	44.6	11.0	10 620
MIMI	130	100	76.0	-	100 000+

(1) See data group definition, Section 4.2.2.

(2) Based on the accident sample distribution shown in Table 4.1 and the accident sample scale factor derived in Section 4.3.4 .

(3) The percentages were derived from the cumulative distributions of RF reported in Chapter 4 (Figures 4.3.4, 4.41 and 4.49), except for the MNI data group which was based on Figure 7.1 for greater accuracy, and the MIMI intersection data group which does not have a predictor model.

In Figure 7.1 they are plotted on normal probability-log scales to provide greater definition of percentages close to 100 . As was explained in Section 4.2.4 (s) , it is possible to predict the distribution of RF for the pole population from that for the accident sample. This process is necessary because the random sample size was not large enough to completely define the distribution for high RF values. This estimated distribution is used throughout the benefit-cost analysis.

It can be seen from Table 7.1 that 100 accidents represents 8.6 percent of the MNI data group annual accident rate. From Figure 7.1, the proportion of all MNI poles which account for these 100 accidents is 0.5 percent. The minimum number of poles which would have to be treated to affect 100 accidents is then 0.5 percent of the number (76,440) of MNI poles (Section 4.3.2).

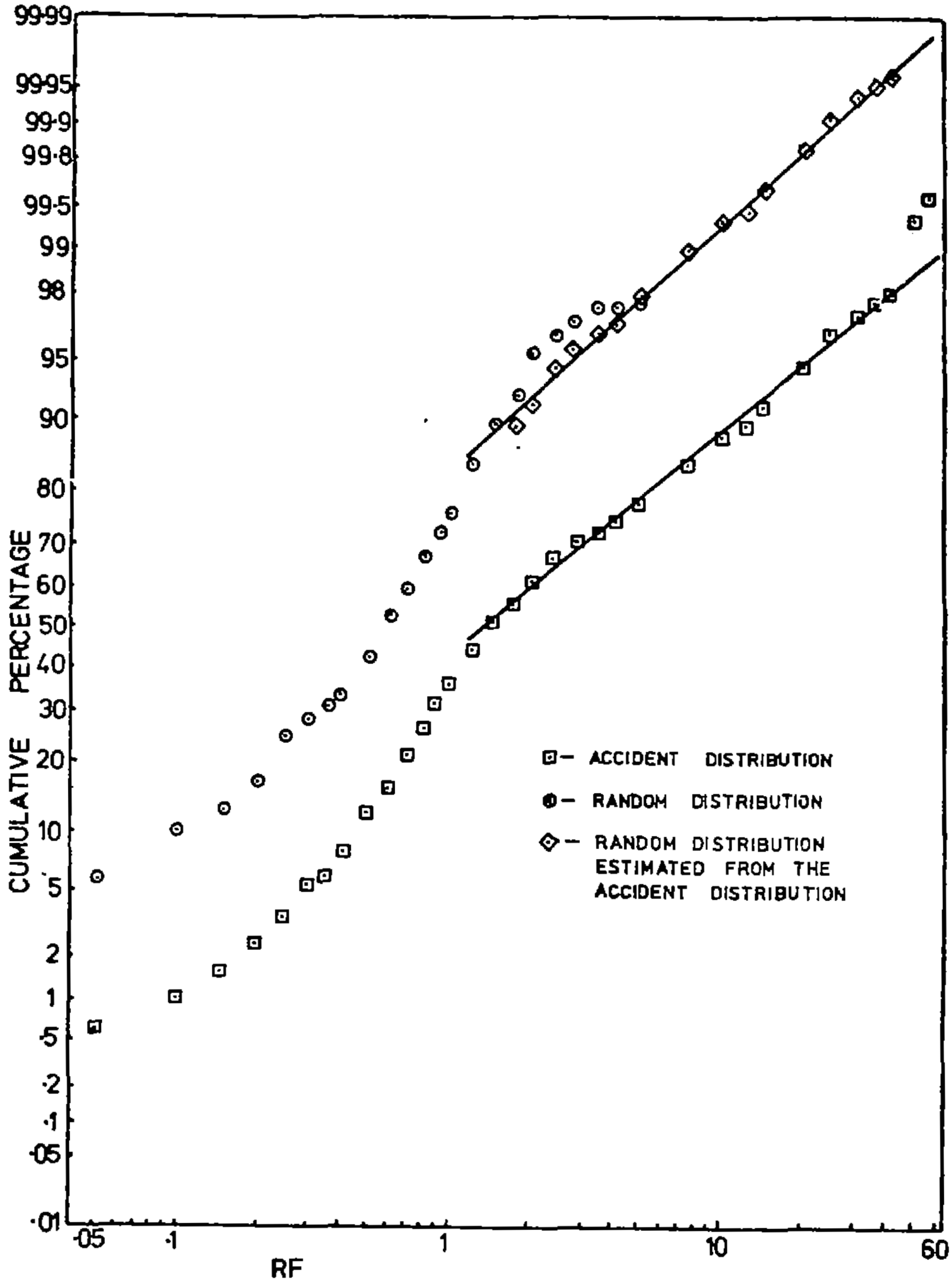


Figure 7.1 Cumulative percentage distributions of risk factor RF plotted on normal probability-log scales for the major road non-intersection (MNI) data group.

That is, 380 poles require treatment. This procedure was followed for the remaining data groups, with the results indicating that the MNI data group is by far the most likely to return expenditure by way of societal benefits. The next most likely group is the MJMJ although, because of the uncertainty associated with the random site distribution of RF, the results shown in Table 7.1 for this group must be accepted with some reservation.

It is noted that the MIMI figure presented in Table 7.1 is approximate only, being estimated on the basis of the MJMI intersection model because of the lack of a MIMI model. This probably results in the figure quoted being an underestimate, as a MIMI model is unlikely to be as good a discriminator of risk as the MJMI model. However such detail is of little relevance as the Table clearly shows that the MIMI data group as a whole is simply not a contender for remedial action. That is not to say that high risk poles exist only in the MNI or MJMJ data groups, but rather that they are concentrated in these groups. Further, they can be most effectively discriminated in the MNI group. Needless to say, poles which emerge in any group as having a high risk, by way of their accident history, should be immediately examined for possible remedial action.

The benefit-cost analyses in the remaining sections of this Chapter will be restricted to the MNI group for several reasons :

(a) The predictor model for this group enables the detection of the relatively small number of poles accounting for the majority of MNI accidents.

(b) Although <u>on average</u> MJMJ intersection poles are at a higher risk than those in any other data group, it is not possible in the model (and probably in fact) to identify a small proportion of intersection poles which are especially hazardous. Thus, as discussed in Section 4.2.6, most poles near certain intersections of major roads are candidates for remedial treatment. As the number of such intersections is relatively small (813 in Melbourne), the MJMJ predictor model should allow an initial priority ranking of intersections for treatment.

This initial 'screening' of poles by data group results in the elimination (so far as the present analysis is concerned) of 86 percent of the pole population from the next, more detailed, stage of analysis. Although this is a significant reduction, the remaining 14 percent (the MNI group) still represents about 76,000 poles. The identification of poles most likely to warrant further examination could be undertaken at council or Country Roads Board level, remembering that the MNI data group is restricted to only 1913 km of roads for the whole of Melbourne. It is desirable that a listing of poles on these roads, according to their RF, be established within each region so that as funds became available, remedial action could be carried out on a priority-treatment basis.

7.3.2 The Average Approach

Sites which have a high accident risk usually do so because of a number of contributing factors. Depending on the circumstances of the site, it may not be possible to eliminate all, or even any, of the factors which contribute to the accident risk. The contribution of any given factor to the overall accident risk will also vary from site to site. It is for these reasons, as well as the fact that treatment costs will also vary from site to site, that the evaluation of remedial programs should be on a site basis, rather than for an 'across the board' policy decision for all sites. The latter 'average approach' (Mackay, 1977) serves only to demonstrate the feasibility of a given treatment being worthy of further examination for particular sites. At best, it provides a guide to whether economically-warranted solutions are likely to be found for the pole accident problem overall. In terms of deciding between the relative merits of alternative treatments at particular sites, the average approach provides little information.

As an example of the 'average' approach, Table 7.2 was constructed to demonstrate that the pole accident problem is indeed one worthy of attention. The Table shows various measures of societal benefits and costs, calculated for a 15-year service life,

TABLE 7.2

COSTS AND BENEFITS ($ MILLION) ASSOCIATED WITH SOME ALTERNATIVE REMEDIAL PROGRAMS FOR THE MELBOURNE METROPOLITAN AREA

Treatment	Cost Group	RF Cut-off	No. of Poles to be Treated	Cost of Program	PWB (1)	NDPV (2)	Casualties saved per annum	
							Fatalities	Injuries
Underground power lines	TC	3.21	1 510	7.55	16.40	8.85	4	66
	TCNC	4.95	874	4.37	7.71	3.34	3	48
	CRC	14.2	119	0.60	0.96	0.36	1	17
Convert luminaires to 'breakaways'	TC	0.56	15 515	11.64	28.80	17.16	8	122
	TCNC	0.94	7 223	5.42	13.24	7.82	6	95
	CRC	3.55	936	0.70	1.40	0.70	3	38
Convert luminaires to 'wrap-around'	TC	0.47	16 585	12.44	35.43	22.99	9	161
	TCNC	0.77	11 503	8.63	19.37	10.74	8	145
	CRC	2.94	1 204	0.90	1.94	1.04	3	55
Modify timber power poles	TC	1.08	8 347	5.84	14.43	8.59	9	72
	TCNC	2.84	1 987	1.39	2.78	1.39	4	37
	CRC	NOT ECONOMICAL TO MODIFY POLES FOR THIS COST GROUP.						

(1) PWB - present worth of benefits accruing over the installation service life.

(2) NDPV - net discounted present value.

(3) All benefit calculations include costs associated with crash damage to the installation, and secondary collisions.

for four alternative treatments, two concerned with timber power poles (i.e., carrying conductor cables) and two with luminaire poles.

TABLE 7.3

APPROXIMATE SITE IMPROVEMENT COSTS

Treatment	Average Capital Cost ($)	Service Life (Years)	Crash Repair Costs ($) (6)
Utility pole relocation (1)	1000	15	130
Luminaire pole relocation	500	15	280
Utility pole removal (1)	5000	15	0
Conversion of luminaire pole to 'breakaway' (2)	750	15	190
Conversion of luminaire pole to 'wrap-around' pole (3)	750	15	500
Utility pole modification (4)	700	15	1000
Resurfacing with Shellgrip (5)	$10/m^2$	8	0
Resurfacing with plant-mix (5)	$2.50/m^2$	15	0
Complete pavement reconstruction	$35/m^2$	15	0
New curbing	15/m	15	0

Notes : (1) Based on a typical high-voltage/low-voltage conductor-pole configuration.

(2) Refers to either slip-base or frangible steel poles.

(3) ESV pole (Chapter 6).

(4) Includes cost of a 'cherry-picker' mobile crane, labour and equipment for two hours as well as an allowance for modifications to the cable-crossarm connections. Applicable to timber poles only.

(5) Assumes that the existing road surface is intact and stable.

(6) Refers to the installation repair costs ; does not include secondary collisions.

The installation cost and the service life adopted for each of the four treatments (as well as others) are shown in Table 7.3 . The costs are approximate and, as was pointed out earlier, will vary from site to site. A nominal figure of 15 years was chosen as the service life for all but the treatment involving resurfacing with Shellgrip. The values used in the literature range from 10 to 20 years and the choice is somewhat arbitrary for installations which show little degradation with time. For such cases the 'foreseeable' future (from the point of view of transport patterns, etc.) is adopted as the guideline ; estimates of the 'foreseeable' future typically lie within this range. It is noted further that maintenance costs associated with all of the treatments have been set to zero, as argued by Glennon (1974) and Hunter, Council and Dutt (1977).

The estimates presented in Table 7.2 were, in general, derived as follows :

(a) Estimates of the present worth of benefits per site for the treatment under study were obtained. This was calculated as a function of risk factor (RF), and took into account changes in collision severity and probability, and assumed present worth factors based on a 7 percent interest rate and a service life of 15 years (Table D.1).

(b) The 'break-even' RF was calculated by dividing the installation cost by the present worth of benefits. The 'break-even' RF represents the level of expected annual accident rate at which the accrued benefits over 15 years balance the cost of treatment. For RF values higher than this value, the benefits of treatment exceed the costs, and treatment is 'warranted'.

(c) Entering Figure 7.1 with the 'break-even' RF, the percentage of poles in the MNI population which warrant treatment, and the percentage of accidents that will consequently be affected, are determined. From these percentages, and the number of poles of the type under study in the MNI group, estimates of the number of poles which warrant treatment and the number of accidents thus affected can be calculated.

(d) The cost of the program is obtained by multiplying the number of poles which can be treated by the cost per pole.

(e) The present worth of benefits for the program is then simply the product of the number of accidents affected per year, the savings per accident, and the sum of the present worth factors for each year of the improvement life.

(f) The net discounted present value is then the present worth of benefits minus the program cost.

(g) The number of lives and injuries saved is calculated from the proportion of accidents affected and the changes in accident severity and probability discussed in Chapter 6.

The 'average' approach to the assessment of a program which alters the probability of collisions occurring (i.e., changes the RF values) is rather less meaningful than for a program which alters the collision severity only. The extent to which various factors contribute to the high accident risk of a particular site will vary from location to location. Therefore, the effect of a program which addresses itself to a particular risk-related factor which does not markedly affect crash severity (e.g., lateral offset) will also vary from site to site. Further, it is possible that for a number of sites with RFs exceeding the 'break-even' value, the treatment may not in fact be possible (e.g., pole relocation or curve re-alignment). These two problems therefore involve additional assumptions and approximations which detract further from the value of the results of an analysis based on the 'average' approach, as in Table 7.2 .

The analysis of the four treatments in Table 7.2 involved a number of assumptions which are listed below :

(a) In the case of power pole removal it was assumed that the poles are house-side-mounted, and that the next object in the errant vehicle's path is a house-fence. The probability of this 'replacement' collision was reduced by a factor of 0.4 , which is based on the mean lateral offset for the accident sample of 1 m , and a fence lateral offset of 3 m.

(b) Similarly, for power pole modifications (conversion to 'pop-out' design), a secondary collision with a house-fence was assumed to occur in all cases.

(c) For the conversion of luminaire poles to a breakaway type (essentially new installations) the secondary collision for house-side-mounted luminaire poles was assumed to be a house-fence, while for median poles it was assumed that no secondary collision would occur. A weighted benefit per collision was used, based on the distribution of luminaire poles between house-side and median strip locations.

(d) It was assumed that collisions with 'wrap-around' poles result in no occupant casualties. For all treatments it was assumed that collisions with house-fences result in non-fatal occupant injury only.

The extent of these assumptions only serves to demonstrate the defects associated with the 'average' approach. As was stated earlier, the results are useful only in the context of establishing whether or not the pole accident problem is worthy of attention on an economic basis.

Table 7.2 indicates that the four treatments are feasible and should result in considerable societal savings. It is again stressed, however, that the true test remains in analysing the alternatives on a site-by-site basis.

7.3.3 The Site-By-Site Approach

The site-by-site approach requires the assessment of the most beneficial and practicable solution for each of the individual sites identified as having a high accident risk by the methods of Chapter 4. The particular site characteristics contributing high relative risks will suggest the most effective remedial measures for that site. Accident attenuation through pole modifications should also be investigated, particularly in situations where little can be done to reduce the accident probability.

To illustrate the approach, a benefit-cost analysis of a number of remedial treatments for the site detailed in Case Study B.1 (Appendix B) was carried out. The relevant model for the site (MNI model) predicts an accident rate for the subject pole (Figure B.1) of 0.536 accidents per annum. Every parameter in the model involves a greater-than-average accident risk. If it is assumed that pole removal or relocation is not possible, and that land is not available for curve re-alignment, then the remaining site characteristics which affect the probability of an accident and which are amenable to treatment are as follows :

(a) Pavement skid resistance
(b) Incorrect camber at curve
(c) pavement corrugations.

Should any of these characteristics be changed in such a way that the total relative risk (TRR) of the subject pole is altered, then benefits will accrue, not only from a reduction in the accident rate at the subject pole, but also from a reduced risk for the other poles in the vicinity of the site alterations. It was established in Chapter 6 that the majority of vehicles leaving the roadway do not collide with poles ; house-fences are typically the fixed object in the vehicle path. A reduction in the accident rate for fence collisions would therefore also be expected to flow from the site improvements (a) - (c) above.

Benefits can also be achieved through a reduction in pole accident severity. The two options investigated for this site involve the luminaire poles placed on the outside of the bend shown in Figure B.1.

Table 7.4 presents the benefit-cost analysis for five treatment alternatives, three involving pavement improvements, and two involving the installation of alternative luminaire pole designs. The pavement treatments analysed are directed at reducing accident probability. The 'zone of influence' for such changes was assumed to include poles and fences a further span outside those shown in Figure B.1 , so that five luminaire poles and five utility poles are involved.

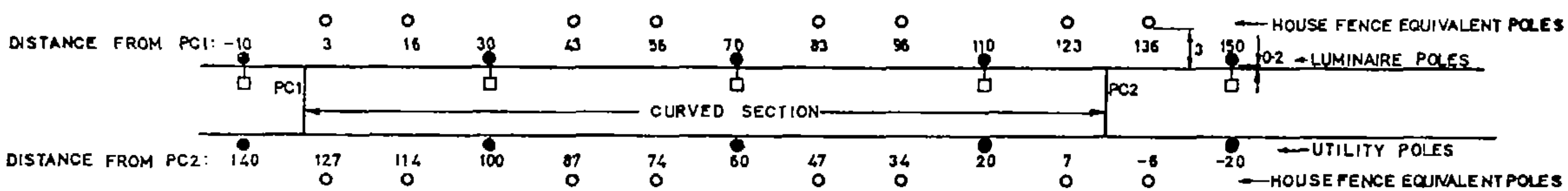
The first step in the analysis is the calculation of the expected accident rate for all poles within the 'zone of influence' for the unmodified site, as illustrated for the subject pole in the case study. In addition, the expected fence accident rate throughout the unmodified site is calculated. Figure 7.2 details this step. The house-fences are modelled by low accident severity 'poles', placed at the appropriate fence lateral offset, in this case 3 m . The number of such 'poles' is determined by the minimum number per span that will ensure that a collision occurs if an errant vehicle misses a pole and encroaches more than 3 m from the road edge. It was estimated in Chapter 6, that for a pole spacing of 40 m , a vehicle which leaves the roadway has roughly a one-in-three chance of colliding with a pole (assuming the pole is at the road edge). Therefore, two equally-spaced 'fence-equivalent' poles, at an offset of 3 m , are required to model the fence between two actual poles. Collision severity for this analysis is measured in terms of average cost per collision, so that the 'fence-equivalent' poles are assigned an average accident cost equal to that calculated for house-fence collisions (Table 6.1).

The expected accident rate can then be calculated for all poles (real and fence-equivalent), as shown in Figure 7.2. All but three of the individual relative risks remain the same as those used in the case study B.1 . The three that change must be determined for each pole. These are :

(i) Inside/outside of the bend
(ii) The distance from the curve start
(iii) Lateral offset.

For two-way roads, such as in this example, each pole has two possible values of distance from curve start, measured from either end of the curve. The value chosen is the one which gives the highest risk, with only positive values being considered.

OIB	OUTSIDE											
DC	140	3	16	30	43	56	60	47	34	20	7	136	150
LO	0·2	3	3	0·2	3	3	0·2	3	3	0·2	3	3	0·2
TRR	118·8	60·7	60·7	202·3	60·7	58·8	192·2	60·7	60·7	202·3	60·7	36·8	108·7
EXPECTED ACCIDENT RATE p.a.	0·45	0·23	0·23	0·77	0·23	0·22	0·73	0·23	0·23	0·77	0·23	0·14	0·41



OIB	INSIDE											
DC	140	3	16	30	43	56	60	47	34	20	7	136	150
LO	0·2	3	3	0·2	3	3	0·2	3	3	0·2	3	3	0·2
TRR	87·8	44·9	44·9	149·5	44·9	43·4	142	44·9	44·9	149·5	44·9	27·2	80·4
EXPECTED ACCIDENT RATE p.a.	0·33	0·17	0·17	0·57	0·17	0·16	0·54	0·17	0·17	0·57	0·17	0·10	0·3

Figure 7.2 Distribution of accident risk over the case study B.1 site.

TABLE 7.4

BENEFIT-COST ANALYSIS (1) OF ALTERNATIVE REMEDIAL TREATMENTS OF CASE STUDY B.1

Treatment	Cost Group	Cost of Treatment ($)	Present Worth of Benefits ($)	Net Discounted Present Value ($)	Annualized Net Benefit ($)	Benefit/ Cost Ratio
1. Road reconstruction with plant-mix	TC	70 000	498 000	427 000	47 000	7.1
	TCNC	70 000	353 000	283 000	31 000	5.0
	CRC	70 000	178 000	108 000	12 000	2.5
2. Road reconstruction with Shellgrip (2)	TC	100 000	641 000	541 000	60 000	6.4
	TCNC	100 000	455 000	355 000	39 000	4.6
	CRC	100 000	229 000	130 000	14 000	2.3
3. Resurfacing with Shellgrip (3)	TC	31 000	406 000	375 000	41 000	13.1
	TCNC	31 000	288 000	257 000	28 000	9.3
	CRC	31 000	145 000	115 000	13 000	4.7
4. Convert 5 luminaires to 'breakaway'	TC	3 750	191 000	187 000	21 000	50.9
	TCNC	3 750	105 000	102 000	11 000	28.0
	CRC	3 750	1 000	- 2 000	- 300	0.3
5. Convert 5 luminaires to 'wrap-around'	TC	3 750	305 000	301 000	33 000	81.3
	TCNC	3 750	185 000	182 000	20 000	49.3
	CRC	3 750	48 000	45 000	5 000	12.8

(1) Interest rate = 7% per annum ; service life = 15 years.

