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COLLISIONS WITH UTILITY POLES

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Abstract

In a survey of utility pole collisions, information on site characteristics and accident severity was obtained. Randomly-selected samples of sites and vehicles provided control information. An accident-predictor model which identifies accident risk on the basis of site measurements is derived. The model is used in conjunction with estimates of the costs of accidents to show that a number of remedial treatments are warranted.

COLLISIONS WITH UTILITY POLES

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February, 1979

Project Sponsor:

Office of Road Safety,
Commonwealth Department of Transport

SUMMARY

A detailed investigation of utility pole collisions is described, with particular emphasis on the engineering aspects of the accident sequence.

During an eight-month accident survey in the Melbourne metropolitan area, 879 pole collisions resulting in vehicle disablement were investigated. Seventy percent of this sample of 'tow-away' accidents resulted in property damage only. From the results of the survey, and other data, it is estimated that collisions with poles in Melbourne account for 45 fatalities and 785 injured persons annually.

Detailed measurements of site characteristics were made at the accident sites and for a control group of 793 randomly-selected pole sites. These data led to the construction of an accident predictor model which permits the estimation of the annual number of accidents at a pole site from simple site measurements. The model reveals a wide range of relative risks in the population of exposed poles (of the order of 1000 : 1) and enables the identification of the relatively small number of poles which account for the majority of accidents. Site characteristics associated with fifty percent of pole accidents on major roads, and sixty-five percent of accidents on minor roads, are associated with only ten percent of the total populations of poles beside these classes of road.

Data obtained from the accident-involved vehicles were compared with those from a control group of 627 randomly-selected vehicles. It was found that tyre tread depths below 3mm result in a progressive increase in accident involvement, as do deviations in tyre inflation pressures from manufacturer's specifications which would change the understeer/oversteer behaviour of the vehicle, or increase its response time to steering inputs.

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Mr. John Howell, the senior technician on the project contributed significantly to its success with his enthusiasm, skill and creativity. The assistance of the other project technicians, Mark Worrell and Paul Mylius, is also acknowledged.

In a study which draws data from such a variety of sources as this one, it is inevitable that the particular contributions of many people will go unacknowledged. This refers largely to the tow truck drivers, the base radio operators, the records staff of the ambulance services and hospitals, and vehicle repair companies. Quite simply, without the co-operation of all of these people there would have been no study.

The contributions of the following organizations and individuals are especially acknowledged:

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Accident cost data:

Motor Accidents Board (Mr. Pratt)
Brunswick City Council
Coburg City Council
Footscray City Council
Melbourne City Council
State Electricity Commission of Victoria
Williamstown City Council

The following towing companies, responsible for the accident notification network:

Alliance, Allnyte, Armstrong's, Amex Panels, Bea-Lyne Autos, B and R, Bentleigh Towing Service, Box Hill Towing, Caulfield Towing, Consolidated Motor Industries, Comack Motors, Eltham Towing, Gardiner Towing, Glenfield Towing, Grahams Body Works, Heidelberg Towing Service, International Towing, Kerrigans Motor Body Works, Kiwi Autos, Lacey's Towing, Littles Black Rock Motors, Lyon Brothers, Martin's Towing, Modern Towing, Peter Mac's Towing, Rising Sun Towing, Rix Motors, Sands Towing, Servis Panels, Southern Towing Service, Suburban Towing, Temple Towing, Town and Country Towing, United Towing, Val's Towing, Vermont Motors.

The medical information network:

Victorian Civil Ambulance Service
Peninsula Ambulance Service.

Hospitals:

Alfred (Mr. Dean)
Austin (Dr. Khong)
Box Hill and District (Dr. Brentnall)
Dandenong and District (Dr. Dreher)
Moorabbin (Dr. DeCrespigny)
Preston and Northcote Community (Mr. Trinca)
Prince Henry's (Mr. Wilson)
Royal Melbourne (Dr. Bush)
Western General (Dr. Walpole)
Coroner's Court (Mr. Hossack)

Other data sources:

Road Safety and Traffic Authority (Victoria)
Traffic Accident Research Unit (N.S.W.)
Municipal Councils
Country Roads Board (Mr. Roland Stewart)

Motor vehicle manufacturers
Vehicle repair firms
South Australian Highways Department.
Melbourne and Metropolitan Board of Works

The Department of Defence made the Monegeetta skid pad available for calibration of the instrumented vehicle.

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The efforts of Mrs. Noelene Paine and Mrs. Ann Walker in the preparation of this report are also gratefully acknowledged.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND TO THE PRESENT STUDY

In 1971 the Australian Government commissioned 24 literature surveys as part of a national review of the road accident situation in Australia undertaken by the Expert Group on Road Safety. One of the reviews (Good and Joubert, 1973) investigated the reduction in accidents, injuries and fatalities which could be expected from appropriate treatment of fixed roadside hazards.