(2) Because of the different service lives associated with the Shellgrip surface and the reconstructed pavement, the cost of treatment includes the present worth of a second Shellgrip application in the ninth year.

(3) The analysis includes a second application of Shellgrip in the ninth year, making a total service life of 16 years.

Figure 7.2 shows the alternative values, measured from the two ends of the curve (PC1 and PC2). The selected value is tabulated in the Figure. The tabulation also shows the appropriate level of lateral offset, and whether the pole is on the inside or the outside of the bend. The corresponding relative risks are then combined with the fixed item relative risks (curvature, skid test, etc.) to determine the expected accident rate. The tabulated values sum to an expected pole accident rate for the unmodified site of 5.43 per annum, and a fence accident rate of 3.53 per annum.

The first three treatment alternatives listed in Table 7.4 effect a reduction in the expected accident rate. The first alternative involves pavement reconstruction and resurfacing with plant-mix. This should eliminate the adverse camber and pavement corrugations, although only a temporary increase in skid resistance will result, with the value returning to somewhere near the present value within 12 months. Skid resistance is therefore assumed to be effectively unaltered. The pavement improvements result in an accident probability reduction factor of 0.35 which is calculated as the product of the new relative risks for superelevation and pavement deficiencies (0.90 x 0.93) divided by the product of the old relative risks (1.20 x 2.00). The number of pole accidents 'saved' per annum is therefore 5.43 x (1-0.35) = 3.53. Similarly the number of fence collisions saved is 1.97 per annum. From Tables 5.16 and 6.1, the relevant average accident costs for each cost group are selected. The benefit accrued per annum is then the product of the number of accidents saved per annum and the average accident cost.

The treatment costs shown in Table 7.4, derived from Table 7.3, are approximate only and will vary from site to site. Costs based on the particular characteristics of each site should, of course, be used in a practical analysis. The various benefit-cost measures shown in Table 7.4 are calculated as described in Section 7.2, using a 15-year accumulated present worth factor of 9.107 from Table D.1 and a capital recovery factor of 0.110 from Table D.2. This procedure was repeated for the other two pavement treatments, with the following additional assumptions :

(i) For the treatment involving road reconstruction and resurfacing with Shellgrip, an additional application of Shellgrip in year 9 was accounted for in the costs, because the service life of this surface is only 8 years. The surface was assumed to maintain the skid resistance level in excess of 55 throughout its service life. The probability reduction factor for this treatment option was calculated as 0.16 .

(ii) It was assumed that the original road surface was of sufficient standard to enable the direct laying of Shellgrip for the third treatment alternative. This alternative resulted in a probability reduction factor of 0.47 . The figures shown in Table 7.4 for this treatment also include a second surface application in year 9 .

The luminaire pole treatments involve a reduction in accident severity rather than accident probability, and obviously have no effect on the fence accidents, except that in the case of breakaway poles a secondary collision with the fence is assumed. The expected accident rate for the five luminaire poles is 3.13 per annum (Figure 7.1). The average cost associated with house-side breakaway luminaire pole collisions is equal to the sum of the pole damage, the vehicle damage resulting from the pole impact, and the fence collision costs detailed in Table 6.1 . The following values were selected :

TC	-	\$ 5800
TCNC	-	\$ 4800
CRC	-	\$ 3650 .

The average savings per collision are obtained as the difference between the original pole collision costs and the breakaway pole collision costs. The annual savings are then simply the expected accident rate (3.13 per annum) by the savings per collision. The assumption of a secondary fence collision after every breakaway pole collision is conservative in that it is quite possible that some drivers will recover vehicle control after the primary impact and avoid colliding with the fence. This assumption results in decreased benefits being calculated.

The calculations involving the 'wrap-around' poles included two main assumptions :

(i) The vehicle entrappment rate was 100 percent.

(ii) The collisions resulted in property damage only.

These assumptions would tend to inflate the benefits associated with this alternative. To estimate the per-collision savings, an average accident cost of $2,000 was assumed for 'wrap-around' pole collisions (see Table 6.4). This cost was deducted from the average unmodified collision costs for each cost grouping shown in Table 5.16 . Once again, the annual savings are equal to the product of the per-collision savings and the expected annual accident rate.

The selection of the 'best' of the alternatives analysed in Table 7.4 has to be a compromise decision based on the funds available and the predicted savings. Obviously, the choice of costing philosophy will have a large bearing on this decision in most cases although, in the present example, all but one of the treatments can be justified for the three cost groups. For less hazardous sites, the choice of the costing philosophy will play a significant part in the warrants for treatment and the choice of treatment for implementation. It appears from Table 7.4 that, given unlimited funds, Treatment 2 will provide the greatest returns of those analysed. However, a combination of resurfacing with Shellgrip (Treatment 3) and the installation of 'wrap-around' luminaire poles (Treatment 5) is worthy of further analysis.

Case Study B.3 (Appendix B) involves many of the defects analysed in the previous example, such as pavement corrugations, low skid resistance and adverse super-elevation (Figure B.3).

TABLE 7.5

BENEFIT-COST ANALYSIS(1) OF SOME ALTERNATIVE REMEDIAL TREATMENTS FOR CASE STUDY B.3 .

Treatment	Cost Group	Cost of Treatment ($)	Present Worth of Benefits ($)	Net Discounted Present Value ($)	Annualized Net Benefit ($)	Benefit/ Cost Ratio
Remove pole (underground conductors)	TC	5 000	86 000	81 000	9 000	17.2
	TCNC	5 000	56 000	55 000	6 000	11.2
	CRC	5 000	21 000	16 000	2 000	4.2
Relocate pole to offset of 3 m	TC	1 000	69 000	68 000	7 000	69.0
	TCNC	1 000	47 000	46 000	5 000	47.0
	CRC	1 000	20 000	20 000	2 000	20.0
Convert utility pole to 'breakaway'	TC	700	34 000	33 000	4 000	48.6
	TCNC	700	13 000	12 000	1 000	18.6
	CRC	700	- 15 000	- 14 000	- 2 000	-

(1) Interest rate = 7% per annum ; service life = 15 years.

Benefit-cost analyses of treatments aimed at these defects would closely follow those presented in the previous example. However, to further illustrate the effect of pole modifications, this time involving a cable-supporting (utility) pole, three treatment options involving the subject pole shown in Figure B.3 were analysed. It is assumed that it is feasible to relocate or remove the pole (by undergrounding the conductors), and that a house-fence, set back 3 m from the curb, is the next obstacle in the path of an errant vehicle. The three options studied were :

(i) Remove the pole and underground the conductors.

(ii) Relocate the pole at least 3 m back from the road edge.

(iii) Convert the utility pole to a breakaway design.

Although not yet a practical solution, the option of modifying the utility pole was included in this example for the purposes of illustration. The reductions in accident severity and the resulting benefits for these treatment options were discussed in Section 6.2.2. The results of the benefit-cost analysis for the three options are shown in Table 7.5.

The benefits of pole removal are calculated on the basis of the number of vehicle encroachments that would have previously resulted in a pole collision (0.866 per annum in this case). These encroachments now possibly result in a house-fence collision, but at a reduced probability because of the difference in lateral offsets of the pole and the fence. For the case at hand, each (previously 'pole accident') encroachment results, on average, in 0.3 fence collisions, so the average benefit per such encroachment is the average pole collision cost (Table 5.16) less the average fence collision cost (Table 6.1) multiplied by 0.3. The annual savings are than equal to the benefits per 'pole collision' encroachment ($10,892 for the TC group) multiplied by the expected 'pole accident' encroachment rate (0.866 per annum). The benefit-cost measures in Table 7.5 are then calculated as previously described. The calculated benefits do not take account of the benefits to the supply authority resulting from the undergrounding of their utilities.

These benefits include less service interruption and the consequent increase in revenue, increased transmission efficiency of (the larger) underground conductors, and reduced maintenance and capital costs associated with equipment damage.

The relocation of the pole to a lateral offsent of 3 m for case study B.3 results in a probability reduction factor of 0.3 (new RR^{LO}_{MNI} ÷ old RR^{LO}_{MNI}). The annual savings are then calculated as the product of the average cost per collision ($12,500 for the TC group), the remaining proportion of pole collisions (1 - 0.3), and the original expected accident rate (0.866 per annum).

The conversion of the utility to a breakaway design results in a reduced primary collision severity, but is assumed to result in a secondary collision with the house-fence (see Section 6.2.2). The savings per collision are equal to the average collision cost of an unmodified pole (Table 5.16) less the collision cost associated with the modified pole (including the secondary collision).

The results indicate that, for this high risk site, the greatest return (net discounted present value) results from pole removal. However, in a program which is directed at treating as many poles as possible within a fixed budget, the option of pole modification would be desirable in that for the price of eliminating one pole, seven poles could be modified. If those seven poles have expected accident rates of the same order as the subject pole in case study B.3, then the total savings from such modifications would exceed those deriving from the elimination of only the subject pole.

It is interesting to note from Table 7.5 that utility pole modification is not economically warranted at this site if the resulting benefits are measured in terms of release of current resources only. The rejection of this relatively inexpensive treatment possibly indicates that the CRC cost philosophy does not accurately reflect society's assessment of the value of a life.

7.4 CONCLUSIONS

This Chapter has investigated the application of benefit-cost methodologies to the evaluation of alternative treatments to alleviate the pole accident problem. Illustrative examples have been presented as a guide to the use of the information on accident probabilities, costs and treatment effectiveness gathered together in this study. Several conclusions have emerged :

(i) The greatest opportunity for cost-effective remedial programs exists for poles beside mid-block sections of major roads (MNI data group) : Fifty-six percent of pole accidents occur with poles in this group, and the predictor model allows the identification of the small proportion of poles which account for the majority of accidents.

(ii) On average, poles at the intersection of major roads have the highest risk of accident involvement of any of the data groups. Selective treatment of poles at an intersection is hindered by the inability to discriminate large variations in risk. However, the number of such intersections in Melbourne is relatively small (813) and the predictor model should allow the priority ranking of intersections for remedial treatment.

(iii) When applied to the MNI data group, the 'average approach' to benefit-cost analysis (which attempts to assess the value of particular treatments for large numbers of sites) indicates that there are a number of treatment options which would return significant net societal benefits, and are worthy of investigation on a site-by-site basis.

(iv) Because the factors contributing to risk, the practical feasibility of various treatments, and the costs and benefits of such treatments all vary from site to site, each candidate site must be investigated individually to determine the performance of alternative remedial treatments. When a number of sites have been so investigated, the choice of the 'best' treatment at each will be determined, in part, also by the amount of capital funds available.

(v) The particular accident costing philosophy adopted will have a significant effect on the warrants for remedial action and the choice of treatment to be applied.

CHAPTER 8

PROJECT SUMMARY AND RECOMMENDATIONS

8.1 INTRODUCTION

As the title suggests, this Chapter is intended to be a self-contained statement of the major accomplishments of the study, unencumbered by the rigor and detail of the body of the report, and is directed at the first-time reader and policy makers. The study objectives, methodology, results and findings are summarised and recommendations are made for remedial action and further research.

8.2 PROJECT OBJECTIVES

The present study differs from most 'in-depth' accident studies previously reported in that it has concentrated on a particular type of accident. Resources were concentrated in this way to enable the collection of sufficiently large accident and control samples for detailed, and statistically reliable, investigations of causes and consequences. The study had the following broad objectives :

(a) To carry out an accident survey, to provide the detailed information on pole crashes which is not available in the regularly-reported accident statistics.

(b) To develop a statistical predictor model which allows the identification of accident risk from measurements of site characteristics.

(c) To further investigate loss reduction measures available for utility pole collisions.

(d) To obtain cost data for application to benefit-cost analyses of proposed remedial measures.

8.3 PROJECT ORGANIZATION

Data collection and analysis was primarily concerned with the engineering aspects of collisions with utility poles (cable-supporting, luminaire, traffic signal and strainer poles). To ensure that the accident survey encompassed all accident severities ranging from property-damage-only (PDO) to fatal injury, a notification network based on tow-truck operators was established. Information supplied by the towing-operators, usually within minutes of a crash, included the accident location, time of day, weather conditions and whether ambulance attendance was required. The ambulance services, in turn provided details of casualty occupants, which enabled the acquisition of detailed injury reports from the hospitals.

It was found, for the purposes of the present study, that little additional information could be obtained by attending the crash scene immediately after notification compared with approximately 12 hours later (i.e., typically, the next morning). This meant that one, centrally-placed research team was able to cover the whole Melbourne metropolitan area (excluding the Mornington peninsula), a task which would otherwise have been impossible because of the size of the survey area and the frequency of accidents. During the survey period, from 7 July 1976 to 7 March 1977, a total of 879 pole accidents were investigated. Detailed measurements of site characteristics, vehicle damage and tyre characteristics were made. Information on costs to all affected parties was also obtained.

Control information on vehicle and site characteristics was obtained by repeating the appropriate measurements for randomly-selected samples of 795 pole sites and 627 vehicles. Without these data few useful inferences could have been made about the factors determining accident occurrence or severity.

8.4 CHARACTERISTICS OF POLE ACCIDENTS

Comparison with Road Safety and Traffic Authority (RoSTA) data on casualty accidents for the Melbourne Metropolitan area in which a pole was the first object struck showed that the present eight-month survey, which included 31 fatalities and 374 injured persons, achieved a 65 percent coverage of all personal injury pole accidents and a complete coverage of fatal pole accidents. The coverage of tow-away PDO accidents was to be 65 percent also. Within the study area the accident coverage was estimated to be 90 percent. Seventy percent of the accidents studied resulted in porperty damage only.

Whereas RoSTA's data (based on police reports) refer to primary pole collisions only, 15 percent of the cases in the present survey involved secondary pole collisions which were judged to have made a significant contribution to the severity of the accident. Including these collisions, it is estimated that pole accidents in the Melbourne metropolitan area result in 45 fatalities and 785 injured persons annually. These figures represent approximately 7.4 ~~4.8~~ percent and 5.7 ~~4.2~~ percent of the respective totals for all road accidents in Melbourne. The RoSTA data show that primary pole collisions account for 45 percent of fatal fixed-object collisions and 52 percent of personal injury fixed-object collisions. They clearly represent a social problem of some magnitude.

A number of characteristics of pole accidents which emerge from the accident sample are :

(a) In terms of the number of fatal accidents per 100 casualty accidents, pole accident severity is 1.5 times greater than the average over all accidents.

(b) The majority (82%) of the present accident sample came from major roads (CBR class 6 or 7).

(c) Sixty-eight percent of the accidents were at non-intersection sites ; nearly half of these involved horizontal curvature of the road.

(d) More accidents occurred on Sunday morning between midnight and 3 a.m. than in any other three-hour period during the week. In terms of the number of vehicles on the road the greatest risk of a pole accident occurs between 3 a.m. and 4 a.m. Fifty percent of the accidents studied occurred in the hours of darkness.

(e) Pole accidents are four times more likely to occur when the roads are wet than when they are dry. Thirty-eight percent of the accident sample arose from wet road accidents.

(f) The majority of poles hit at curved-road sites were on the outside of the bend. The proportion was reduced when the roads were wet, apparently because of a change in the loss of control mechanism.

(g) Alcohol seems to play a larger role in pole accidents than in other accident types.

(h) Sixty-nine percent of the accidents involved frontal impacts. Side and oblique impacts were generally more severe than frontal impacts because of higher occupant space penetration. A strong relationship between level of injury and depth of intrusion was found. Despite the increased severity of side and oblique impacts, sixty-six percent of casualties arose from frontal impacts.

(i) Pole material and function seem to be unrelated to accident occurrence and have only a slight effect on accident severity. This is because all poles presently in service are effectively rigid.

(j) Sixty-one percent of the casualty occupants were male and were typically in the age group between late teens and early twenties.

(k) Nearly half of the injuries sustained were classified as minor. The most common injury location was the head, face and neck region (45%), followed by the upper torso (15%).

(ℓ) In frontal impacts the life-threatening injuries were fairly evenly divided between the head and neck, the upper torso and the abdominal regions. In side impacts they were concentrated more on the head and neck and upper torso areas. The location of injuries was correlated with the direction of impact.

8.5 POLE ACCIDENT OCCURRENCE AND SEVERITY AS RELATED TO SITE, VEHICLE AND POLE CHARACTERISTICS

8.5.1 Site Characteristics Related to Pole Accident Occurrence

As previously stated, a major aim of the present study was the determination of a statistical model which would allow the identification of variations in accident probability as a function of measurable pole site characteristics. To this end measurements of roadway, traffic and pole placement variables were made at a sample of sites at which pole accidents had occurred, and at a control group of randomly-selected pole sites. To ensure that subsequent statistical analysis was possible, the 'random' sample was stratified according to site description (intersection/non-intersection) and road class (as defined by the Commonwealth Bureau of Roads, 1969). Accordingly, the analysis of the effects of site characteristics on pole accident occurrence was carried out within these data groups.

The statistical analysis was based on the concept of 'relative risk' which measures the accident involvement of poles with a given site attribute (e.g., curvature) relative to their numbers in the population of all poles. The final model allows the calculation of the expected annual accident rate for a given site as a function of measured site characteristics. For the major road non-intersection model, the following data are required :

(a) Maximum horizontal curvature upstream of the pole.

(b) Annual average daily traffic.

(c) Pendulum skid test.

(d) Lateral offset of pole.

(e) Road width (for undivided roads only).

(f) Distance between the pole and the start of the curve.

(g) Pavement deficiencies (corrugations etc.).

(h) Superelevation at curve.

(i) Pole on the inside/outside of bend.

This model was highly successful in discriminating between poles at risk : the range of risks identified was of the order of 1000 : 1 ; site characteristics associated with only 10 percent of the poles in the population were found in 50 percent of the accident sites. For the minor road non-intersection model the corresponding figure was 65 percent of accident sites.

The groups of poles subsequently shown to afford the greatest opportunity for cost-effective remedial action are those at non-intersection major road sites and at the intersections of major roads. For the latter group the data required for the predictor model are :

(a) Annual average daily traffic for both roads.

(b) Pendulum skid test.

(c) Grade into the intersection.

(d) Roads divided/undivided.

(e) Lateral offset of the pole.

(f) Intersection type.

It can be seen that these variables largely describe the characteristics of the intersection. Apart from its lateral offset, there is little to distinguish the accident risk of one pole from another at the intersection of major roads.

8.5.2 Accident Severity as a Function of Site Characteristics

Levels of occupant injury and vehicle damage were compared for the three major site categories :

(a) Curved road non-intersection sites.

(b) Straight road non-intersection sites.

(c) Intersection sites.

It was found that accidents on curves were slightly more severe than on straight roads because of an increased number of side impacts on curves. The crashes with poles in both non-intersection categories were considerably more severe than those at intersections. Damage to poles and their associated utilities did not vary between site classifications.

8.5.3 The Effect of Vehicle Characteristics on Accident Occurrence

There is a lack of detailed information on the distribution of vehicle characteristics in the population of vehicles on the road. Because of this lack the analysis of the effect of vehicle characteristics on accidents was somewhat limited. To overcome the deficiency, in part, a random survey of vehicles was made, concentrating on the measurement and recording of tyre variables. The distributions of vehicle make, year of manufacture and body style in the random sample were found to be very similar to those in Australian Bureau of Statistics (ABS) figures for all vehicles on register in Victoria, suggesting that the tyre characteristics measured were representative of the general population.

A number of tyre-related variables had a significant effect on accident occurrence :

(a) Relative accident involvement increased markedly for tread depths less than 3 mm, particularly on wet roads. It was found that a vehicle with a tread of only 0.5 mm was about 15 times more likely to be involved in an accident than one with 5 mm tread depth.

(b) The effects of under- and over-inflation of tyres relative to specifications was investigated from the point of view of the influence on vehicle handling characteristics known to be important to driver/vehicle performance. A strong relationship was found between average pressure margin (the difference between observed and specified inflation pressure averaged over all four wheels) and accident occurrence. Average pressure margin is related to the response time of the vehicle to steering inputs. General under-inflation (associated with longer response time) is associated with a higher accident risk.

Vehicle understeer/oversteer, on the other hand, is sensitive to the difference between the front and rear tyre cornering stiffnesses and, hence, to the front-rear pressure margin (FRPM). A positive FRPM indicates that, compared with the specified balance between front and rear tyre pressures, the front tyres are over-inflated, leading to a reduction in the amount of understeer or possibly the production of oversteer characteristics. The data showed that deviations in FRPM in both directions caused an increase in accident involvement ; the effect of reduced understeer being associated with increased hazard for curved sites was particularly strong. As with the average pressure margin, a substantial proportion of the accident vehicles had hazardous deviations of tyre pressures from the specified levels.

(c) Tyre construction. Compared with other tyre factors the effect of tyre construction on accident risk was relatively weak. Radial-ply tyres proved marginally 'safer' than cross-ply or recapped tyres.

8.5.4 Accident Severity as a Function of Vehicle Characteristics

The only vehicle characteristic analysed which had a significant effect on accident severity was the vehicle mass. Reduced vehicle mass was associated with higher injury levels and slightly less pole and utility damage.

8.5.5 Accident Severity as a Function of Pole Type

All the poles in the present study were effectively rigid. No difference in accident severity, as measured by injuries and vehicle damage, was detected between poles classified by material or function. The level of damage to the pole and its utilities did vary with pole classification however.

8.6 THE COST OF POLE ACCIDENTS

A review of the available literature revealed a wide range of accident cost estimates, particularly with regard to assigning a value to the loss of life, largely dependent on the inclusion or non-inclusion of the loss of future production associated with permanent disability or death.

Three broad philosophies relating to the costing of road accidents emerged from the literature. The societal cost associated with each level of the Abbreviated Injury Scale was calculated for the three costing philosophies, using local data collected in this study where possible and employing Faigin's (1976) study for the U.S. Department of Transportation as a guide otherwise. The calculations may be regarded as underestimates as they make no allowance for intangibles such as pain and suffering.

If the loss in societal welfare is measured in terms of consumption of current resources and foregone production, the cost to the community of a fatality is estimated to be $204 600. The annual cost of pole accidents in the Melbourne metropolitan area, according to the same costing philosophy, is estimated to be $23 million and average cost per tow-away accident is $11 200.