Good and Joubert found published Australian accident statistics to be inadequate for the purposes of their study. The classification of accidents by the 'first event' particularly reduced the usefulness of the available data. They reported that during 1971 in New South Wales (the only State for which data were available at that time), utility pole collisions represented at least 2.2 percent of all reported accidents, 7.5 percent of all road deaths and 9.3 percent of non-pedestrian fatalities. Further, pole collisions accounted for 26 percent of reported fixed object collisions, produced 42 percent of the fatalities, and poles were the class of object most frequently involved in single-vehicle crashes. In terms of casualties per one hundred collisions, pole accidents were, on average, the most severe of all accident types. Added to this, it was noted that utility poles are concentrated in urban areas ; a fact which reduces the task of investigating possible remedial action.

From their review of available data, Good and Joubert concluded in relation to pole accidents that the following should be determined:

- the actual involvement of poles in accidents, related to road type, traffic volume, pole location geometry, road geometry, etc. ;
- whether some locations are proving to be particularly hazardous ;

- the cost of relocating poles thought (from accident records or site inspection) to be in hazardous locations.

On the basis of these recommendations, a one-year study was commissioned in 1974 to collect and analyse all available accident data, both local and overseas, relating to utility pole collisions to ascertain the full extent of the problem, and to enable the identification of critical pole locations. However, it was found that the data required for such an identification process, either by way of a predictor model or a 'black-spot' method, were not in existence. While the total extent of the pole accident problem could not be determined precisely from the available data, its importance within the overall road accident situation was confirmed. The available statistics, which were based on the first impact showed that utility pole collisions accounted for 6 percent of reported road accident fatalities, 4.6 percent of injuries, 35 percent of fixed-object fatalities. Further, it was found that no relevant accident predictor model existed.

The present study was commissioned in 1976 with 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 to allow 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 in benefit-cost analyses of proposed remedial measures.

1.2 A REVIEW OF PREVIOUS POLE ACCIDENT STUDIES

There has been very little work carried out specifically on pole accidents. A number of studies have investigated fixed roadside hazard collisions, including utility poles as one category of object. Typically, however, these studies have been based on rural or interstate highway accident data (see the review by Good and Joubert, 1973).

A few studies have investigated luminaire pole crashes on rural and interstate highways (Edwards et al., 1969 ; Walton, Hirsch and Rowan, 1972 ; Glennon, 1974), although the emphasis was on the development of breakaway luminaire poles, rather than on accident data or predictor models.

Wentworth (1973) summarized the available data related to utility (cable-supporting) pole collisions and concluded that such data were limited. Amongst his recommendations were the following :

(a) Warrants should be established for underground placement of utilities.

(b) Assuming acceptable frangible or breakaway utility pole designs can be developed, warrants should be established to identify where frangible or breakaway utility poles should be utilized.

In a follow-up paper, Graf, Boos and Wentworth (1975) pointed out that, apart from the lack of adequate accident statistics, problems such as the lack of uniform standards for locating utility poles, and insufficient legal authority for States to undertake corrective action, add further to the complexity of the problem.

The only Australian data relating to pole collisions published prior to the present study were presented by Vaughan (1975). Based on police accident reports, a number of aspects of pole collisions were investigated, namely :

(a) The distribution of accidents by

    (i) time of day, day of week, etc.
    (ii) vehicle types

(iii) severity
(iv) weather
(v) road features ;

(b) the role of alcohol.

However, the data presented failed to meet the requirements of the present study for the derivation of an accident predictor model. Further, as the data were based on police reports, it is quite likely that the sample was incomplete. It is noted that Vaughan's work subsequently proved to be a valuable source of comparative data for verification of the results of the present study in relation to the broad characteristics of pole accidents.

A study is currently being carried out in the United States at Southwest Research Institute, which is investigating the relationship between pole type and performance, vehicle crashworthiness, occupant injuries, highway design and operating characteristics (Cromack et al., 1975). The particular emphasis of the project is with the in-service performance of breakaway poles. A final report is not expected to be published until 1980.

It was clear from the review of available information that, if an accident predictor model relevant to conditions on Australian urban roads was to be developed, suitable accident data would first have to be collected.

1.3 OBJECTIVES OF THE PRESENT STUDY

1.3.1 Philosophy Adopted

The approach adopted for the data collection phase of this study was to concentrate all resources on a particular accident type, so as to obtain enough detailed data to allow meaningful statistical analysis. In the past, the majority of 'in-depth' accident surveys have collected data for all accident types. While this approach allows the identification of possible problem areas, little detailed information of the nature required to plan remedial action in these areas can be obtained, because of low case numbers. An alternative to both these approaches is the 'blackspot' technique, which consists of analysing accident records and identifying those locations with 'higher than average' accident rates (Deacon, Zegeer and Deen, 1974 ; Pleyte, Geissler and Dillon, 1975 ; Brown, 1976 ; Taylor and Thompson, 1977). The disadvantages of this approach are that :

(a) sites must have large numbers of accidents to come under notice.

(b) it does not allow the prediction of the effect of remedial programs ;

(c) the results are relevant only to the specific area covered by the accident statistics.