Considering the effect of impact direction on the vehicle on societal costs, it was found that :

(a) Side and oblique impacts have a higher mean cost per accident than frontal impacts if the value of lost production is accounted for.

(b) Because of their greater frequency, the bulk of the societal costs result from frontal impacts. However, there are significant gains to be made from side impact crashworthiness improvements as well.

8.7 PERFORMANCE OF ALTERNATIVE LOSS REDUCTION MEASURES

The term 'loss reduction' is taken here to refer to a lowering of the societal cost of pole accidents, the emphasis being on the cost to the community as a whole rather than costs to specific groups or individuals. Loss reductions at a particular accident 'black spot' can be achieved by a reduction in accident severity or probability or both. An analysis of the literature relating to available loss reduction measures revealed that :

(a) The most effective method of loss reduction in relation to pole accidents is pole removal. As with other methods, of course, the benefits must be weighed against the costs.

(b) The installation of crash barriers or attenuators would not be an effective loss-reduction measure for pole accidents in the urban road system.

(c) Crashes with breakaway or wrap-around luminaire poles produce significantly lower societal costs than those with rigid luminaire poles. It has been the South Australian Highways Department's experience that such savings can be achieved at little or no extra cost to the authority owning and installing the poles.

(d) The argument sometimes advanced against breakaway poles, suggesting that they would involve unacceptably hazardous secondary collisions, danger to pedestrians, or increased cross-median collisions, have been shown to be unfounded. Such effects, if any, would be insignificant compared with the reduction in the severity and cost of pole accidents.

(e) Based on the results of preliminary scale model tests, a scheme for modifying timber, cable-supporting, utility poles has a significant potential for loss reduction.

(f) Substantial improvements in vehicle crashworthiness in pole impacts do not appear feasible at current levels of technology, and within societal constraints on cost and consumption of material and fuel resources.

(g) Resurfacing and re-aligning the road can also provide societal returns for high-risk locations. The 'Shellgrip' resurfacing technique appears to provide an accident-reducing treatment which maintains its effectiveness over a long service life.

8.8 THE EVALUATION OF SELECTED LOSS REDUCTION PROGRAMS

The application of benefit-cost methodologies to the evaluation of alternative treatments to alleviate the pole accident problem was investigated. The practical application of the information gathered together in this study with respect to accident probability, costs and treatment effectiveness, in conjunction with the selected benefit-cost measures, was demonstrated by way of a number of illustrative examples. Several conclusions emerged :

(a) The greatest opportunity for cost-effective remedial programs exists for poles beside mid-block sections of major roads (MNI data group) : Fifty-six percent of pole accidents occur with poles in this group, and the predictor model allows the identification of the small proportion of poles which account for the majority of accidents.

(b) On average, poles at the intersection of major roads have the highest risk of accident involvement of any of the data groups. Selective treatment of poles at an intersection is hindered by the inability to discriminate large variations in risk. However, the number of such intersections in Melbourne is relatively small (813) and the predictor model should allow the priority ranking of intersections for remedial treatment.

(c) When applied to the MNI data group, the 'average approach' to benefit-cost analysis (which attempts to assess the value of particular treatments for large numbers of sites) indicates that there are a number of treatment options which would return significant net societal benefits, and are worthy of investigation on a site-by-site basis.

(d) Because the factors contributing to risk, the practical feasibility of various treatments, and the costs and benefits of such treatments all vary from site to site, each candidate site must be investigated individually to determine the performance of alternative remedial treatments. When a number of sites have been so investigated, the choice of the 'best' treatment at each will be determined, in part, also by the amount of capital funds available.

(e) The particular accident costing philosophy adopted will have a significant effect on the warrants for remedial action and the choice of treatment to be applied.

8.9 RECOMMENDATIONS

8.9 .1 Recommendations for Remedial Action

It has been demonstrated that significant societal savings, both in terms of life and limb and consumed resources, could be made through the implementation of known remedial measures at selected sites on urban roads. In order that these potential savings may be realized, the following recommendations are made :

1. Central government should establish a policy on the costing of accidents and allocate funds for remedial programs which will result in net societal gains. Mechanisms should be established for ensuring that costs and benefits are equitably shared.

2. A central co-ordinating body in each State should be given responsibility for implementing the following program of remedial action, concentrating initially on the major road system:

    (a) Compile an inventory of pole site characteristics coded for computer analysis.

    (b) Apply the accident predictor model to rank sites in order of accident probability.

(c) Starting with the highest ranked sites automatically generate a list of candidate remedial treatments which appear warranted for each site, based on the site characteristics making the greatest contribution to risk, and average treatment costs.

(d) From site inspection determine the practicability of the candidate treatments and any special site requirements and costs.

(e) Apply benefit-cost analyses to the selected treatments.

(f) Within the context of available funds, co-ordinate **select and** implement the combination of sites and treatments which will result in the greatest societal benefits.

3. 'Black spot' poles identified during the accident survey and/or from accident records should be investigated immediately. As a matter of on-going policy, all pole collisions should be investigated with a view to remedial site treatment.

4. As a further matter of policy, all luminaire poles requiring replacement, either due to crash damage or routine maintenance, should be replaced with 'breakaway' or 'wrap-around' designs. These poles should also be installed as part of a selective program using the method of recommendation 1 .

5. For new installations :

(a) Breakaway or wrap-around luminaire supports should be mandatory.

(b) The undergrounding of conductor cables should always be considered, taking into account the expected accident cost savings and aesthetic benefits.

(c) Poles which are required should be offset at least 3 m from the road edge (Figure 4.14), and should not be placed on the outside of curves (Table 4.4) or near curve entry and exit points (Figure 4.22).

(d) Horizontal curvature of the road should not exceed 0.005 m^{-1} (Figure 4.9) and should be accompanied by appropriate superelevation (Table 4.3).

(e) Four-lane, two-way roads should preferably be divided (Figures 4.17 and 4.18).

(f) Pavement skid resistance should be maintained to give a pendulum skid test value greater than 50 (Figure 4.11) and the road surface should be free from corrugations and other defects (Table 4.5).

8.9.2 Recommendations For Future Research

1. The present approach of concentrating study resources on a particular accident type known to result in significant losses should be applied to other accident types in both rural and urban areas.

2. The intersection of major roads model would benefit from a better structured control sample. Obtaining one would be a relatively simple task as there are only about 800 such intersections in the Melbourne metropolitan area.

3. Accident attenuating modifications to pole designs should be investigated further for both traffic-signal poles and cable-supporting poles.

4. Although vehicle 'handling' characteristics appear, from the present study results, to be related to pole accident occurrence, it is not yet possible to define mandatory standards for vehicle design. However, an education campaign directed at drivers and garage attendants, on the importance of maintaining tyre inflation pressures at manufacturers' recommended levels, is worthy of consideration. Further work is required to define the relationship between vehicle characteristics and accident causation.

5. Strictly on a safety basis the minimum legal tread depth should be 3 mm. Investigations of the economic consequences of such a standard should be made. As the relationship between lower tread depths and increased accident involvement was found to be quite strong even on dry roads, enformement of the tread depth limit could well result in the detection of other accident-related driver or vehicle characteristics.

6. The legal responsibilities of the owners of unnecessarily hazardous roadside assets(such as rigid luminaire supports) should be clarified.

7. In Chapter 5 it was found that local data are not available for a number of accident cost components. Further research is required to improve accident cost estimates.

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APPENDIX A

THE DERIVATION OF THE VARIANCE OF A POINT ESTIMATE OF RELATIVE RISK

The author is indebted to Mr. Max Cameron, consultant statistician, for the structure of the following analysis.

A guide to the level of 'confidence' that can be placed in a particular estimate of relative risk, for a given level of an attribute (e.g., curvature), can be provided by the variance of that estimate.

The following analysis derives an estimate of the variance of a point value of relative risk.

For a sample of N accident poles, let n have the attribute A, and for a sample of M random poles let m have the attribute A. For the purposes of this analysis, attribute A is defined as a particular level of a given site parameter such as curvature. For example, attribute A could be defined as roadway horizontal curvature between 0.01 and 0.02 m^{-1} ; poles associated with curvatures between these limits are then said to have attribute A. If a pole is selected from either population, then the possible outcomes of the selection 'trial' are that it has attribute A or not A.

Define the probability of selecting a random pole with attribute A as

$$\Pr\{A \mid \text{random pole}\} = p$$

Define the probability of selecting an accident pole with attribute A as

$$\Pr\{A \mid \text{accident pole}\} = \mu p$$

where μ = relative risk.

For a sample of N accident poles, the probability of finding n with attribute A is given by the binomial distribution :

$$\Pr\{n\} = \frac{N!}{n!(N-n)!} (\mu p)^n (1-\mu p)^{N-n}$$

Similarly, for a sample of M random poles, the probability of finding m poles with attribute a is

$$\Pr\{m\} = \frac{M!}{m!(M-m)!} (p)^m (1-p)^{M-m}$$

If n and m are independent, then the probability that both observed numbers are obtained is

$$\Pr\{n,m\} = \Pr\{n\}\Pr\{m\}$$

$$= \frac{N!}{n!(N-n)!}\ \frac{M!}{m!(M-m)!} (\mu p)^n (1-\mu p)^{N-n} (p)^m (1-p)^{M-m} \tag{A.1}$$

The method of maximum likelihood is used to find the values of μ and p that maximise the probability of $\Pr\{n,m\}$. Such values are known as maximum likelihood estimators and are denoted $\hat{\mu}$ and $\hat{p}$.

The likelihood function, L , for (A.1) is written (Kendall and Stuart, 1973) :

$$L(n,m|\mu,p) = (\mu p)^n (1-\mu p)^{N-n} (p)^m (1-p)^{M-m} \tag{A.2}$$

The estimators $\hat{\mu}$ and $\hat{p}$ are then the values of μ and p that maximise the likelihood function (A.2). They are found by setting the partial derivates of L with respect to μ and p equal to zero. It is easier in this case to work with the logarithm of L . Log L and L will have maxima together, and therefore lead to the same result. From (A.2), the logarithm of L is obtained,

$$\ell og\ L = m\ \ell og\ p + (M-m)\ \ell og\ (1-p) + n\ \ell og\ \mu p + (N-n)\ \ell og\ (1-\mu p) \tag{A.3}$$

For the likelihood function to be a maximum

$$\frac{\partial \, \ell og \, L}{\partial p} = 0 \,, \quad \text{when} \quad p = \hat{p} \tag{A.4}$$

and

$$\frac{\partial \, \ell og \, L}{\partial \mu} = 0 \,, \quad \text{when} \quad \mu = \hat{\mu} \tag{A.5}$$

From (A.3)

$$\begin{aligned} \frac{\partial \, \ell og \, L}{\partial p} &= \frac{M}{p} - \frac{M-m}{1-p} + \frac{n}{p} - \frac{(N-n)\,\mu}{1-\mu p} \\ &= \frac{m+n}{p} - \frac{M-m}{1-p} - \frac{(N-n)\,\mu}{1-\mu p} \end{aligned} \tag{A.6}$$

$$\frac{\partial \, \ell og \, L}{\partial \mu} = \frac{n}{\mu} - \frac{(N-n)\,p}{1-\mu p} \tag{A.7}$$

from (A.5) and (A.7)

$$n(1 - \hat{\mu}\hat{p}) = (N-n)\,\hat{\mu}\hat{p}$$

$$\therefore \quad \hat{\mu}\hat{p} = \frac{n}{N} \tag{A.8}$$

From (A.4) and (A.6), an expression for $\hat{p}$ can be obtained :

$$(1-\hat{p})\,[(m+n)(1-\frac{n}{N}) - (N-n)\frac{n}{N}] = (M-m)\,\hat{p}\,(1 - \frac{n}{N})$$

$$\therefore \quad \hat{p} = \frac{m}{M} \tag{A.9}$$

Inserting (A.9) into (A.8) gives an expression for $\hat{\mu}$:

$$\hat{\mu} = \frac{n/N}{m/M} \tag{A.10}$$

It is heartening to note that the maximum likelihood estimator of $\hat{\mu}$ is in fact the expression derived for relative risk in Section 4.2.

The variance $\text{var}(\hat{\mu})$ is obtained from the dispersion matrix (Kendall and Stuart, 1973), the converse of which, for the present two parameter case, is given by :

$$[R] = [V]^{-1} = E\begin{bmatrix} -\dfrac{\partial^2 \ \ell og\ L}{\partial p^2} & -\dfrac{\partial^2 \ \ell og\ L}{\partial p\ \partial \mu} \\ -\dfrac{\partial^2 \ \ell og\ L}{\partial \mu\ \partial p} & -\dfrac{\partial^2 \ \ell og\ L}{\partial \mu^2} \end{bmatrix}$$

From (A.2)

$$\frac{\partial^2 \ \ell og\ L}{\partial p^2} = -\frac{m+n}{p^2} - \frac{M-m}{(1-p)^2} - \frac{(N-n)\mu^2}{(1-\mu p)^2} \tag{A.11}$$

$$\frac{\partial^2 \ \ell og\ L}{\partial^2\ \mu^2} = -\frac{n}{\mu^2} - \frac{(N-n)\ p^2}{(1-\mu p)^2} \tag{A.12}$$

$$\frac{\partial^2 \ \ell og\ L}{\partial \mu\ \partial p} = \frac{\partial^2 \ \ell og\ L}{\partial p\ \partial \mu} = -\frac{N-n}{(1-\mu p)^2} \tag{A.13}$$

Since m has the binomial distribution, the expected value of m, $E[m]$, is given by

$$E[m] = Mp \tag{A.14}$$

Similarly the expected value of n, $E[n]$, is

$$E[n] = N\ \mu p \tag{A.15}$$

Substituting (A.14) and (A.15) into equations (A.11) through (A.13) gives

$$[R] = \begin{bmatrix} \dfrac{M(1-\mu p) + N\mu(1-p)}{(p(1-p)\ (1-\mu p)} & \dfrac{N}{1-\mu p} \\ \dfrac{N}{1-\mu p} & \dfrac{Np}{\mu(1-\mu p)} \end{bmatrix}$$

The inverse of [R] is equal to the dispersion matrix [V] :

$$[V] = \frac{\mu(1-p)(1-\ p)}{MN} \begin{bmatrix} \dfrac{Np}{\mu(1-\mu p)} & -\dfrac{N}{1-\mu p} \\ -\dfrac{N}{1-\mu p} & \dfrac{M(1-\mu p)+N\mu(1-p)}{p(1-p)\ (1-\mu p)} \end{bmatrix}$$

From Kendall and Stuart, $\mathrm{var}(\hat{\mu})$ is given by V_{22}

$$\mathrm{var}(\hat{\mu}) = \frac{\mu}{p}\left[\frac{1-\mu p}{N} + \frac{\mu(1-p)}{M}\right] \tag{A.16}$$

For example, let

$$n = 115$$
$$m = 28$$
$$N = 481$$
$$M = 433$$

From (A.8)

$$\hat{\mu} = \frac{n/N}{m/M}$$

$$\hat{\mu} = 3.69$$

From (A.7)

$$\hat{p} = \frac{m}{M}$$

$$\hat{p} = 0.065$$

Therefore $\hat{\mu}\hat{p} = 0.240$.

From (A.16), the estimate of the variance of $\hat{\mu}$ is

$$\widehat{\mathrm{var}(\hat{\mu})} = \frac{3.69}{0.065}\left[\frac{1-0.240}{481} + \frac{3.69(1-0.065)}{433}\right]$$

$$\widehat{\mathrm{var}(\hat{\mu})} = 0.54 \ .$$

So that the standard deviation of $\hat{\mu}$ is estimated by

$$\widehat{\mathrm{SD}(\hat{\mu})} = \sqrt{\widehat{\mathrm{var}(\hat{\mu})}}$$

$$= 0.74 \ .$$

The example chosen is in fact a point on Figure 4.9, the plot of relative risk versus absolute maximum curvature. The relative risk plotted at $|K_{MAX}| = 0.015$ is equal to 3.69, with the 'confidence' intervals plotted as $\hat{\mu} = 3.69 \pm 0.74$.

APPENDIX B

USERS MANUAL FOR THE ACCIDENT PREDICTION MODEL

In this appendix the results derived in Chapter 4 are summarized for convenience in application of the accident prediction model. Three case studies are also presented, as a guide to the use of the model. They cover the range of most possible applications, and are worked out step-by-step.

Table B.1 describes the predictor variables used in the various detailed models, and defines the units of measurement and the symbols used to represent the variables.

Table B.2 classifies poles into the various data groups and assigns the relative risks associated with membership of each group. It should be noted that:

'Major road' refers to an arterial or sub-arterial road (CBR Functional Classes 6 and 7)
'Minor road' refers to a residential street (CBR Functional Class 8).

A complete set of relative risk graphs and tables follows, the information for each data group being preceded by a face sheet which lists the predictor variables for which values are required. If any item of data required for the model is unavailable, or cannot be estimated, its relative risk should be set to 1.0. However, the discriminatory power of the model will be progressively weakened with each ommission of a data item.

CASE STUDY NO. 1

Introduction

The first case study involves the road layout depicted in Figure B.1. The vehicle shown is travelling in such a direction that it has to negotiate a right hand curve. Clearly, there are a number of poles at risk in a situation such as this, and all poles in the vicinity of the curve need to be examined. The risk changes for each pole as a function of its position in relation to the curve, parameters stay fixed. The model should be applied to each pole in turn, producing a total relative risk for each. These can then be used in the calculations of accident probability which are required for decisions concerning possible remedial treatment.

TABLE B.1

VARIABLE DESCRIPTION AND NOMENCLATURE

Symbol	Variable Description
$\lvert K_{MAX} \rvert$	The absolute maximum horizontal curvature of the roadway at or upstream of the pole (m^{-1})
AADT	Annual average daily traffic.
ST	British pendulum portable skid test result.
LO	Lateral offset of the pole, measured from the roadside edge of the pole to the curb, or to the edge of sealed pavement where no curb is present (m)
W	The width of the road, as defined by the distance between curbs (m). It is equal to the total road width for an individed road, and the 'one-way' road width for a divided road.
DC	This variable relates to curved sites and measures the distance between the start of the curve and the pole (m).
PD	Pavement deficiencies, such as corrugations, tramlines, or a dip or sharp crest.
e	Super elevation at the curve. Positive if pavement is rotated clockwise from horizontal when viewed in direction of travel of vehicles.
IOB	Dichotomous variable denoting the placement of the pole on the outside or the inside of a bend.
G	Grade of the roadway (%). Positive when uphill.
DV	Dichotomous variable denoting a divided or undivided road.
IT	Intersection type ('cross' or 'tee').
RP	Radial distance of the pole from the centre of the intersection (m).

For this example, the pole marked with an "X" in Figure B.1 will be analysed, with the direction of travel of the vehicle as shown.

POLE CLASSIFICATION

The subject pole is not close to an intersection and, as it is adjacent to a major road, it is classified as a member of the MNI data group. Table B.2 assigns a relative risk of 4.36 to the pole on this account. The face sheet to the MNI detailed model information lists the predictor variables for which values are required.

Detailed Model

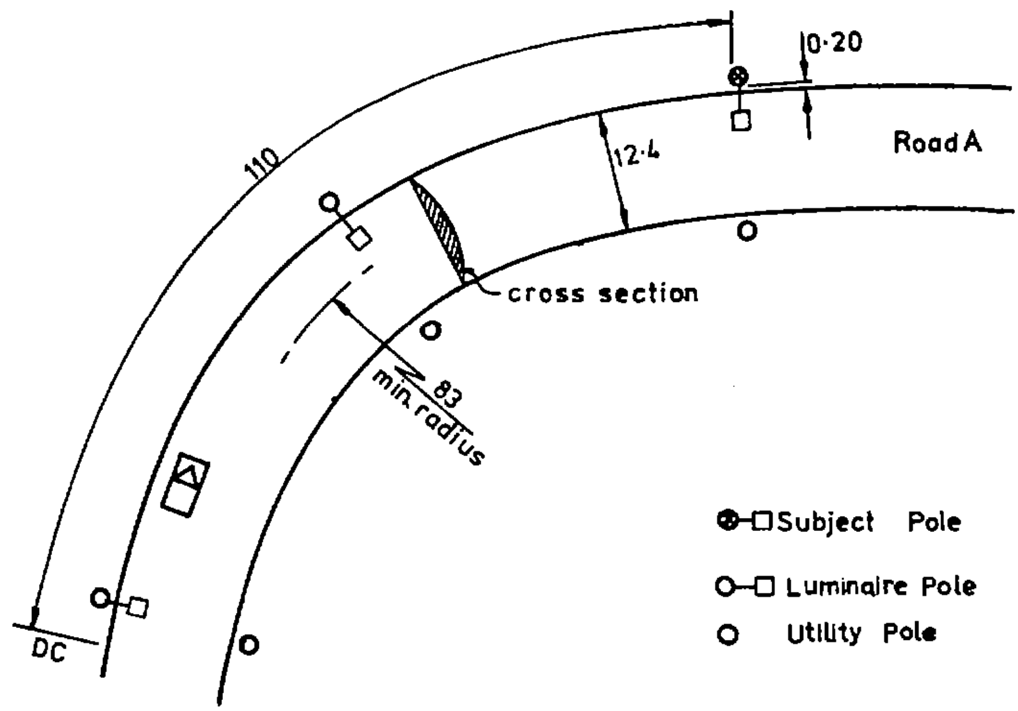
Continuous measurements of horizontal curvature for the present study were made using an instrumented vehicle. The predictor variable adopted for the model was maximum curvature rather than average curvature, and it is important to observe this distinction. Measurements of maximum curvature do not require an instrumented vehicle, of course, and could be obtained from plans or site measurements.

It is recommended that the measurements of road surface friction using the British pendulum skid tester be taken at several locations in the vicinity of the pole, with at least five readings being taken at each location. The figure used in the model is the average of all these readings.

The convention concerning the sign of the superelevation is important (see Table B.1). The correct 'banking' for a right hand curve would be positive superelevation. In the present case study, the superelevation is negative, which is unfavourable for a right hand curve.