The occurrence and consequences of a pole accident result from a number of contributing factors which can be broadly classified as follows :

(a) human factors
(b) engineering factors (roadway characteristics, roadside layout, vehicle crashworthiness, etc.)
(c) environmental factors (weather, etc.).

It was decided to concentrate the present study on the engineering aspects of accident occurrence and severity. Programs aimed at identifying and modifying the human factors associated with road accidents have met with mixed success in terms of accident reduction. Henderson (1971) presented a comprehensive review of the literature to that date concerning the role of human factors in road accidents. In relation to modifying human behaviour to reduce the incidence of road crashes he concluded :

> Review of measures so far undertaken with the aim of modifying deviant behaviour to prevent the occurrence of traffic accidents indicates that such measures have shown very little success to date. In the present state of the art, the prevention of traffic accidents lies mostly in modification and control of parts of the system <u>other</u> than the human beings concerned, and such modification and control must take into account known human variables and human frailties.

> As human failure will inevitably continue to occur during the driving task, which is perhaps the most complex one undertaken by the ordinary person, the system should be designed so that as far as possible it "fails safe". In this way, when human failure does occur, a crash does not necessarily result.

Work published since Henderson's review on the results of driver education, training and retraining programs have done little to resolve the uncertainty about the effectiveness of these programs. In the main, the studies reviewed were unable to detect any significant reductions in accident rates resulting from such programs, although it was acknowledged by most that the measurement of any such effects (or lack of them) is extremely difficult (Asher, 1968 ; Asher and Dodson, 1970 ; Boulton, 1972 ; Whittenburg and Baker, 1974 ; Williams and O'Neill, 1974 ; Ferreira, 1975 ; Raymond, Risk and Shaoul, 1975 ; Council, Roper and Sadof, 1976).

The role of alcohol in road accidents is well established : Zylman (1974) presents a comprehensive review of the related literature. However, the long term effects of drink-driving campaigns and law enforcement on accident reduction are not so well defined. The introduction of tougher drink-driving legislation results in an immediate reduction in the accident rate, but the effects appear to be short-lived, with accident rates gradually returning to 'pre-legislation' levels (Ross, 1975 ; Sabey and Codling, 1976 ; Codling, 1978).

It is apparent that existing programs aimed at reducing the accident rate by altering driver attitudes, by improving driver skills, or by introducing tougher legislation, have been relatively inconclusive, either because they are ineffective or have effects that are difficult to quantify. By contrast, solutions to the engineering aspects of the problem generally have readily quantifiable costs and benefits. This is not to say that the human factors in accident causation should be ignored, as it is true that a multi-cause problem generally requires a multi-treatment solution. However, because of the clear potential for benefits arising from engineering treatments, and the fact that human fallibility (which is unlikely to be eradicated) results in the need for a 'forgiving' environment, the present study was primarily addressed to the engineering aspects of pole accidents.

1.3.2 Specific Objectives

The specific objectives developed for this project may be summarized as follows :

(a) Collect detailed pole accident data that will enable :

  (i) the establishment of the extent of the pole accident problem in Melbourne (both primary and subsequent pole impacts) in the terms of the number of accidents, fatalities and injured person per year.

  (ii) the derivation of an accident predictor model that will identify potentially hazardous pole locations as a function of measurable site characteristics.

(b) Estimate the annual cost of pole accidents in Melbourne, taking account of occupant injury, vehicle damage, pole and utility damage and other sundry accident-related costs.

(c) Investigate the role of vehicle characteristics in accident occurrence and severity.

(d) Investigate the costs and benefits associated with available loss-reduction measures, ranging from pole removal to roadway improvements.

(e) Evaluate the cost-effectiveness of programs based on the accident predictor model and a number of loss-reduction treatments, for both 'across-the-board' and 'spot-improvement' programs.

The pole types to be included in the study are :

(a) Cable-supporting poles.

(b) Luminaire poles.

(c) Traffic signal poles.

(d) Strainer poles.

1.4 OUTLINE OF THE REPORT

The format of the remainder of the report is as follows :

Chapter 2	describes the organization of the project and the data collected.
Chapter 3	presents the broad characteristics of the accident sample, such as the distribution of accidents by road class, accident type, weather and time of day. Occupant injury distributions and details of vehicle damage are also presented.
Chapter 4	contains the derivation of the statistical model which enables the identification of high risk locations as a function of quantifiable site characteristics. The effect of site description on accident severity is also investigated. The role of a number of vehicle characteristics in determining the probability of pole accident occurrence is established.
Chapter 5	reviews previous accident cost studies, and presents calculations of the societal costs associated with various levels of injury severity, using locally collected data. Estimates of the annual societal cost of pole accidents are also presented.
Chapter 6	investigates the performance and benefits of a number of loss-reduction measures. Treatments analysed range from pavement resurfacing to pole removal.
Chapter 7	presents a recommended procedure for evaluating the costs and benefits associated with a number

of alternative remedial treatments. Comparisons are made between the 'across-the-board' and 'spot-improvement' approaches.