Note that the relative risk for distance between curbs (road width) for divided roads in this data group is set equal to 1.0. However, as the roadway in this case is undivided, the relative risk is obtained from Figure B.8.

For the data listed in Figure B.1, the individual relative risks are obtained from the relevant graph or table as shown in the following tabulation.



DATA TABLE

Variable	Road A
Road class	Major road
$\lvert K_{max} \rvert$	0·012 (m^{-1})
AADT	17500
ST	45
LO	0·20 (m)
W	12·4 (m)
DC	110 (m)
PD	Corrugations
e	Negative
OIB	Outside

Figure B.1. Case Study Number 1

MNI MODEL -- CASE STUDY NO. 1

Variable	Value	RR	Source [1]
Data group	MNI	4.36	T/B.2
$\lvert K_{MAX} \rvert$	0.012	3.10	F/B.4
AADT	17500	1.24	F/B.5
ST	45	1.50	F/B.6
LO	0.20	1.38	F/B.7
W	12.4	1.32	F/B.8
DC	110	1.12	F/B.9
PD	Corrugations	2.00	T/B.3
e	negative	1.20	T/B.4
OIB	outside	1.15	T/B.5

(1) T-denotes Table
F-denotes Figure

The total relative risk is then the product of all the individual relative risks:

$$TRR = 141.6$$

Expected Accident Rate.

The total relative risk, when multiplied by the mean probability $\bar{P}$ that a 'pole-second' trial will result in an accident, and by the number T of trials in a year, yields the expected number of accidents per year :

$$\begin{aligned} \nu &= TRR \times \bar{P}T \\ &= 141.6 \times \frac{3.785 \times 10^{-3}}{T} \times T \\ &= 0.536 \text{ acc. p.a.} \end{aligned}$$

Therefore the probability of one or more accidents occurring in a year is

$$\begin{aligned} Pr(N\geq 1) &= 1 - Pr(N=0) \\ &= 1 - e^{-0.536} \\ Pr(N\geq 1) &= 0.415 \end{aligned}$$

This information may then be used with a cost-benefit model to decide on what course of remedial action is warranted.

CASE STUDY NO. 2

Introduction

This case study represents a common situation: the intersection of a major road and a minor road (Figure B.2). The tables and graphs pertaining to the intersection models refer to roadway 1 and roadway 3. (The origins of this convention lie in the coding of the accident cases where roadway 2 was reserved to denote the road on which a second vehicle was travelling before it collided with the 'pole vehicle', prior to a secondary pole collision.)

For this MJMI data group, the 'pole vehicle' road -- roadway 1 -- was the major road in 90% of the accident cases, and the relative risk graphs have been derived accordingly. For this group then

roadway 1 = major road

roadway 3 = minor road (also referred to as the intersecting road).

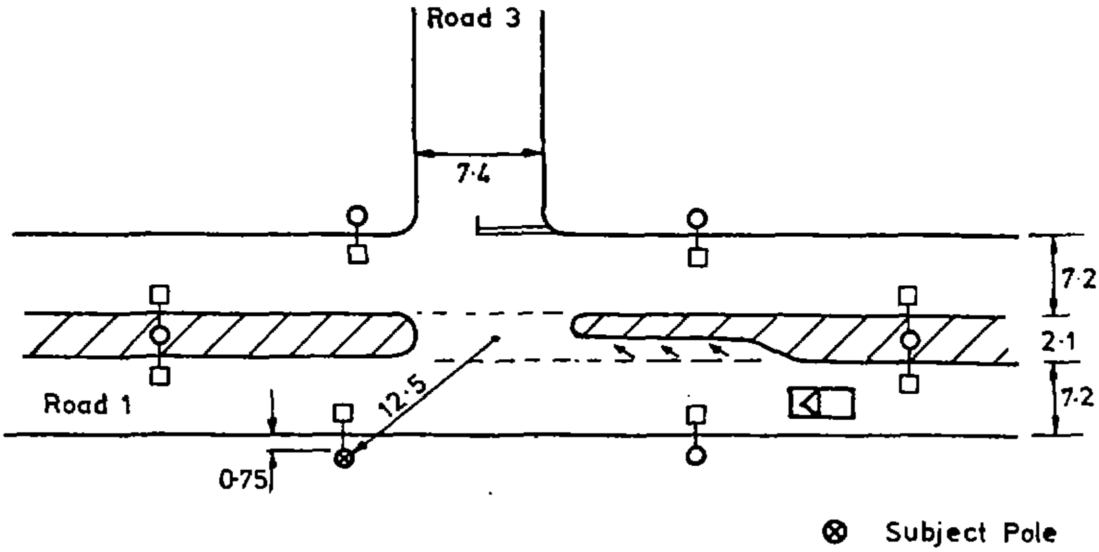
Once again, in this case study there is more than one pole at risk. For the purposes of illustration, however, only one will be analysed. For the case in Figure B.2, with the vehicle shown travelling in a westerly direction, the poles on the northern 'house-side' of the road have a lower accident risk than the median or near house-side (NHS) mounted poles. However, having applied the model to NHS and median poles for the direction of travel shown, it should also then be applied for the easterly direction of travel for which the northern house-side poles would be more at risk.

Pole Classification

A decision regarding whether to classify the subject pole shown as a MNI or as a MJMI is best left to the models. It is recommended that all possible relevant models (in this case MNI and MJMI) be tried on the pole, with the model giving the highest total relative risk being adopted. It suffices to say that, given the urban speed limits, and the observations made during the accident survey, poles within two 'pole spacings' of an intersection can be considered worthy of testing with the intersection model.

Detailed Models and Accident Rates

For the pole shown, the intersection model leads to the following result:



DATA TABLE

Variable	Road 1	Road 3
Road class	Major	Minor
Int. type	T	T
AADT	12500	—
ST	64	—
LO	0·75 (m)	—
W	—	7·4 (m)
DV	Divided	—
G	— 2·6 %	—
PR	12·5 (m)	—

Figure B.2. Case Study Number 2

MJMI MODEL -- CASE STUDY NO. 2

Variable[1]	Value	RR	Source
Data group	MJMI	0.65	T/B.2
Int. type	T	0.70	T/B.1D
AADT1	12500	0.65	F/B.20
ST1	64	0.60	F/B.21
LO	0.75	1.42	F/B.22
W3	7.4	0.64	F/B.23
DV1	Divided	0.58	T/B.9
G1	-2.6	1.00	F/B.24
PR	12.5	1.04	F/B.25

(1) The tags on the variables (ie 1 or 3) refer to the roadway numbers. (e.g. AADT1 = AADT on roadway 1).

The total relative risk for the intersection model is then the product of all the individual relative risks:

$$TRR = 0.0973$$

The predicted annual accident rate is then

$$\begin{aligned} \nu &= TRR \times \bar{P}T \\ &= 0.0973 \times 3.785 \times 10^{-3} \\ &= 3.68 \times 10^{-4} \text{ acc. p.a.} \end{aligned}$$

The probability of one or more accidents in a year at this pole, as a result of its proximity to the intersection is

$$\begin{aligned} Pr(N \geq 1) &= 1 - \exp(-3.68 \times 10^{-4}) \\ &= 3.68 \times 10^{-4} \end{aligned}$$

In other words, it is highly unlikely that an intersection caused pole accident will occur.

The case is now reworked for the MNI model. As the road is divided, the W relative risk associated with road width is set to 1.0. Also, since this site does not involve curvature, the curvature-related variables DC, e and OIB have assigned relative risks of 1.0.

MNI MODEL -- CASE STUDY NO. 2

Variable	Value	RR	Source
Data group	MNI	4.36	T/B.2
$\lvert K_{max} \rvert$	0.0	0.60	F/B.4
AADT	12500	1.04	F/B.5
ST	64	0.70	F/B.6
LO	0.75	1.25	F/B.7
DC	-	1.0	-
PO	None	0.93	T/B.3
e	-	1.0	-
OIB	-	1.0	-

The total relative risk is then

$$TRR = 2.214$$

and $\nu = 8.38 \times 10^{-3}$ acc. p.a.

and $Pr(N \geqslant 1) = 8.34 \times 10^{-3}$

The MNI model also results in a low accident probability, although higher than for the MJMI model. There will of course, be situations where the reverse is true.

CASE STUDY NO. 3

Introduction

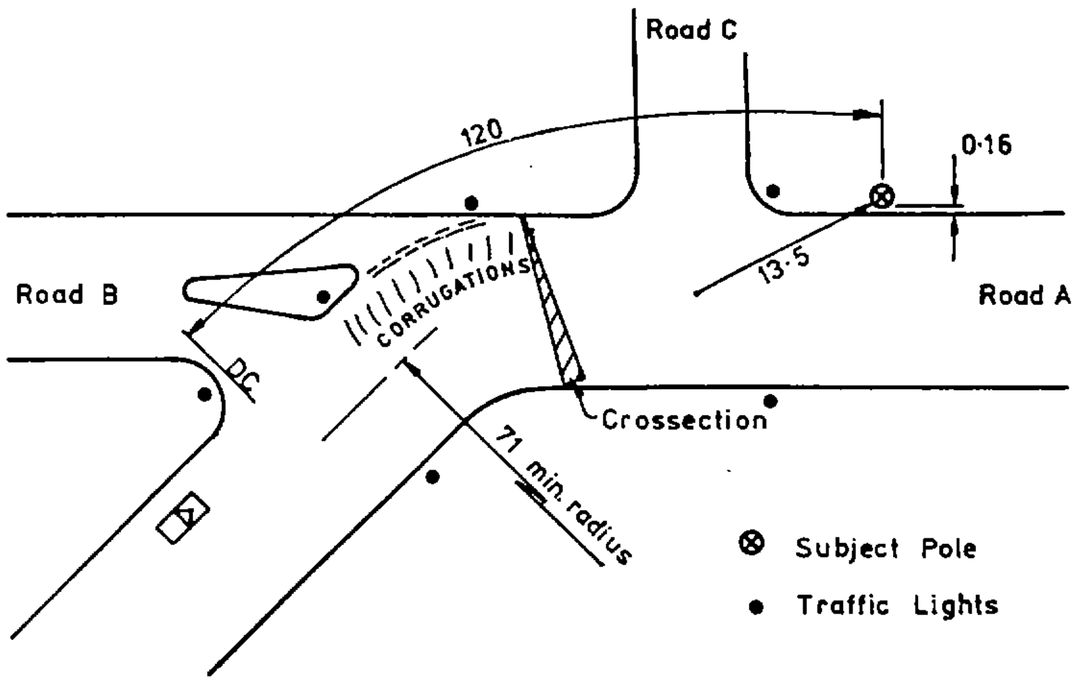
The third example chosen is shown in Figure B.3. For the subject pole there are three possible models which can be applied:

(a) MNI (road A)
(b) MJMJ (roads A and B)
(c) MJMI (roads A and C)

All three will be worked through, although it is apparent at the outset that the MNI model will give the highest total relative risk.

MNI Model

For this model, the vehicle travelling on road A, a major road, has to negotiate a right hand bend (Figure B.3). The relative risk table below is based on the data presented in Figure B.3 for road A. Note that, as road A is undivided, a road width relative risk is included.



DATA TABLE

Variable	Road A	Road B	Road C
Road class	Major	Major	Minor
AADT	15340	5900	—
ST	45	60	70
LO	0·16 m	0·16 m	0·16 m
W	12·9	12·8	7·4
DV	Undivided	Divided	Undivided
G	−0·5 %	−0·8 %	0
DC	120	—	—
e	negative	—	—
OIB	outside	—	—
PR	13·5 m	—	—
$\|K_{max}\|$	0·014	—	—
PD	Corrugations	—	—

Figure B.3. Case Study Number 3

MNI MODEL -- CASE STUDY NO. 3

Variable	Value	RR	Source
Data group	MNI	4.36	T/B.2
$\lvert K_{MAX} \rvert$	0.014	6.00	F/B.4
AADT	15340	1.18	F/B.5
ST	45	1.50	F/B.6
LO	0.16	1.40	F/B.7
W	12.9	1.23	F/B.8
DC	120	1.04	F/B.9
e	Negative	1.20	T/B.4
OIB	Outside	1.15	T/B.5
PD	Corrugations	2.00	T/B.3

Total Relative Risk = 228.9

ν = 0.866

$Pr(N \geq 1)$ = 0.579

The chances are good that at least one accident will occur at this site each year.

MJMJ Model (roads A and B, Figure B.3)

Throughout the relative risk graphs and tables for the intersection of major roads, reference is again made to roadway 1 and roadway 3. It was seen in the previous case study that roadway 1 was the 'pole-vehicle' road in the coding of the accident cases. The decision as to which road to assign as roadway 1 at the intersection of two major roads is somewhat arbitrary and the model should be applied twice, with the two roads being regarded as roadway 1 in turn. For the example shown, road A will be chosen as roadway 1, leaving road B as roadway 3 in the MJMJ model. The zone of influence of an intersection on pole accidents can be considered to extend to a radius of 50 m, for the purposes of model application. The following relative risk table for the subject pole results from the MJMJ model.

MJMJ MODEL -- CASE STUDY NO. 3

Variable (1)	Value	RR	Source
Data group	MJMJ	7.27	T/B.2
Intersection Type(2)	T	1.00	T/B.8
AADT 1	15340	0.92	F/B.15
ST 1	45	1.15	F/B.16
LO	0.16	1.23	F/B.17
AADT 3	5900	0.62	F/B.18
DV 1 (2)	Undiv.	1.80	T/B.7
DV 3 (2)	Div.	1.00	T/B.7
G 1	- .5%	0.86	F/B.19

(1) The variable tags 1 and 3 refer to the relevant roadway numbers.

(2) Intersection controlled by traffic lights.

The total relative risk can then be calculated:

TRR = 9.08

This value is well below the MNI result.

The MJMI Model (Roads A and C, Figure B.3)

In this model, as in case study No. 2, the major road (road A) is defined as roadway 1 and the minor road (road C) as roadway 3. The following relative risk model for the MJMI model results:

MJMI MODEL -- CASE STUDY NO. 3

Variable	Value	RR	Source
Data group	MJMI	0.65	T/B.2
Int. type	T	0.70	T/B.10
AADT 1	15340	0.70	F/B.20
ST 1	45	1.70	F/B.21
LO	0.16	1.55	F/B.22
W3	7.4	0.68	F/B.23
DV 1	Undiv.	1.43	T/B.9
G 1	-0.5	0.70	F/B.24
PR	13.5	1.09	F/B.25

The total relative risk is then

TRR = 0.623

which is less than the MJMJ model result, and orders of magnitude less than the MNI result.

As users become more familiar with the models, it will be apparent which model applied to a particular pole will lead to the highest total relative risk. However, it is recommended that all poles in the area under study be tested with all relevant models, until such familiarity is achieved.

TABLE B.2

RELATIVE RISK VERSUS POLE CATEGORY

Pole Category	Symbol	RR
Major road non-intersection	MNI	4.36
Minor road non-intersection	MINI	0.33
Major/Major intersection	MJMJ	7.27
Major/Minor intersection	MJMI	0.65
Minor/Minor intersection	MIMI	0.21

MAJOR ROAD NON-INTERSECTION (MNI) MODEL

Data Required

Symbol	Variable	Relative Risk Figure or Table
$\lvert K_{max} \rvert$	Absolute maximum curvature	F/B.4
AADT	Annual average daily traffic	F/B.5
ST	British pendulum skid test result	F/B.5
LO	Lateral offset of the pole	F/B.7
W	Distance between curbs (undivided roads)	F/B.8
DC	Distance from the curve start	F/B.9
PD	Pavement deficiencies	T/B.3
e	Superelevation of the curve	T/B.4
OIB	Pole on inside or outside of bend	T/B.5

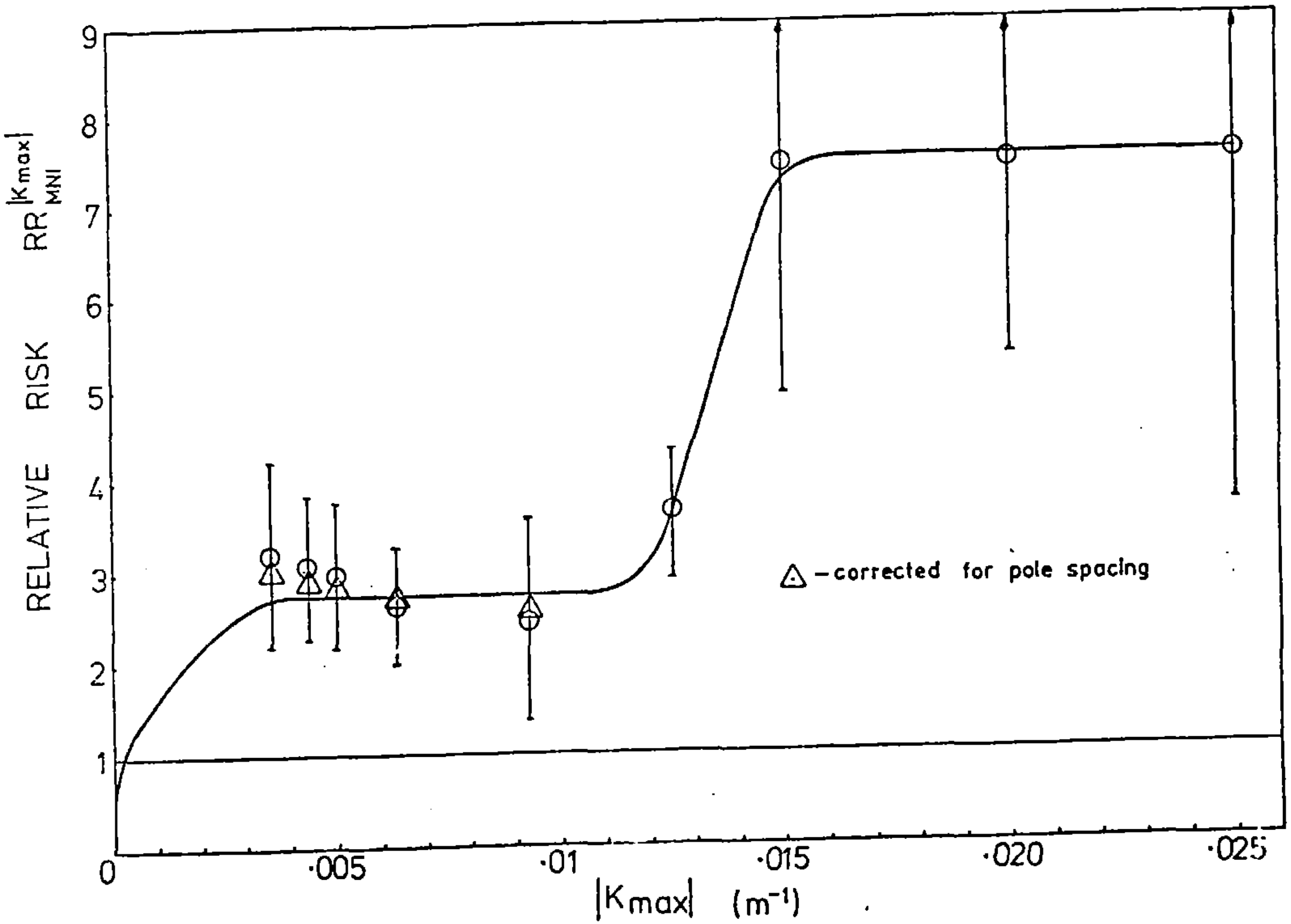


Figure B.4 Relative risk versus absolute maximum curvature upstream of the pole - MNI data group