Chapter 8 is an executive summary of the project methods, results and conclusions, and contains recommendations for further work.

CHAPTER 2

ORGANIZATION OF THE STUDY

2.1 PROJECT TIMING AND PERSONNEL

The project consisted of five distinct phases covering a period of 33 months. Table 2.1 lists the phases, their duration and the number of workers involved at each stage.

TABLE 2.1

PROJECT TIMING AND PERSONNEL

Project Phase	Duration (Months)	Number of Workers
Preparation for the accident survey (1)	6	2
Accident survey (2)	8	3 + part-time
Random site survey planning and execution	6	3
Coding of data	4	2
Analysis and report preparation	9	1

(1) This phase involved organizing the data collection network and the development of an instrumented road-survey vehicle.

(2) Additional part-time assistance was obtained over the weekends and on Mondays because of the heavy case loads during these periods.

2.2 THE DATA SOUGHT

As was established in Chapter 1, this study was primarily aimed at investigating a number of the engineering aspects of pole collisions. The objectives were to investigate the effects of certain roadway, roadside, vehicle and pole characteristics on the probability and severity of pole accidents. In addition, accident cost data was sought to enable a benefit-cost analysis of alternative improvement programs.

The derivation of an accident predictor model required detailed site data on the characteristics of both the crash sites (the 'accident sample') and a control sample of randomly selected sites (the 'random sample'). The data sought for the predictor model described the roadway characteristics (curvature, skid resistance, traffic flows, etc.) and the layout of the roadside (i.e., the position of the subject pole in relation to the roadway).

Accident severity data was sought for two reasons :

(a) to provide information regarding the numbers of occupant deaths and injuries resulting from pole crashes, so as to establish the relative magnitude of the problem in comparison with other sources of road trauma ;

(b) to allow the quantification of societal losses resulting from occupant injury, vehicle damage and pole and utility damage.

To enable local monetary values to be assigned to these losses, data concerning hospital and medical costs, vehicle damage costs, pole and utility damage costs and local wage scales were sought. To enable benefit-cost analyses, estimates of remedial program costs were also needed.

Further data relating to environmental conditions, vehicle characteristics (for both accident-involved and randomly selected vehicles) and some comparative figures for other accident types were also required to complete the analysis.

2.3 DATA ACQUISITION

2.3.1 The Pole Accident Survey

(a) Organization

The survey was intended to cover the area of Melbourne denoted by the Country Roads Board as the 'inner urban area'. This boundary closely corresponds to the 1976 Australian Bureau of Statistics Melbourne urban boundary for the population census, shown in Figure 2.1. The so-called inner urban area covers approximately 200 square kilometres and includes approximately 10,500 kilometres of road.

A notification system was sought that would cover this area and encompass all accident severities, including property-damage-only (PDO) collisions. Police, ambulance and tow-truck services were canvassed. It became apparent that tow-truck operators formed the only group that could provide a viable notification network that would meet the project objectives. Tow-trucks are generally the first emergency service to arrive at a crash scene, and are the only group that attend virtually all accidents in which a vehicle is disabled, ranging in severity from PDO to fatal.

It was fortunate from the point of view of establishing a reliable information system (which is a fundamental requirement of any crash survey), that most regions in the survey area finally covered (see Figure 2.1) were serviced by more than one towing company. This ensured a high rate of accident notification because of the increased number of potential sources of information, and also, at times, because of the effects of inter-company competition. The success of this aspect of the project organization was due in the main to the co-operation and support given by the towing industry.

It was initially decided to visit the accident sites and inspect the damaged vehicles the morning after the crash. Typically this meant being at the scene 12 hours after the crash. It was thought that the increased expense and man-power required to man the telephone 24 hours a day, and respond immediately, would not be justified by a corresponding improvement in data quality. This was later confirmed by attending a small number of crashes soon after their occurrence. It was found that little additional information could be gained from this approach, and the site usually had to be revisited the following morning anyway, for skid mark measurement and detailed photography. Another factor was the