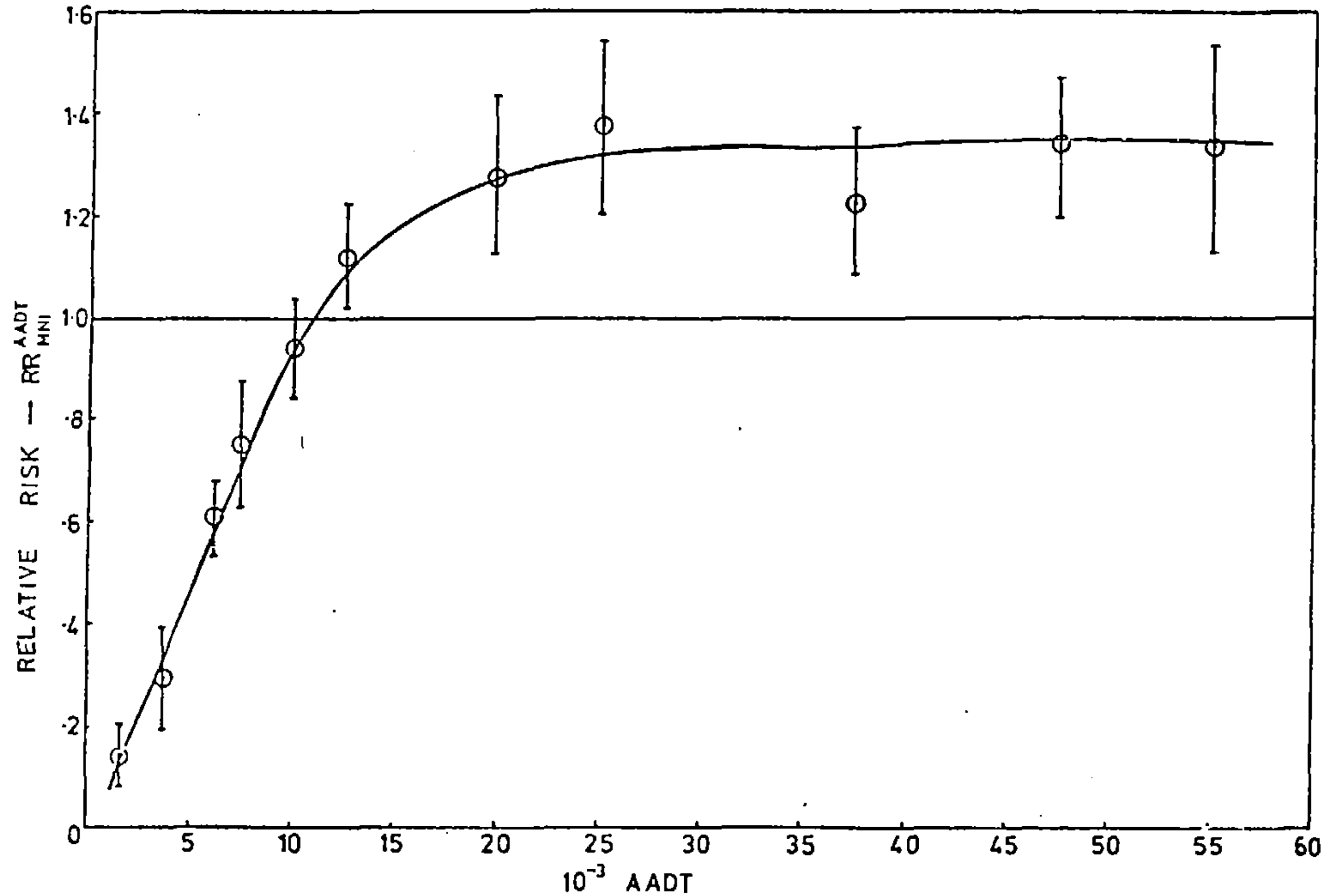


Figure B.5 Relative risk versus AADT - MNI data group

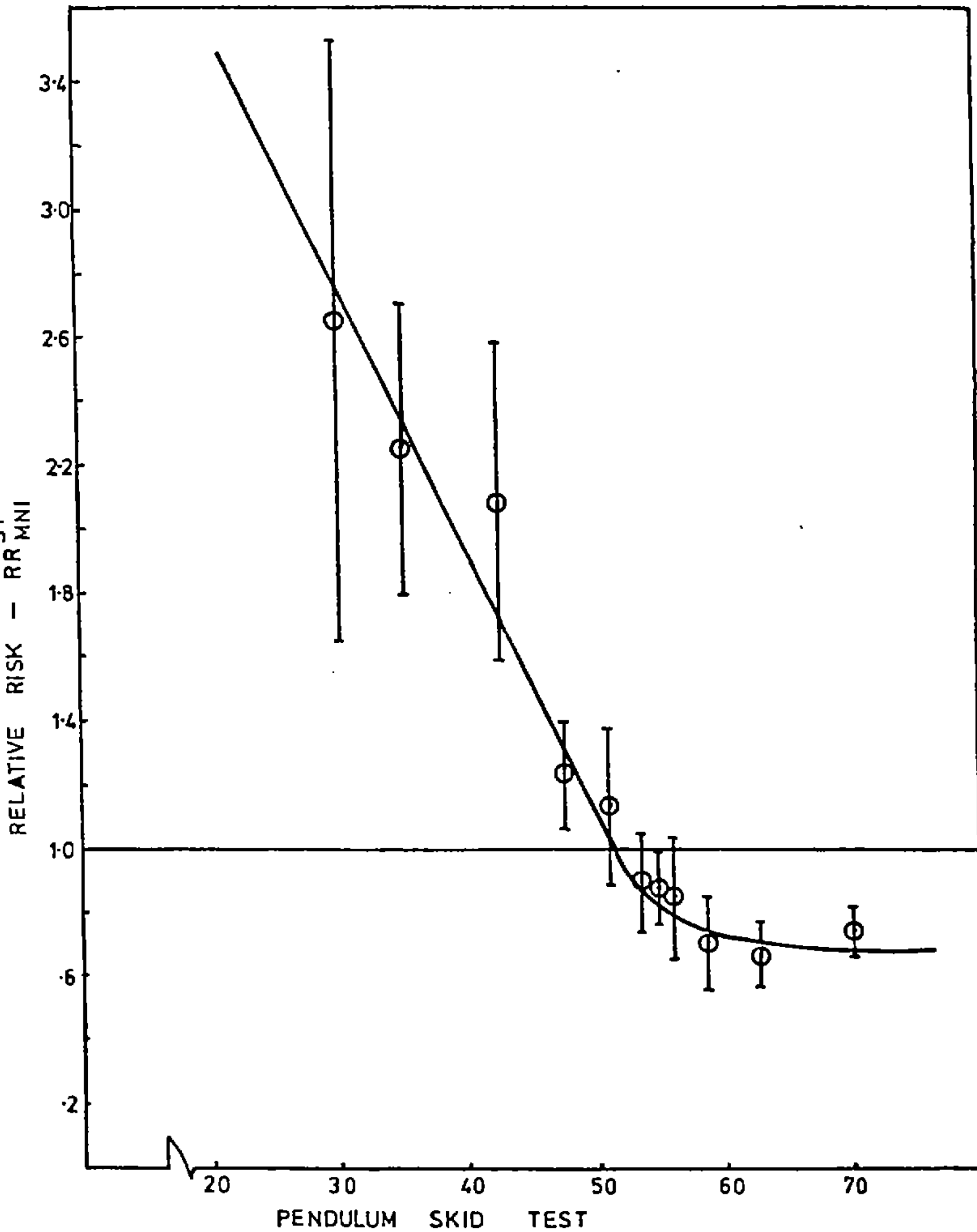


Figure B.6 Relative risk versus British pendulum skid test - MNI data group

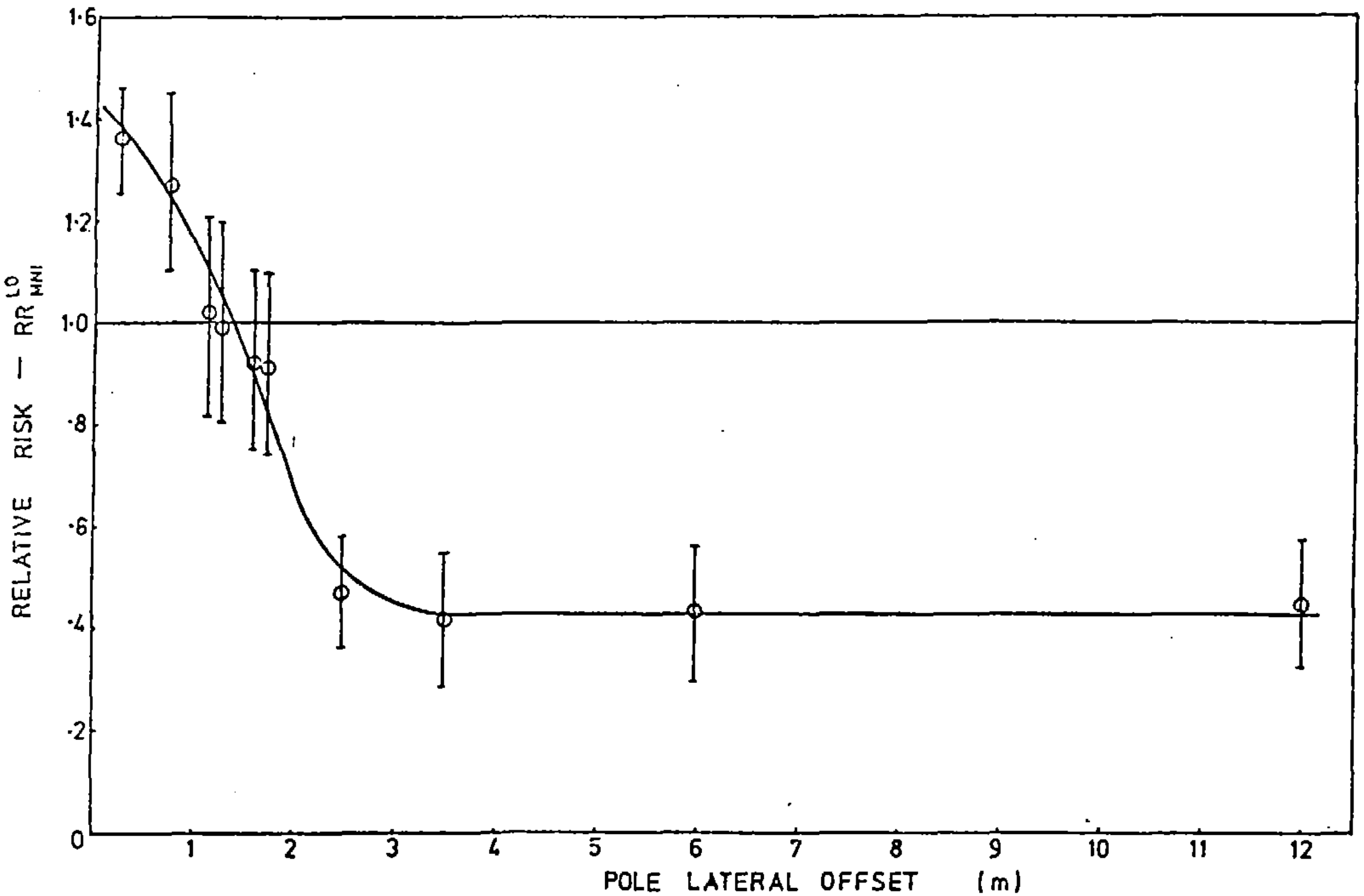


Figure B.7. Relative risk versus pole lateral offset - MNI data group

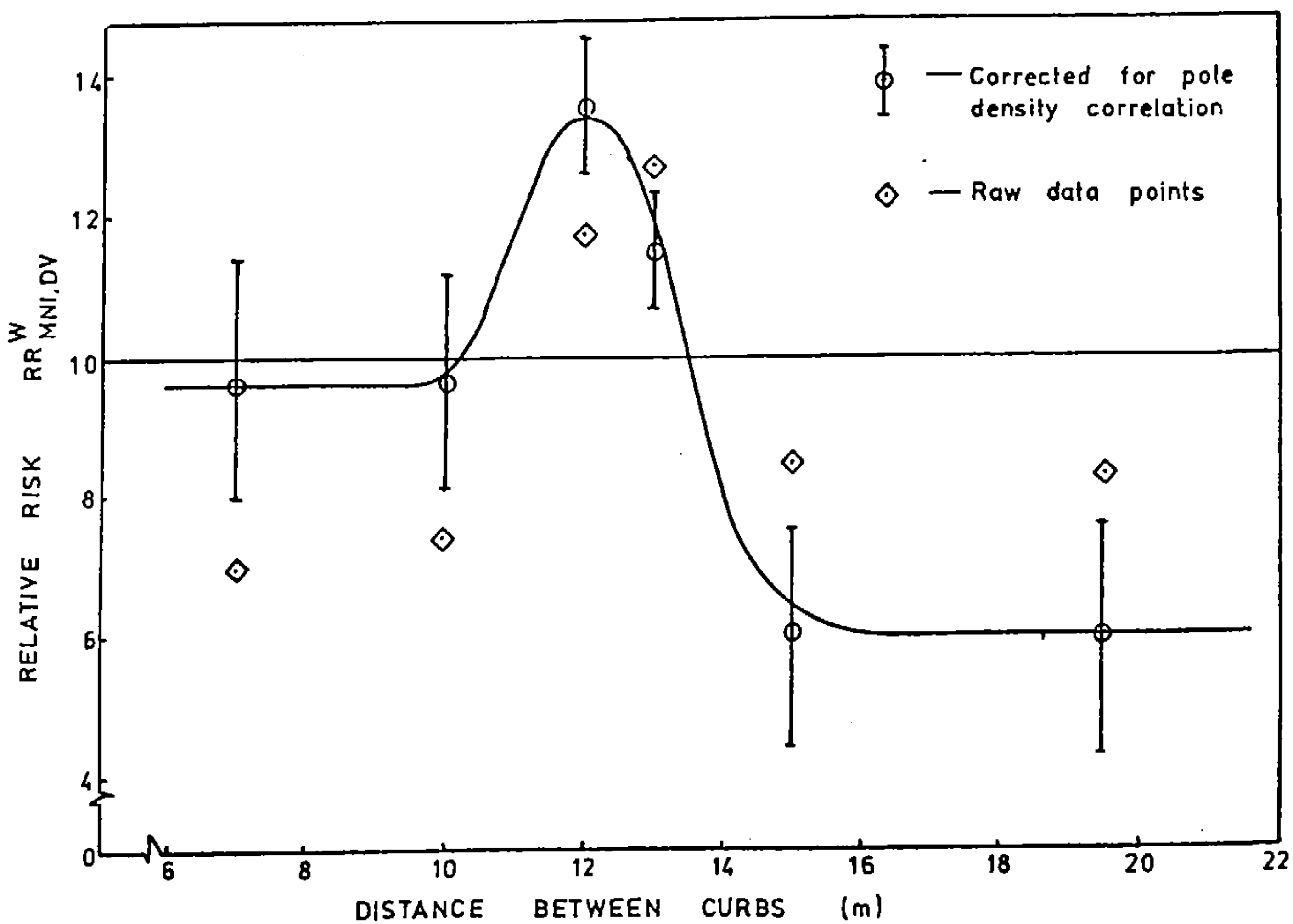


Figure B.8. Relative risk versus distance between curbs (road width) for undivided roads - MNI data group

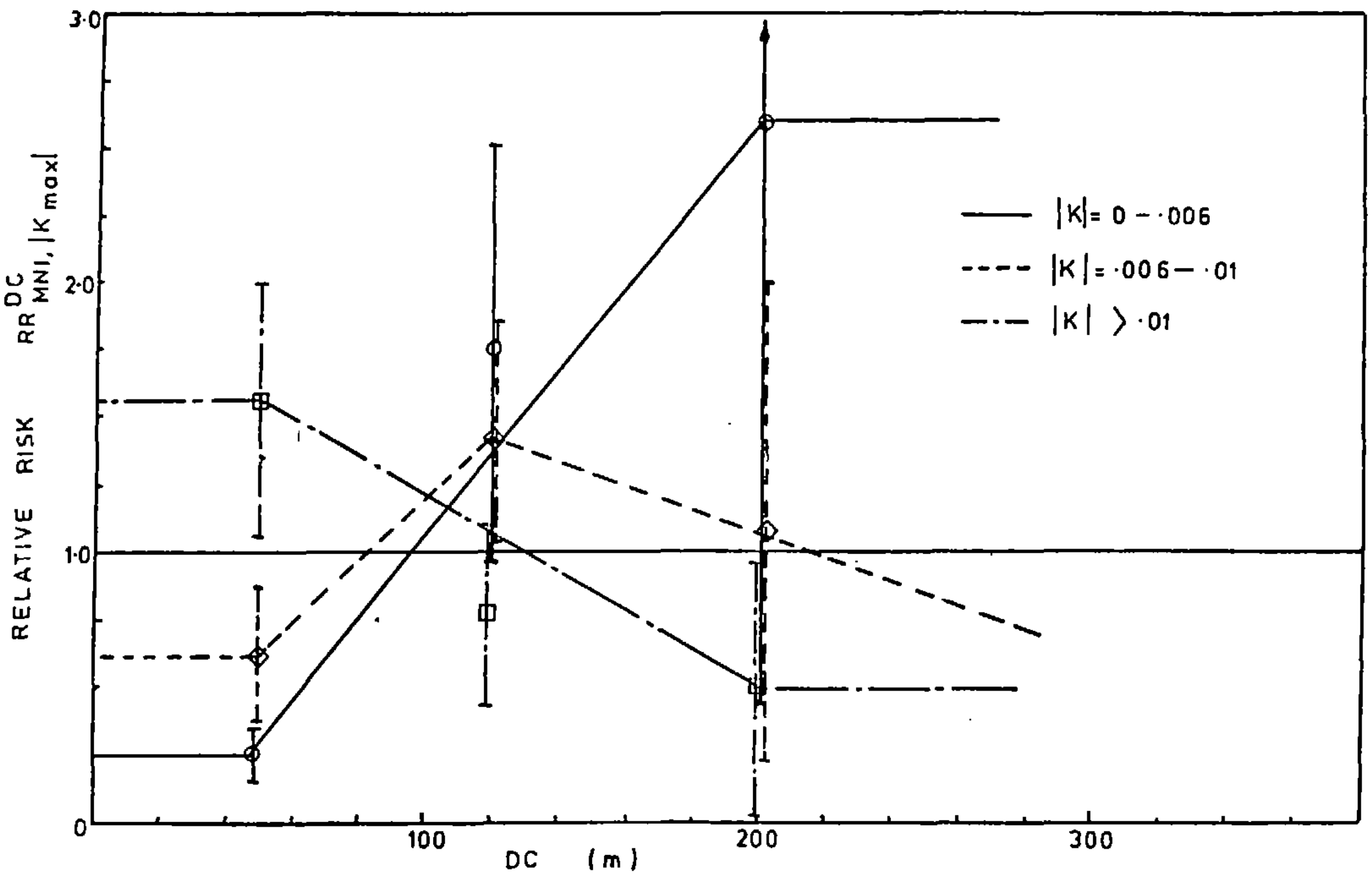


Figure B.9. Relative risk versus distance from curve start controlling for absolute maximum curvature - MNI data group

TABLE B.3

RELATIVE RISK ASSOCIATES WITH PAVEMENT DEFICIENCIES -- MNI DATA GROUP

Pavement deficiency	Relative Risk	Standard Deviation
None	0.93	0.04
Tram tracks	0.99	0.17
Dip/Crest	1.89	0.60
Corrugations, holes	2.00	0.60

TABLE B.4.

RELATIVE RISK FOR SUPERELEVATION GIVEN CURVATURE (RR_k^e) - MNI DATA GROUP

Curvature	Calculated RR_k^e Superelevation		Selected RR_k^e Superelevation	
	−	+	−	+
Left	0.93	1.23	0.9	1.2
Right	1.22	0.78	1,2	0.9

TABLE B.5

RELATIVE RISKS ASSOCIATED WITH POLES ON THE INSIDE AND OUTSIDE OF CURVES -- MNI DATA GROUP

Location of Pole	Relative Risk
Inside	0.85
Outside	1.15

MINOR ROAD NON-INTERSECTION (MINI) MODEL

Data Required

Symbol	Variable	Relative Risk Figure or Table
K_{max}	Absolute maximum curvature	F/B.10
G	Grade at 30 m upstream of pole	F/B.11
ST	British pendulum skid test result	F/B.12
LO	Lateral offset of pole	F/B.13
W	Road width	F/B.14
OIB	Pole on inside or outside of bend	T/B.6

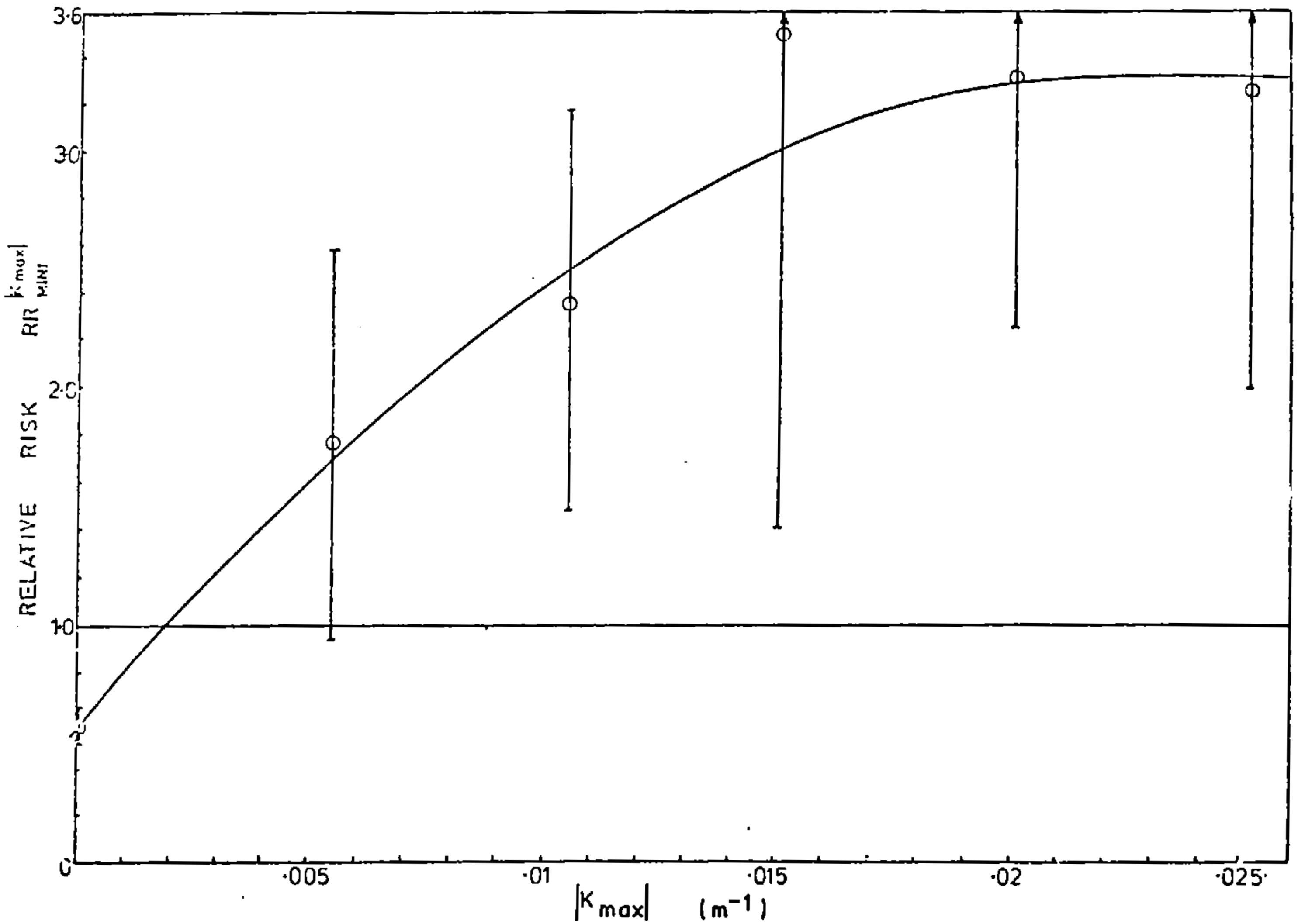


Figure B.10. Relative risk versus absolute maximum curvature upstream of the pole - MINI data group