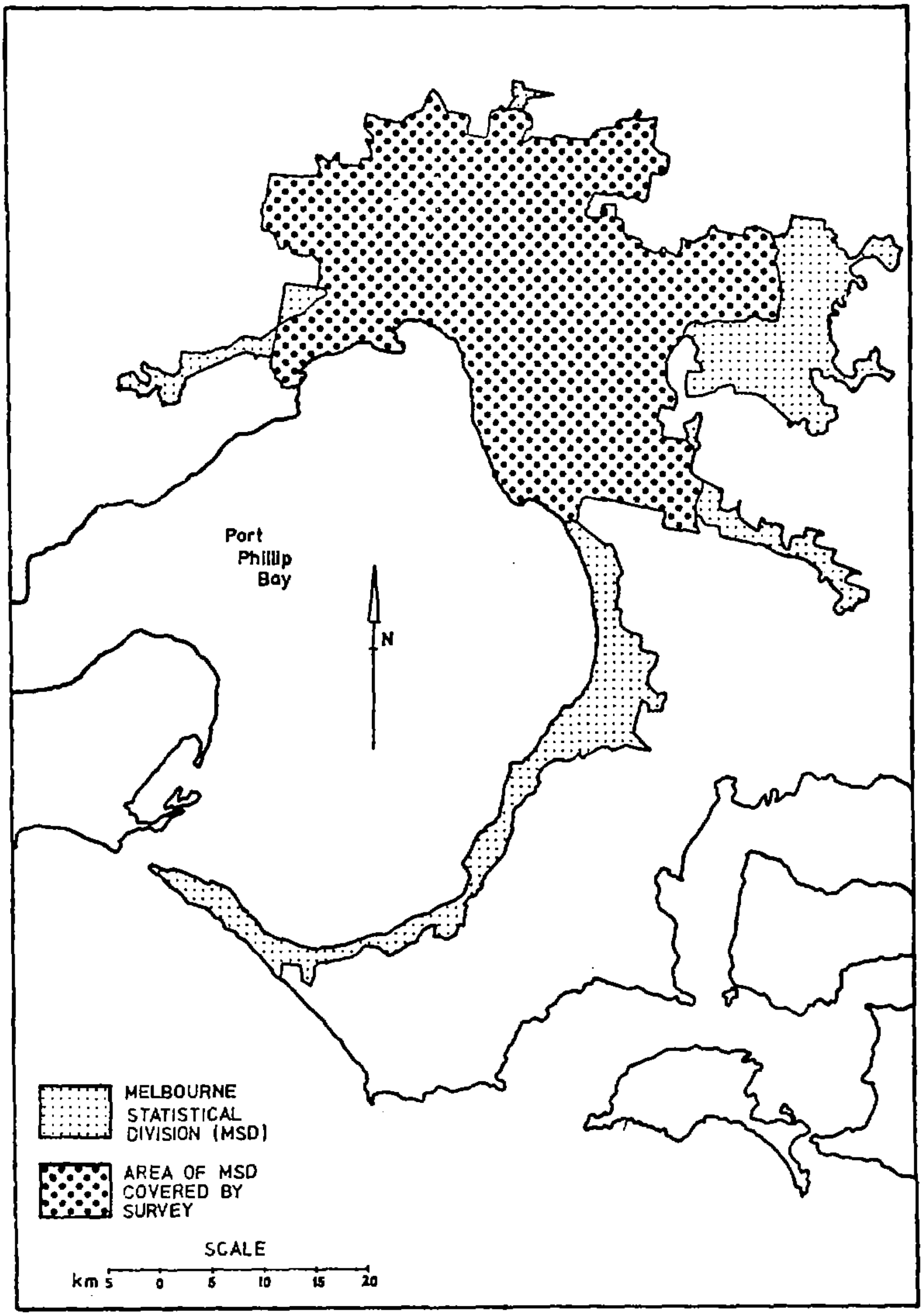


Figure 2.1 A map of Melbourne, showing the urban statistical division and the area covered by the survey.

size of the survey area, which made it impossible for one, centrally-located research team to reach outlying crash scenes before vehicles had been removed, or to attempt to attend all of the crashes on, say, a wet Saturday night. The reconstruction of the sequence of events involved in a pole accident from the physical evidence the morning after is usually straight-forward. For the requirements of the present study, there was little to be gained by being on-site. It is noted that Hendricks (1977) has compared the accuracy of data obtained from on-scene crash investigators with those obtained by teams following up after delays ranging from 2 to 7 days. The two sets of data, collected primarily for computer reconstruction of the accidents, were found to be comparable, and only slight differences in the accident reconstructions resulted. Most of the discrepancies were a result of the skid marks being erased before the follow-up team inspected the site.

In the present accident survey, when the telephones were unmanned, incoming calls from towing companies were recorded, and then returned the following morning. Where possible, the towing operators provided the following information :

(i) the location of the crash
(ii) the time of the crash
(iii) the number of vehicles involved
(iv) the location and details of the damaged vehicles
(v) the weather at the time of the crash
(vi) whether or not the ambulance attended.

The vehicles were photographed and inspected, usually within 24 hours of the crash. Initial site inspection and photographing was also carried out within 24 hours. Damage to the pole and its utilities and the pole material, size and function were also noted during the initial site inspection. However, to improve the efficiency of the detailed site data collection process, a number of sites in a given area were allowed to accumulate before they were revisited. Typically, this resulted in a delay of two weeks between the accident and the detailed measurement of site characteristics.

The ambulance services (Victorian Civil Ambulance Service and the Peninsula Ambulance Service) provided details of the casualty occupants so that they could be traced to the hospitals. Typically this was done within 48 hours. The casualty departments of all the major hospitals throughout Melbourne then completed a form detailing the injuries suffered by each injured occupant.

All data collected were ultimately coded for computer analysis. A code book was written giving precise definitions and instructions for coding each of the 752 data items on the computer file. Summary descriptions only are presented here, as in Table 2.2, which lists the general descriptive data coded for each accident.

TABLE 2.2

GENERAL DESCRIPTIVE DATA CODED
FOR EACH ACCIDENT

Case number
Time of day
Day of week
Day of month
Month of year
Class of roads involved (CBR(1) class)
CRB(2) node numbers (road inventory file)
CRB(2) road numbers (road inventory file)
Accident classification (curved road, ran off to left, etc.)
Weather
Light conditions
Number of traffic units involved
Number of vehicles which hit poles
Vehicle classifications
Number of casualty occupants
Evidence of alcohol involvement
Data group (road class ; intersection/non-intersection)

---

(1) Commonwealth Bureau of Roads

(2) Country Roads Board. These items allowed matching of the site with CRB data.

(b) Casualty occupant data

Detailed casualty occupant data was provided by the major hospitals around Melbourne. It was necessary to supply the hospitals with the identity of the victims and their approximate time of arrival at the casualty ward, for cross-matching of records. This vital cross-matching was possible because of the details regarding the number of persons transported to hospital, the age, sex and name of each injured occupant and the hospital to which they were taken, all of which were supplied by the relevant ambulance service.

The hospitals then completed a form for each occupant which detailed the injuries suffered (location, nature and severity) and the length of hospitalization. The overall injury severity was coded according to the Abbreviated Injury Scale (AIS) of the American Association for Automotive Medicine (1976). Up to six specific injuries were also coded in the manner of Marsh (1973).

Figures 2.2 and 2.3 show examples of hospital report forms for two fatally-injured persons. Table 2.3 summarizes the data coded for each injured occupant.

TABLE 2.3

DATA CODED FOR EACH CASUALTY OCCUPANT

General

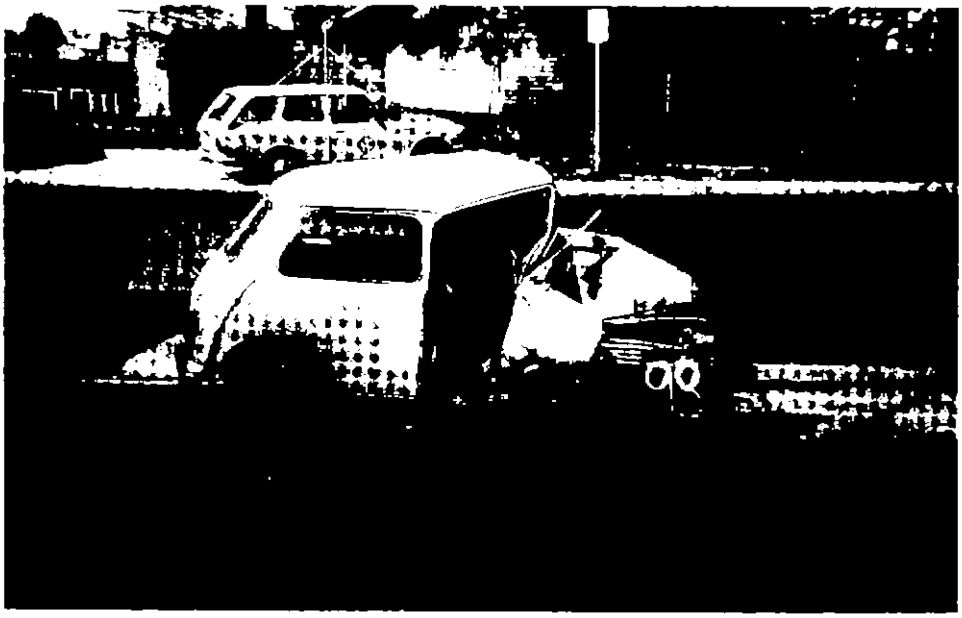
Occupant location in the vehicle (if known)
Hospital
Occupant sex
Occupant age
Expected length of hospitalization
Evidence of alcohol
Overall Abbreviated Injury Score (AIS) (1)

Specific Injuries (up to six coded per person) (2)

Body region
Aspect
Lesion (nature of the trauma)
System/organ
Severity (after the AIS system)
Restraint-induced injury

---

(1) American Association for Automotive Medicine (1976).
(2) In the manner of Marsh (1973).