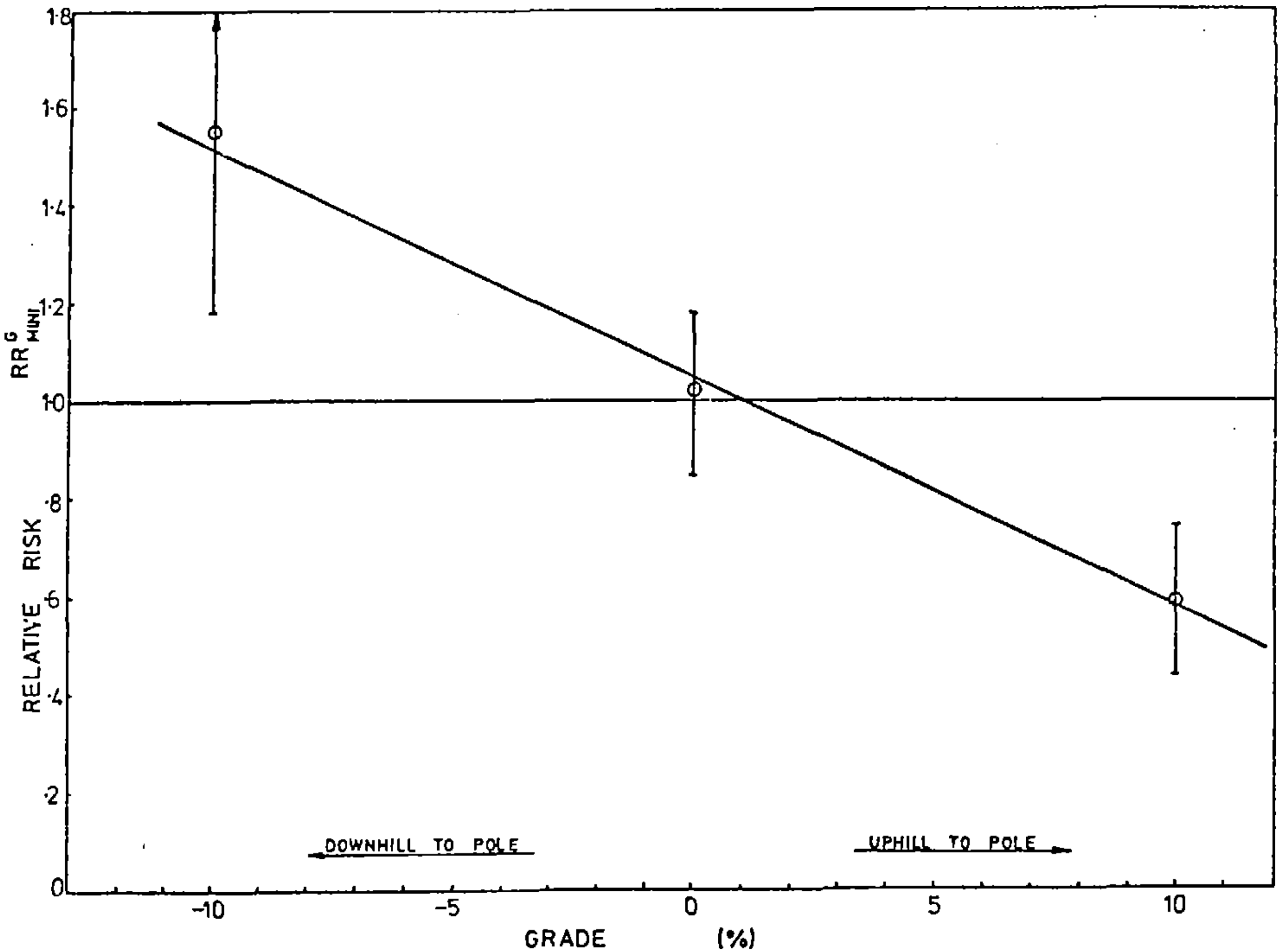


Figure B.11. Relative risk versus grade 30m upstream of the pole - MINI data group

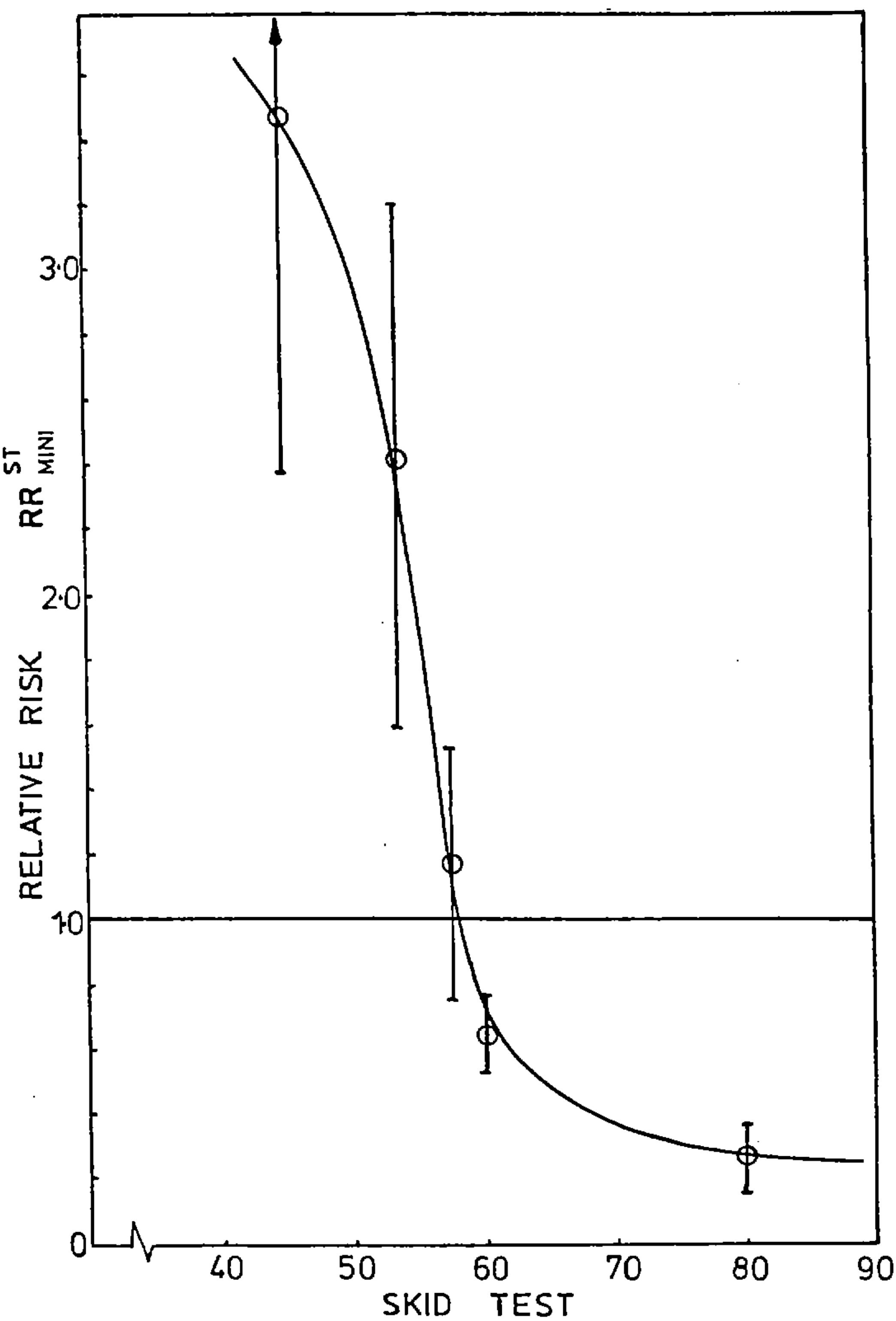


Figure B.12. Relative risk versus skid test - MINI data group

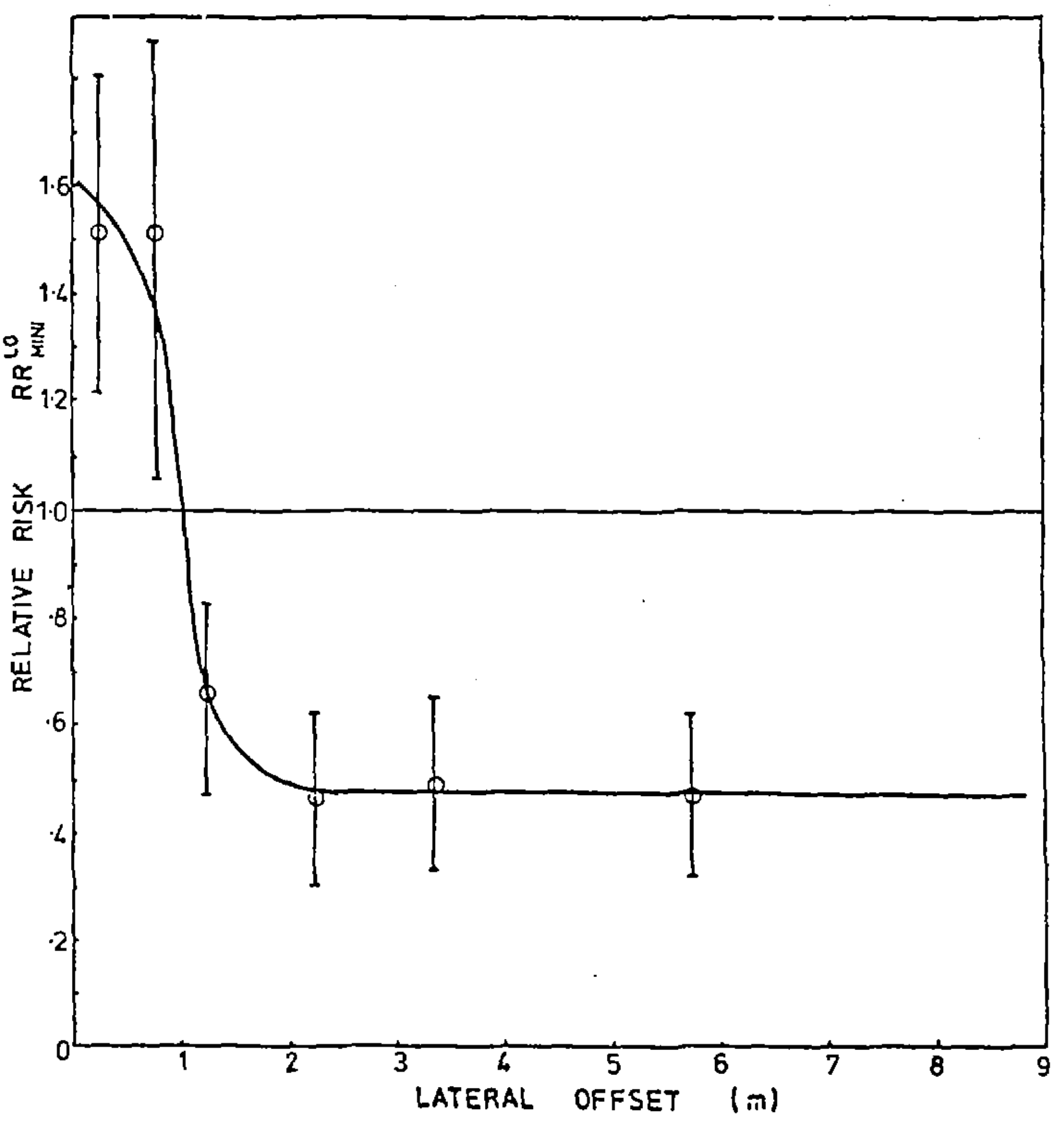


Figure B.13. Relative risk versus pole lateral offset - MINI data group

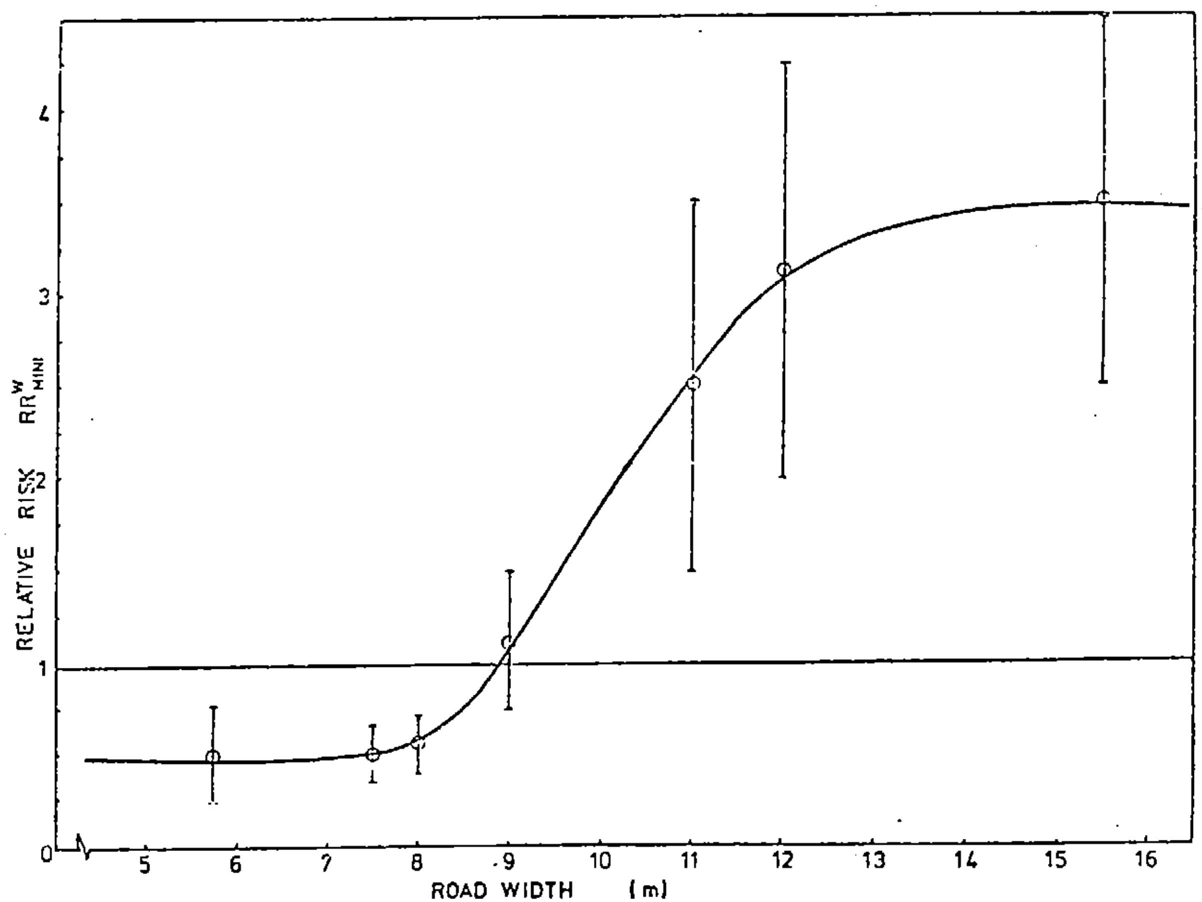


Figure B.14. Relative risk versus road width - MINI data group

TABLE B.6

RELATIVE RISK VERSUS LOCATION OF POLE ON A CURVE -- MINI DATA GROUP

Position of Pole	RR	SD
Inside of curve	1.25	0.40
Outside of curve	0.70	0.25

INTERSECTION OF MAJOR ROADS (MJMJ) MODEL

Data Required

Symbol	Variable	Relative Risk Figure or Table
	Intersection type	T/B.8
AADT1	Annual average daily traffic, roadway 1	F/B.15
ST1	British pendulum ski test, roadway 1	F/B.16
LO	Lateral offset of the pole	F/B.17
AADT3	Annual average daily traffic, intersecting roadway 1	F/B.18
DV1	Roadway 1 divided/undivided	T/B.7
DV3	Intersecting roadway divided/undivided	T/B.7
G1	Grade 30m upstream of intersection on roadway 1	F/B.19

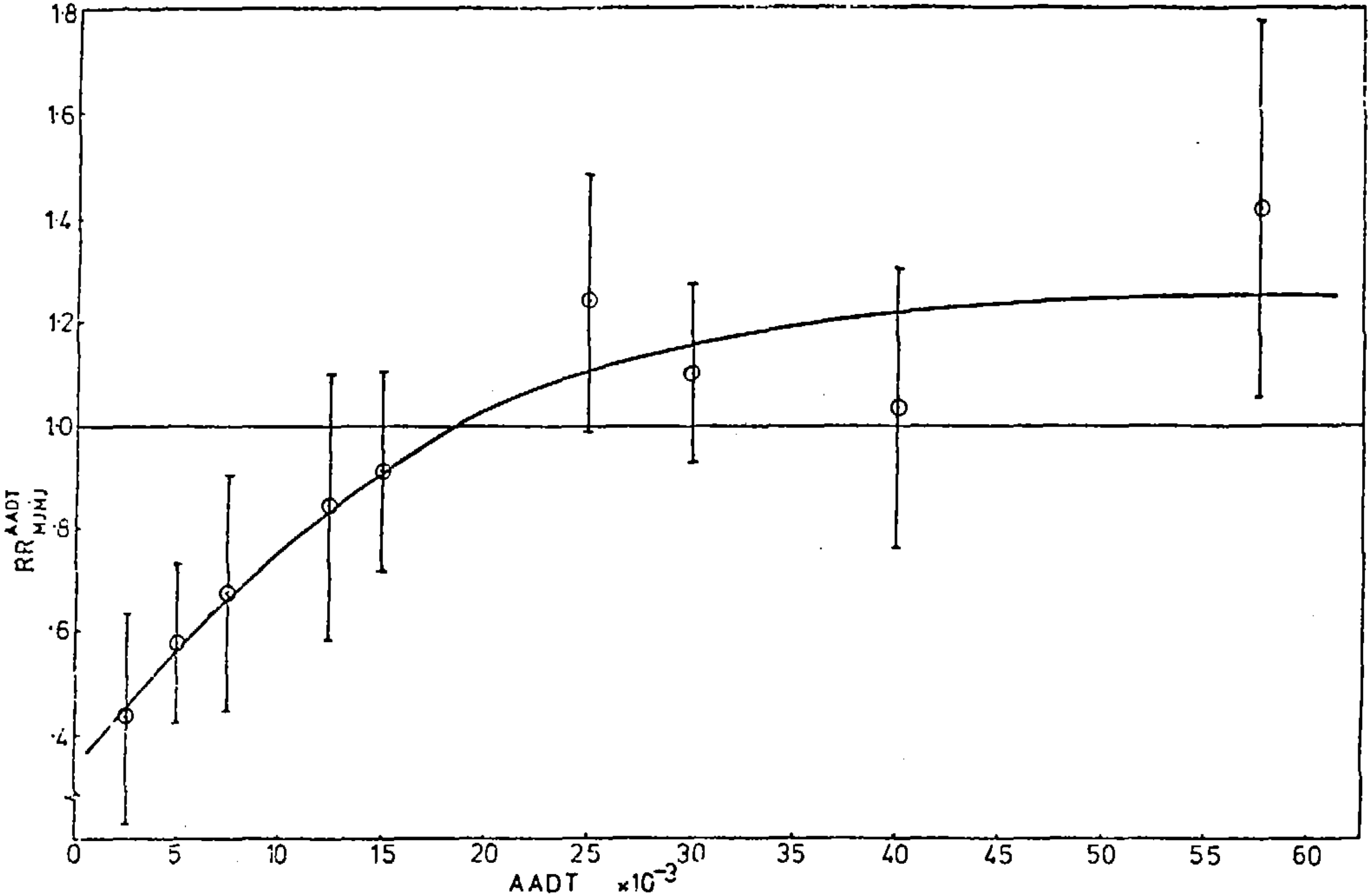


Figure B.15. Relative risk versus AADT on roadway 1 - MJMJ data group

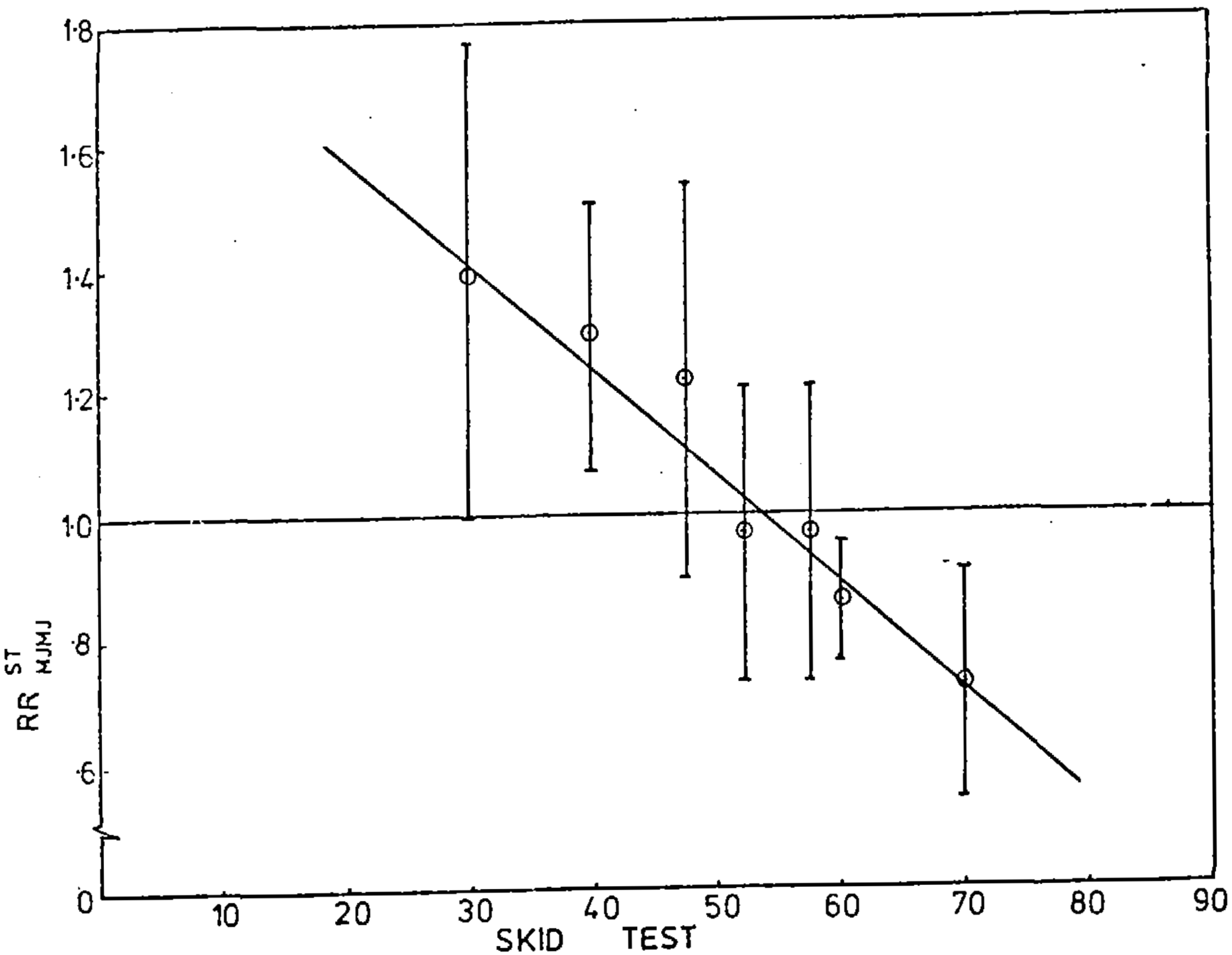


Figure B.16. Relative risk versus skid test on roadway 1 - MJMJ (intersection) data group