Sex M

Age 19

Time of Admission Died in ambulance

Expected length of hospitalization to Alfred Hospital

INJURY SCHEMATIC

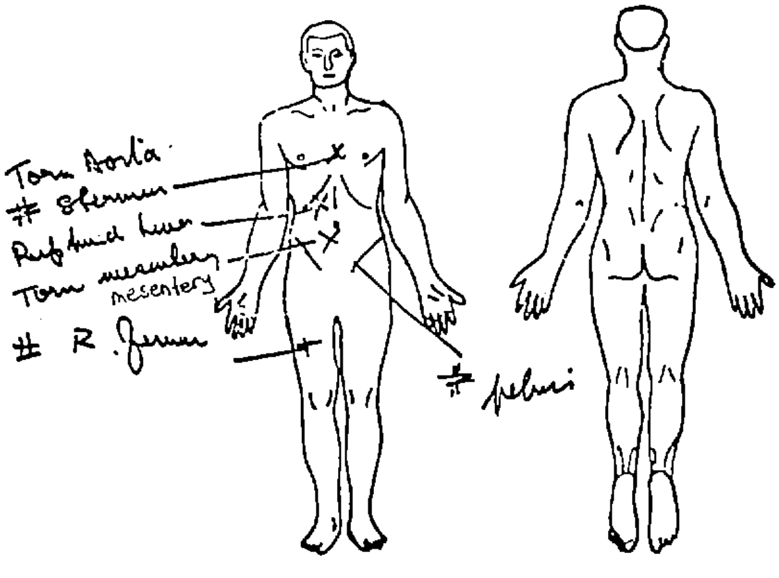
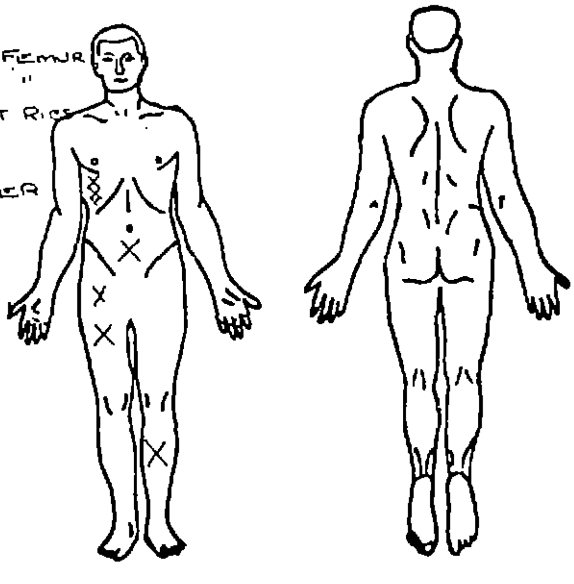


Figure 2.2 Vehicle damage and driver injuries resulting from a collision with the pole shown in Figure 2.4

Sex	M
Age	22.
Time of Admission	
Expected length of hospitalisation	DIED 29 8 76

INJURY SCHEMATIC



RIGHT NECK FEMUR
" SHAFT "
7, 8 & 9 RIGHT RIBS
LEFT TIBIA
RUPTURED LIVER

Figure 2.3 Vehicle damage and driver injuries resulting from a pole collision at the same site as the case shown in Figure 2.2 The crash occurred just eight days later.

Figure 2.4 The site involved in two fatal crashes within eight days. In both cases the road was wet and the impacts resulted in only 'scruffing' of the pole.

(c) Vehicle data

The pole accident vehicles were inspected and photographed soon after the crash - usually within 24 hours. Figures 2.2 and 2.3 show photographs of two vehicles involved in fatal accidents within eight days of each other at the same pole. Note particularly in Figure 2.2 the heavily distorted steering wheel and column resulting from impact with the driver's chest. The injuries recorded clearly reflect a severe impact in this body region. Details of vehicle make, year, model and body style were recorded. Engine details were also recorded, the precise specifications being inserted during the data coding phase. Table 2.4 shows the vehicle data coded.

The main emphasis in the vehicle data was with the tyres and the extent of the crash damage. Tyre construction, tread depth, size and inflation pressure were recorded, as well as the tyre manufacturer. Recommended tyre inflation pressures for the specific tyres and vehicle were incorporated in the data during the coding phase.

Crash damage was coded according to the Collision Deformation Classification (CDC), or Vehicle Damage Index as it is more commonly known (Society of Automotive Engineers, 1972). Measurements of deformed and undeformed vehicle dimensions were recorded, as well as the extent of occupant space penetration. As pointed out by Ashton, Hardy and Mackay (1973), the CDC system cannot be used for comparing accident severity between different cases ; rather, it allows comparison of damage characteristics. The amount of vehicle deformation gives a guide to the crash severity, provided the dynamic crush characteristics of the vehicle are known. It was proposed by Mackay (1968) that accident severity could be assessed by comparing the vehicle damage to that sustained in a controlled barrier collision test. This was later extended to collision tests involving impacts other than frontal distributed barrier impacts. However, the extensive array of pole collision test results which would be required for this method of crash severity classification are not currently available. Because of the weaknesses associated with current accident severity measures

TABLE 2.4

DATA CODED FOR EACH VEHICLE THAT COLLIDED WITH A POLE

Vehicle Description and Damage
Vehicle body style
Manufacturer and year of manufacture
Vehicle model
Engine location and orientation, driven wheels
Engine capacity, number of cylinders and horsepower
Total damage costs
Cost of damage caused by pole impact
Market value of the vehicle
Brake pedal travel
Evidence of brake line leakage
Date of next service overdue
Recommended service mileage overdue
Odometer reading
Overall maintenance appearance
Evidence of vehicle modifications
Position and weight of load (if any)
CDC damage code (1)
VIDI damage code (2)
Measurement of deformed and undeformed length
Occupant space penetration
Interior impact zones
Vehicle dimensions and mass

Tyre data - coded for all wheels
Manufacturer and model
Size
Tread depth
Uneven tyre wear
Tyre inflation pressure
Recommended tyre inflation pressure
Tyre not original specification

(1) Coded after the Collision Deformation Classification, Society of Automotive Engineers (1972).