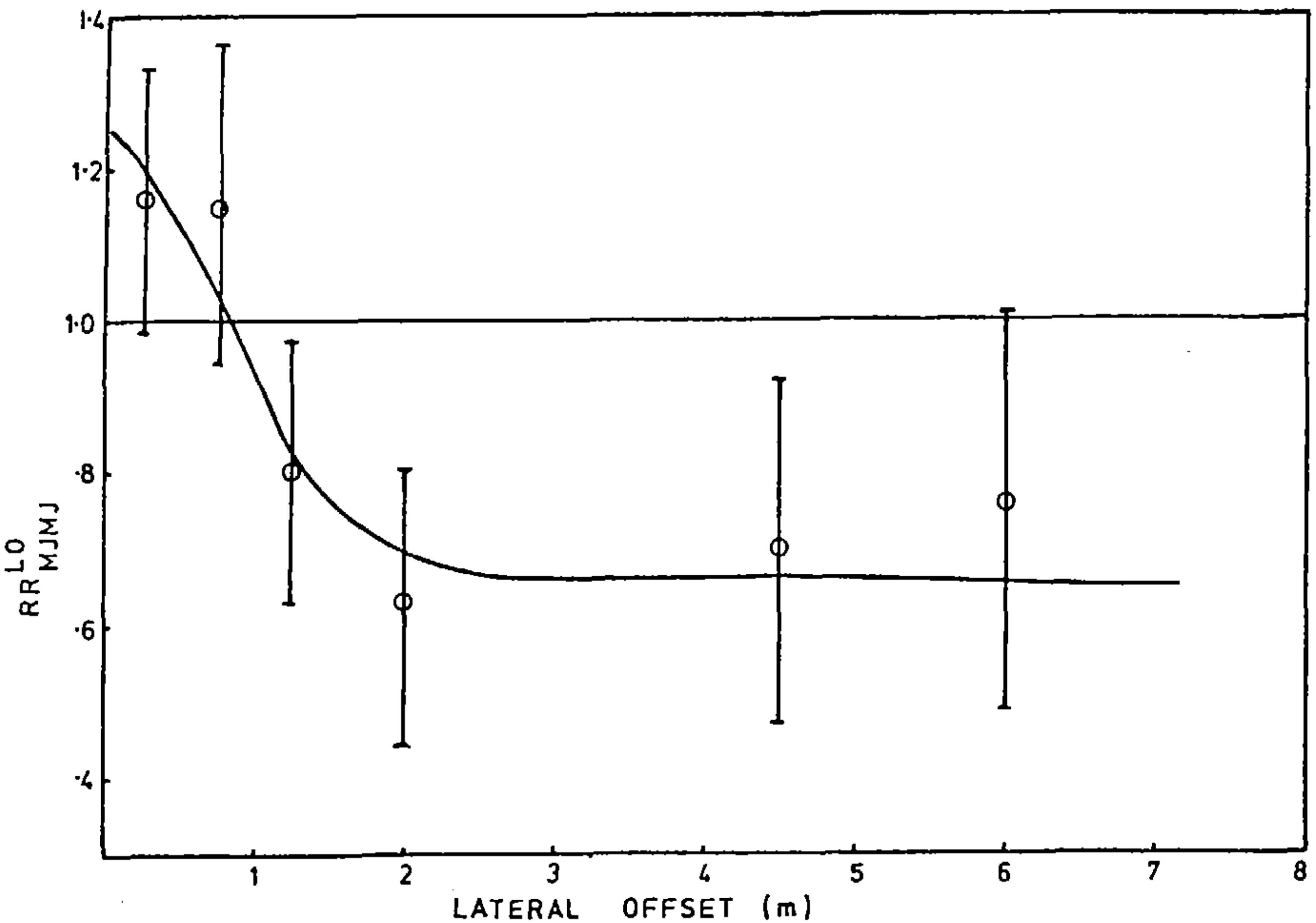


Figure B.17. Relative risk versus pole lateral offset - MJMJ data group

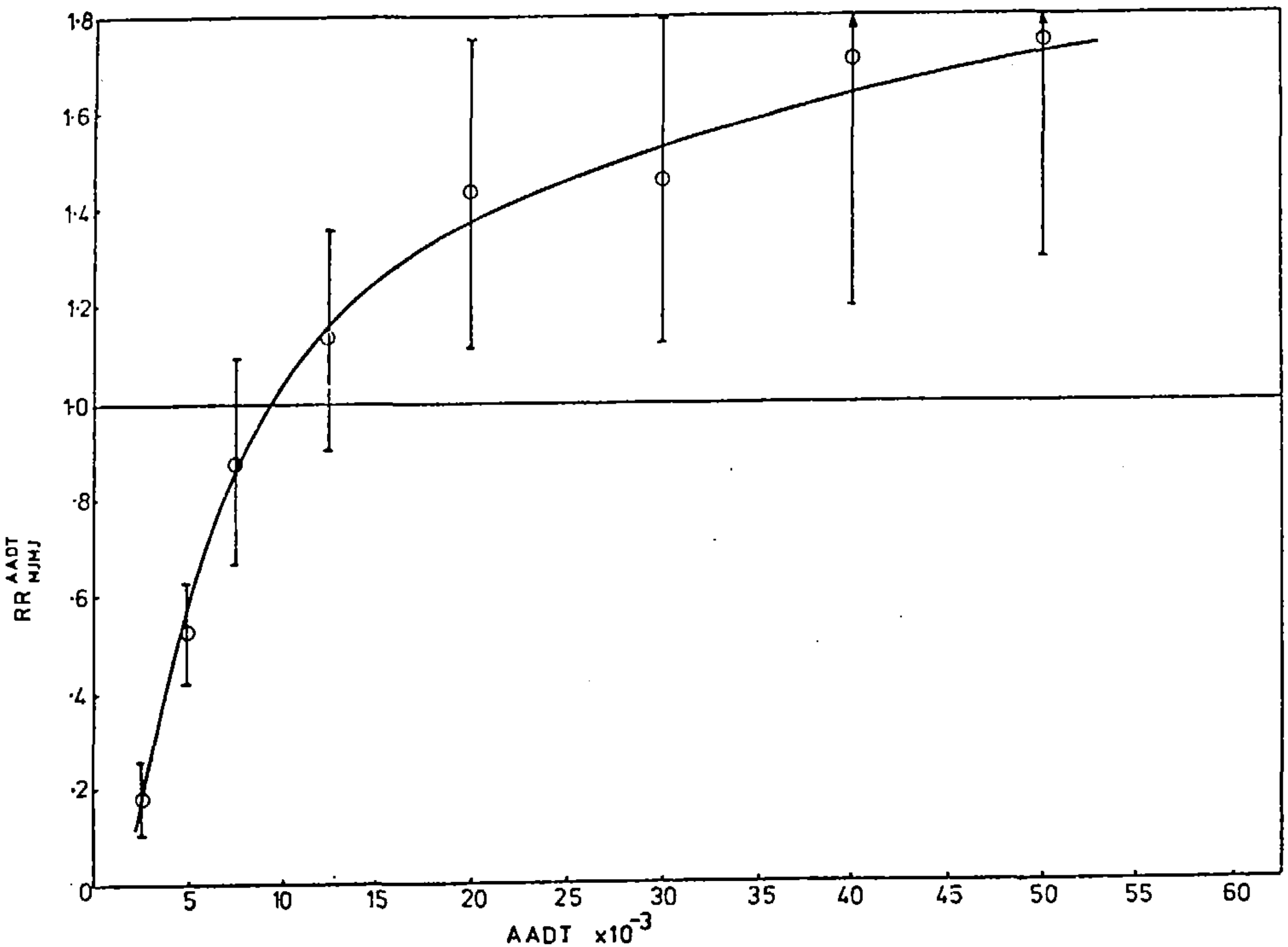


Figure B.18. Relative risk versus AADT on the intersecting roadway - MJMJ data group

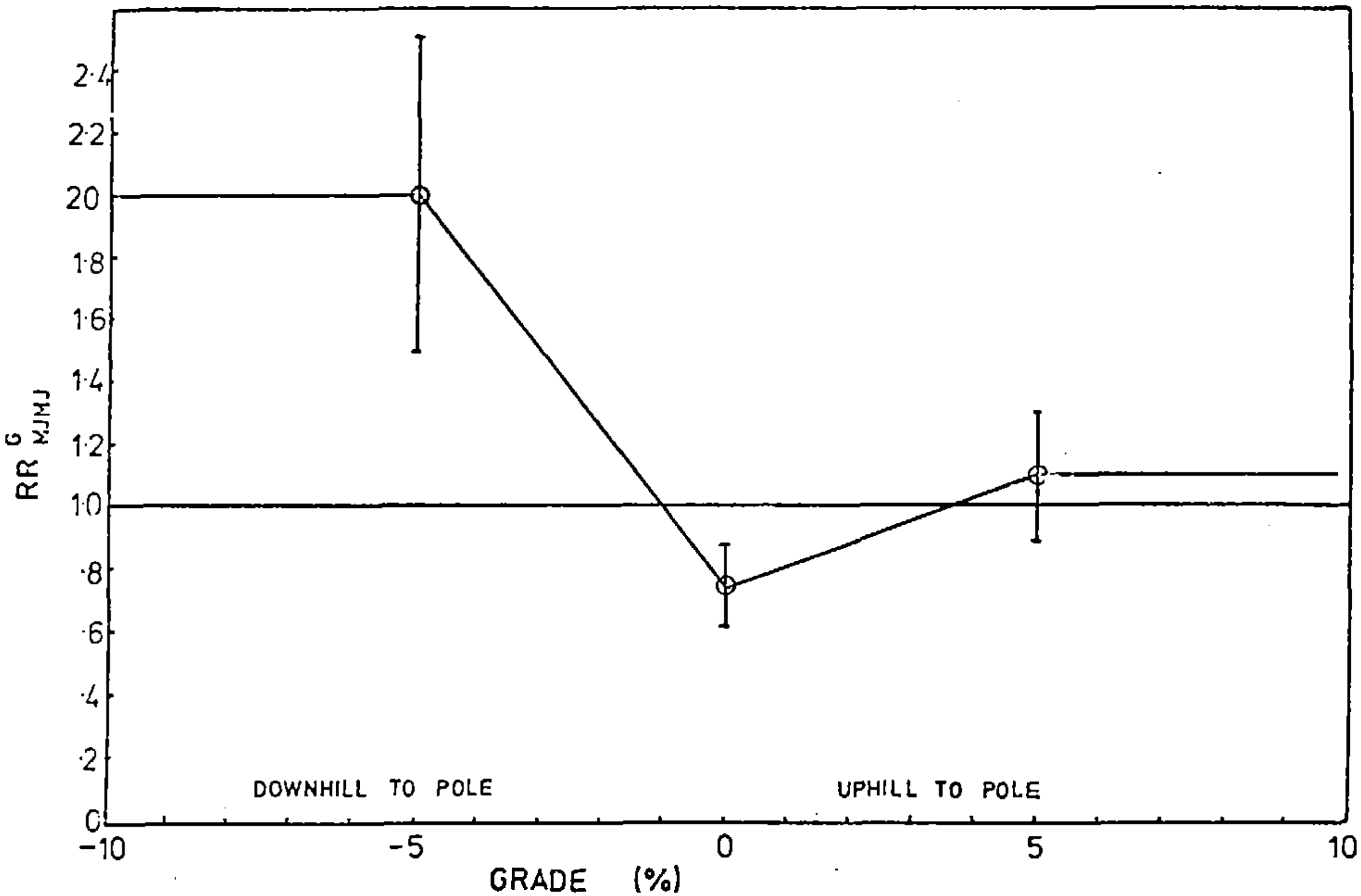


Figure B.19. Relative risk versus grade of roadway 1, 30m before the intersection - MJMJ data group

TABLE B.7

CHOSEN VALUES OF RELATIVE RISK AGAINST BOTH INTERSECTING ROADWAYS DIVIDED/UNDIVIDED CONTROLLING FOR THE PRESENCE OF TRAFFIC LIGHTS -- MJMJ

Roadway Divided/Undivided	Relative Risk	
	Traffic Lights	Other
Divided	1.00	0.11
Undivided	1.00	1.80

TABLE B.8

RELATIVE RISKS FOR CROSS AND TEE INTERSECTIONS, CONTROLLING FOR PRESENCE OF TRAFFIC LIGHTS -- MJMJ

	Type of control	
Intersection Type	Traffic lights	No traffic lights
	RR	RR
Cross	1.0	1.9
Tee	1.0	0.7

INTERSECTION OF MAJOR AND MINOR ROADS (MJMI) MODEL

Data Required

Symbol	Variable	Relative Risk Figure or Table
-	Intersection type	T/B.10
AADT1	Annual average daily traffic, roadway 1	F/B.20
ST1	British pendulum skid test result, roadway 1	F/B.21
LO	Lateral offset of pole	F/B.22
W3	Distance between curbs, intersecting roadway	F/B.23
DV1	Roadway 1 divided/undivided	T/B.9
G1	Grade 30 m upstream of the intersection on roadway 1	F/B.24
PR	Radial distance of pole from centre of intersection	F/B.25

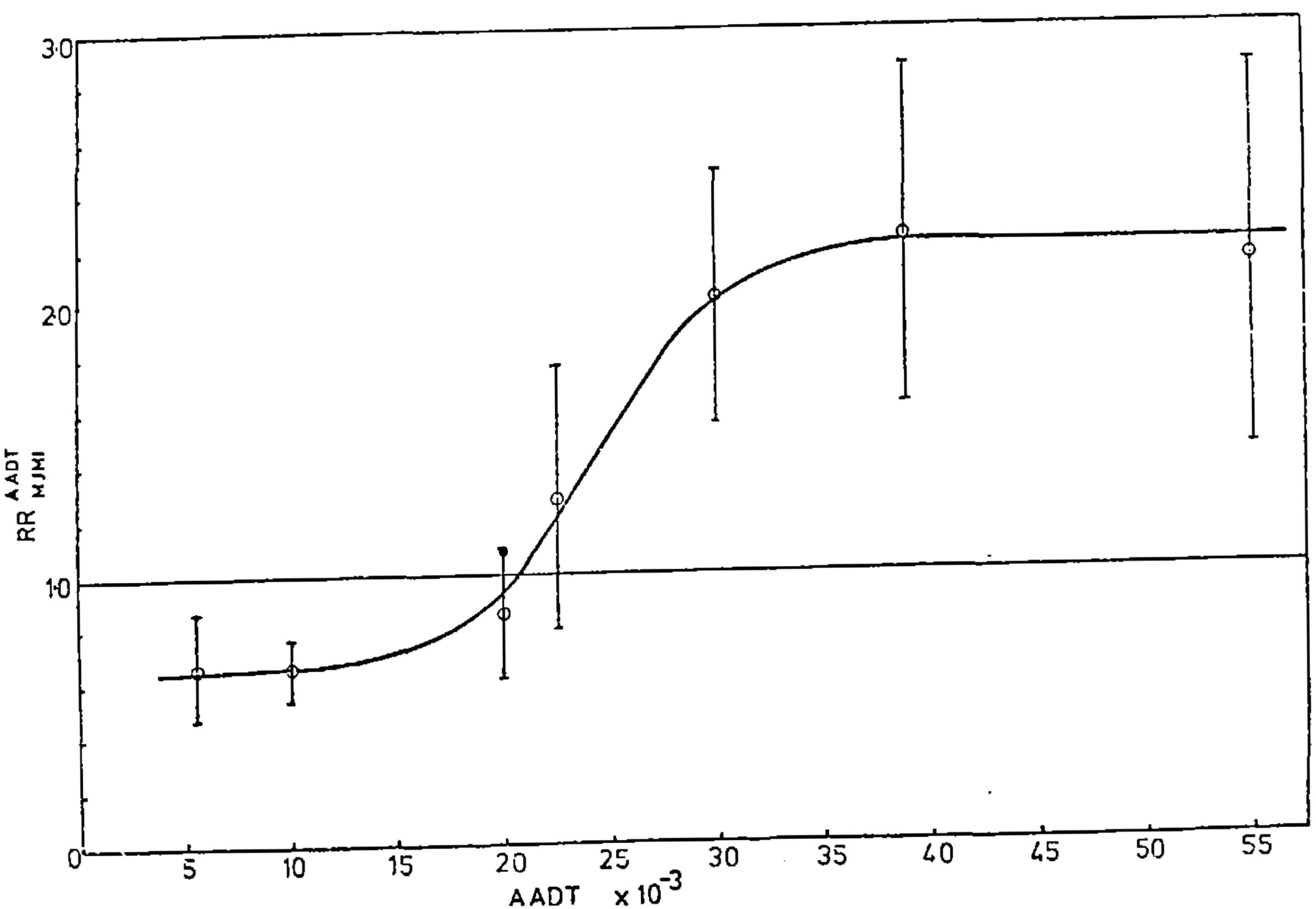


Figure B.20. Relative risk versus AADT on the major road - MJMI data group

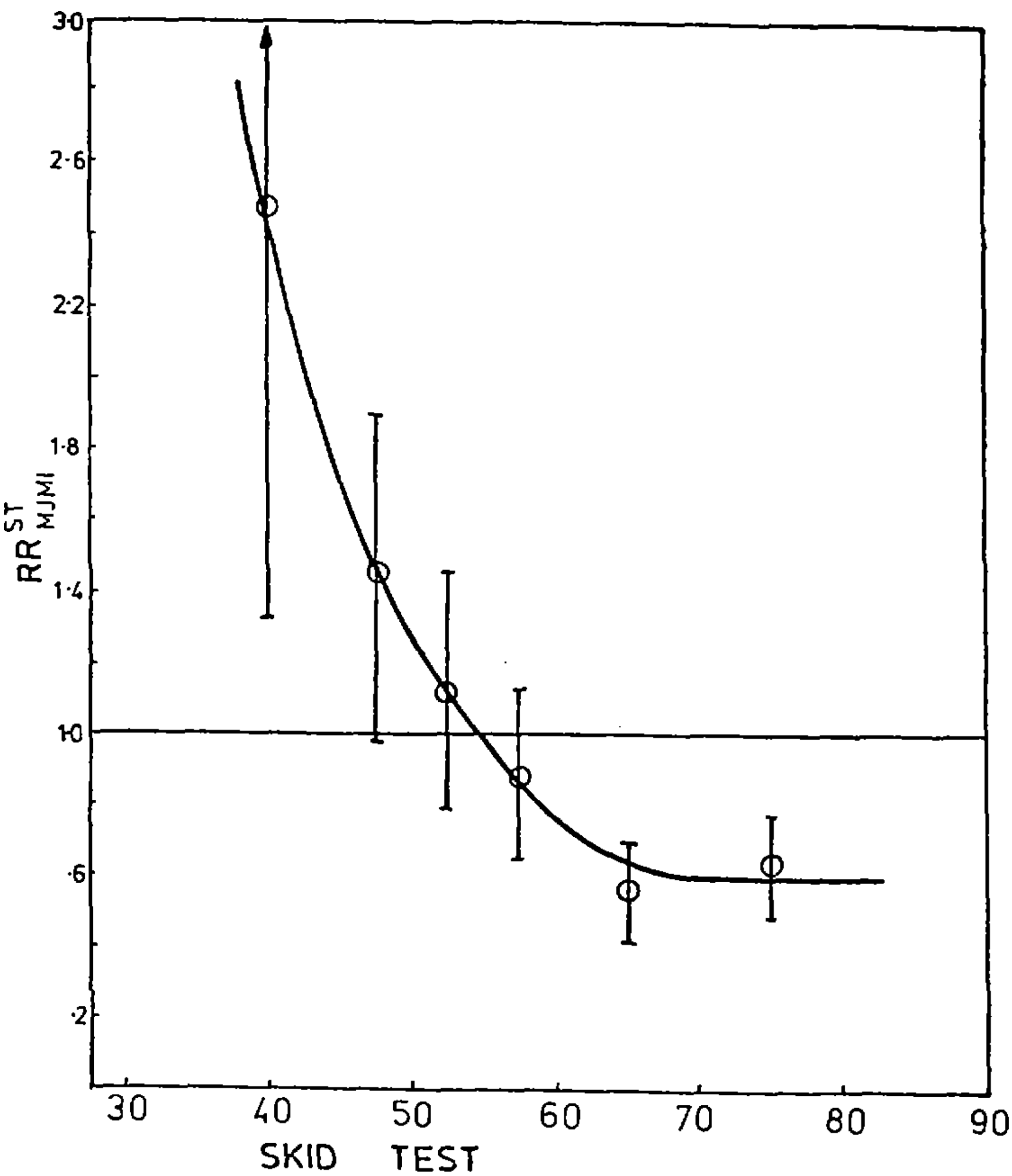


Figure B.21. Relative risk versus British pendulum skid test on the major road - MJMI data group

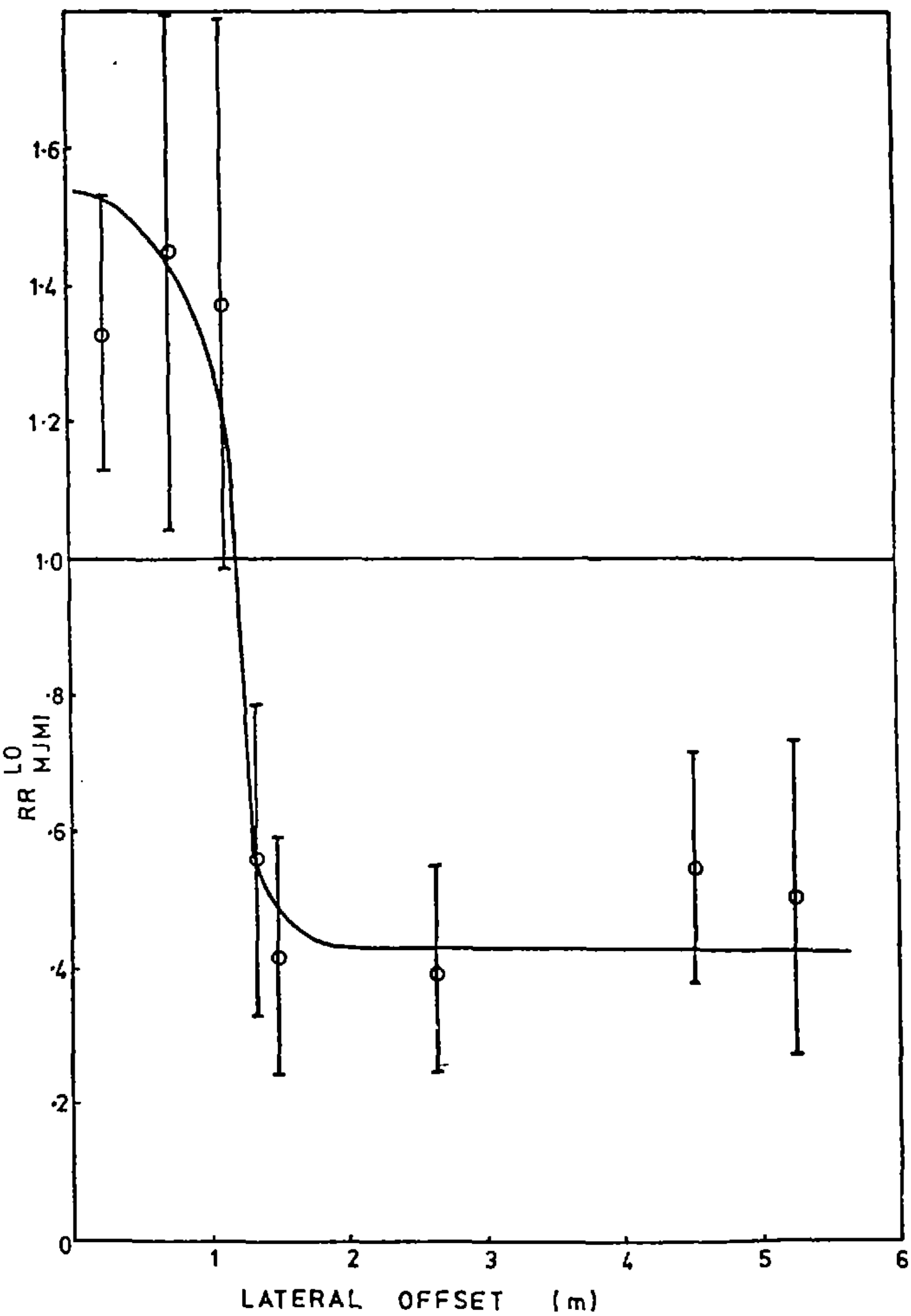


Figure B.22.Relative risk versus pole lateral offset - MJMI data group

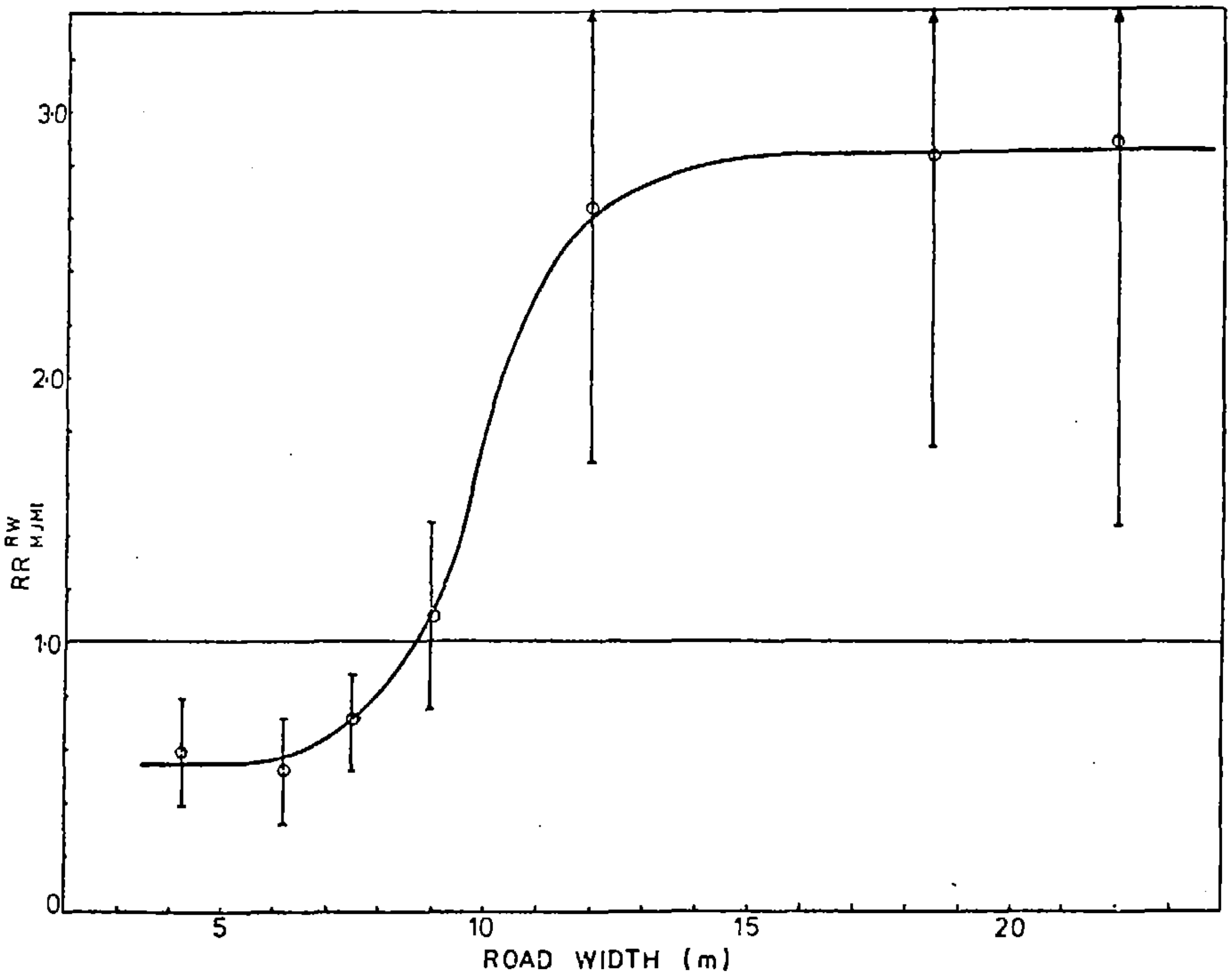


Figure B.23. Relative risk versus width of intersecting minor roadway - MJMI data group

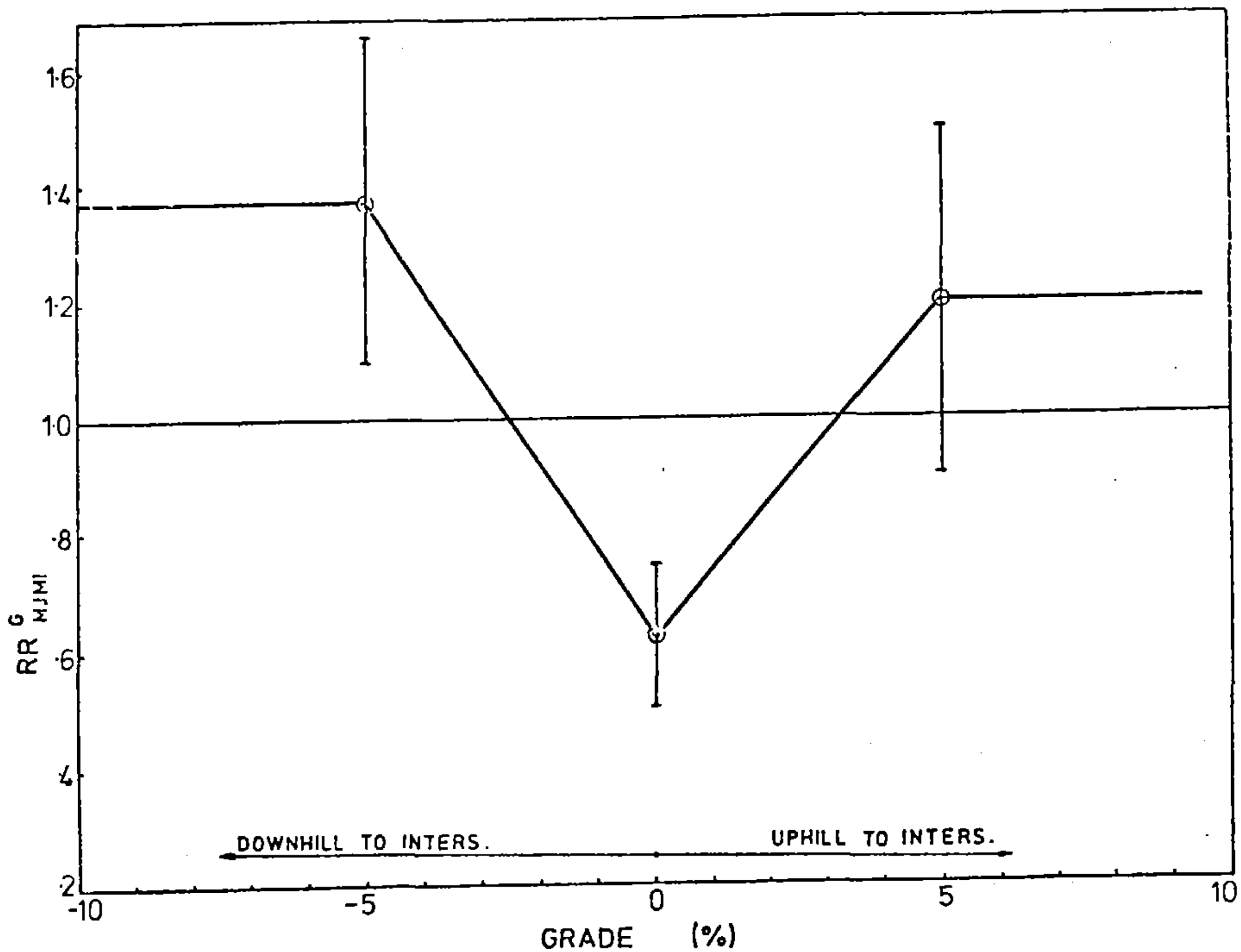


Figure B.24. Relative risk versus grade of the major road 30m before the intersection - MJMI data group

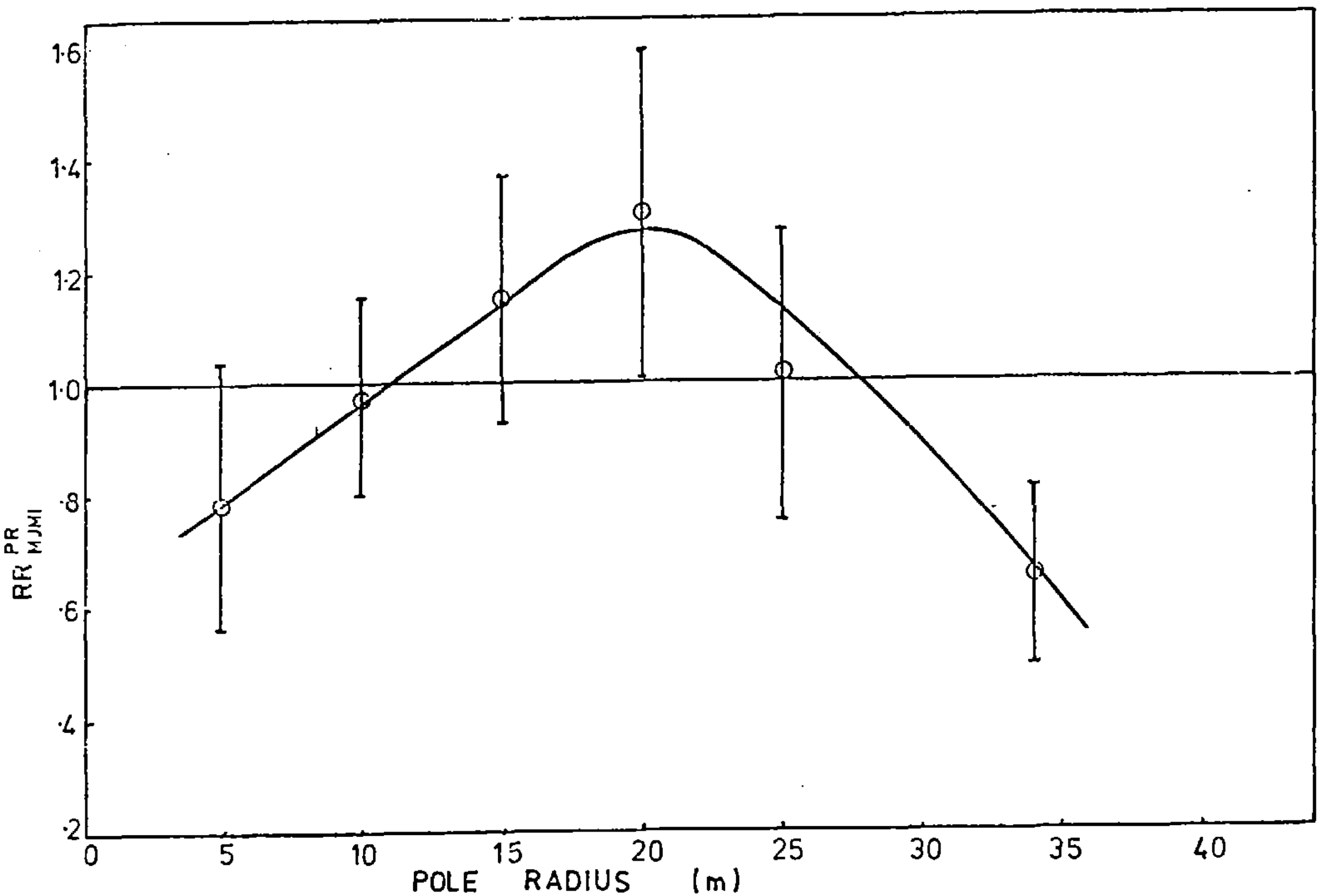


Figure B.25. Relative risk versus radial distance of the pole from the centre of the intersection - MJMI data group

TABLE B.9

RELATIVE RISK FOR ROADWAY 1 DIVIDED/UNDIVIDED -- MJMI DATA GROUP

Roadway Divided/Undivided	RR	SD
Divided	0.58	0.21
Undivided	1.43	0.30

TABLE B.10

RELATIVE RISK BY INTERSECTION TYPE (+ OR T) MJMI DATA GROUP

Intersection Type	RR	SD
+	2.50	0.53
T	0.70	0.13

APPENDIX C

FIXED OBJECT COLLISION DATA FOR 60 km/h SPEED ZONES IN NEW SOUTH WALES DURING 1977

TABLE C.1.

FIXED OBJECTS INVOLVED IN FIRST IMPACT OF CRASHES IN 60 km/h SPEED ZONES FOR NEW SOUTH WALES DURING 1977

Type of Object struck	Crashes with only one impact				Crashes with more than one impact			
	No. of casualty crashes	No. of Towaway crashes	No. of Fatalities	No. of Injuries	No. of casualty crashes	No. of Towaway crashes	No. of Fatalities	No. of Injuries
Pole	1005	847	37	1360	97	98	4	133
Tree	240	211	9	321	26	21	3	33
Boulder/Embankment	99	201	1	133	52	63	7	68
Bridge/Tunnel	74	140	1	90	22	23	2	32
Guide Post	21	58	1	23	29	31	4	36
Safety Fence	49	125	0	65	28	31	4	40
Boundary Fence	20	70	0	21	16	15	0	24
House Fence/House	133	519	1	158	48	96	0	57
Kerb/Island/Mound	150	323	3	176	382	523	17	533
Sign Post/Traffic Lights	82	194	3	98	36	43	2	49
No object	626	467	8	751	67	68	2	91
Other	212	193	1	237	92	64	2	108
Total	2711	3348	65	3433	895	1066	47	1204

Source: Traffic Accident Research Unit, Department of Motor Transport, New South Wales.

TABLE D.1

PRESENT WORTH FACTORS BY YEAR NUMBER AND DISCOUNT RATE

	Discount Rate (%)									
Year	1	2	3	4	5	6	7	8	9	10
0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909
2	0.980	0.961	0.943	0.925	0.907	0.890	0.873	0.857	0.842	0.826
3	0.971	0.942	0.915	0.889	0.864	0.840	0.816	0.794	0.772	0.751
4	0.961	0.924	0.888	0.855	0.823	0.792	0.763	0.735	0.708	0.683
5	0.951	0.906	0.863	0.822	0.784	0.747	0.713	0.681	0.650	0.621
6	0.942	0.888	0.837	0.790	0.746	0.705	0.666	0.630	0.596	0.564
7	0.933	0.871	0.813	0.760	0.711	0.665	0.623	0.583	0.547	0.513
8	0.923	0.853	0.789	0.731	0.677	0.627	0.582	0.540	0.502	0.467
9	0.914	0.837	0.766	0.703	0.645	0.592	0.544	0.500	0.460	0.424
10	0.905	0.820	0.744	0.676	0.614	0.558	0.508	0.463	0.422	0.386
11	0.896	0.804	0.722	0.650	0.585	0.527	0.475	0.429	0.388	0.350
12	0.887	0.788	0.701	0.625	0.557	0.497	0.444	0.397	0.356	0.319
13	0.879	0.773	0.681	0.601	0.530	0.469	0.415	0.368	0.326	0.290
14	0.870	0.758	0.661	0.577	0.505	0.442	0.388	0.340	0.299	0.263
15	0.861	0.743	0.642	0.555	0.481	0.417	0.362	0.315	0.275	0.239
16	0.853	0.728	0.623	0.534	0.458	0.394	0.339	0.292	0.252	0.218
17	0.844	0.714	0.605	0.513	0.435	0.371	0.317	0.270	0.231	0.198
18	0.836	0.700	0.587	0.494	0.416	0.350	0.296	0.250	0.212	0.180
19	0.828	0.686	0.570	0.475	0.396	0.331	0.277	0.232	0.194	0.164
20	0.820	0.673	0.554	0.456	0.377	0.312	0.258	0.215	0.178	0.149

TABLE D.2

CAPITAL RECOVERY FACTOR FOR COMBINATIONS OF
SERVICE LIFE AND ANNUAL INTEREST RATE

Service Life (Years)	Interest Rate (%) 1	2	3	4	5	6	7	8	9	10
1	1.010	1.020	1.030	1.040	1.050	1.060	1.070	1.080	1.090	1.100
2	0.508	0.515	0.523	0.530	0.538	0.545	0.553	0.561	0.568	0.576
3	0.340	0.347	0.354	0.360	0.367	0.374	0.381	0.388	0.395	0.402
4	0.256	0.263	0.269	0.276	0.282	0.289	0.295	0.302	0.309	0.315
5	0.206	0.212	0.218	0.225	0.231	0.238	0.244	0.250	0.257	0.264
6	0.173	0.179	0.185	0.191	0.197	0.203	0.210	0.216	0.223	0.230
7	0.147	0.155	0.161	0.167	0.173	0.179	0.186	0.192	0.199	0.205
8	0.131	0.137	0.143	0.149	0.155	0.161	0.167	0.174	0.181	0.187
9	0.117	0.123	0.128	0.135	0.141	0.147	0.153	0.160	0.167	0.174
10	0.106	0.111	0.117	0.123	0.130	0.136	0.142	0.149	0.156	0.163
11	0.097	0.102	0.108	0.114	0.120	0.127	0.133	0.140	0.147	0.154
12	0.089	0.095	0.101	0.107	0.113	0.119	0.126	0.133	0.140	0.147
13	0.082	0.088	0.094	0.100	0.107	0.113	0.120	0.127	0.134	0.141
14	0.077	0.083	0.089	0.095	0.101	0.108	0.114	0.121	0.128	0.136
15	0.072	0.078	0.084	0.090	0.096	0.103	0.110	0.117	0.124	0.131
16	0.068	0.074	0.080	0.086	0.092	0.099	0.106	0.113	0.120	0.128
17	0.064	0.070	0.076	0.082	0.089	0.095	0.102	0.110	0.117	0.125
18	0.061	0.067	0.073	0.079	0.086	0.092	0.099	0.107	0.114	0.122
19	0.058	0.064	0.070	0.076	0.083	0.090	0.097	0.104	0.112	0.120
20	0.055	0.061	0.067	0.074	0.080	0.087	0.094	0.102	0.110	0.117