(2) Asberg (1973).

related to vehicle damage, indirect measures such as vehicle damage costs, occupant injury levels, and occupant space penetration are investigated at various stages throughout this report.

(d) The accident site measurements

The measurements of the roadway and roadside in the vicinity of the pole involved in the collision form the main part of the data file. As previously mentioned, these data were essential for the derivation of a model to predict the frequency (and possibly severity) of pole accidents as a function of measurable site characteristics.

Measurements of the roadway characteristics common to both intersection and non-intersection cases are shown in Table 2.5. For intersection cases the roadway measurements were taken for the following 'arms' of the intersection :

(i) the road along which the 'pole' vehicle was travelling
(ii) in the case of a vehicle-to-vehicle collision prior to the pole impact, the road along which the non-pole vehicle was travelling
(iii) the road intersecting roadway (i), which usually, but not always, corresponded to roadway (ii).

The equipment used to make these measurements consisted of :

(i) pedometer (distances)
(ii) ruler (curb heights, pole diameters)
(iii) British pendulum skid tester
(iv) Bubble inclinometer (superelevation)
(v) K.C. automatic level (grade).

For non-intersection sites the primary reference point for measurements was the struck pole. At intersection sites measurements were referenced to the centre of the intersection. In large measure, therefore, the intersection data were descriptive of the whole intersection, rather than a specific pole location.

TABLE 2.5

DATA CODED FOR AT EACH ACCIDENT SITE, COMMON TO BOTH INTERSECTION AND NON-INTERSECTION CASES (1)

Direction of travel of the 'pole' vehicle
Ran off the roadway to the left/right
Distance to nearest intersection
Roadway total and one-way widths
Number of running and service lanes
Width of service lanes
If a median strip pole, distance to median end
Roadway divided/undivided
Speed zone
Road surface description
Pavement deficiencies (corrugations, tramlines, etc.)
Pole on the verge (houseside) or median
Width and height above roadway of verge/median
Curb type and height
Footpath width
Environment behind the pole
Distance to nearest luminaire
Longitudinal spacing of luminaires
Deployment and type of luminaires
Pole material, size and function
Pole and utility damage (including costs)
Distance to nearest adjacent pole
Lateral offset of the pole from road edge
Presence of pole delineators
Pavement skid resistance
Grade of the roadway at 10, 30 and 50 m upstream
Combination of vertical and horizontal curvature
Superelevation (crossfall) at 10, 20, 50 m upstream

---

(1) Roadway-related data and lighting details coded for all relevant arms of the intersection cases.

For the non-intersection cases additional data relating to road curvature was obtained, as listed in Table 2.6. To collect this data, an instrumented vehicle was developed to provide a strip chart record of the following variables as the vehicle was driven through the curve :

(i) velocity
(ii) lateral acceleration
(iii) yaw rate
(iv) steering wheel angle
(v) body roll relative to the roadway.

This enabled the determination of the horizontal curvature of the road and the side friction factor developed at all points on the curve upstream of the pole. The side friction factor f, which can be calculated from the expression

$$f = V^2/Rg - e$$

where V is the vehicle speed, R the instantaneous curve radius, g the gravitational acceleration and e the superelevation, was evaluated for the legal speed limit, or the posted advisory speed for the curve.

Additional variables were also coded for intersection sites to supplement the data in Table 2.5. These data are listed in Table 2.7.

For all the major (CBR class 6 or 7) roadway sections measured and coded, data were obtained from the Country Roads Board (CRB) 1975 road inventory file. This file divides the major road system into segments, terminated by numbered nodes. The major item sought from this file was the annual average daily traffic for each segment, which was then scaled up to 1977 levels.

TABLE 2.6

DATA CODED FOR NON-INTERSECTION SITES ONLY

Location of the point of maximum roadway curvature
Distance between pole and curve start
Curvature at 0, 20, 50 m upstream of pole
Value of maximum curvature upstream of pole
Side friction factor at 0, 20, 50 m upstream of pole
Value of maximum side friction factor
Advisory speed for curve

TABLE 2.7

DATA CODED FOR INTERSECTION SITES ONLY

Channellized left and right turns

Intersection controls

Control facing 'pole' vehicle

Length of radius vector from intersection centre to pole

Angle between radius vector and 'pole-vehicle' road

Intersection area and angle

Corner sight distances

Intersection type

TABLE 2.8

DATA TAKEN FROM COUNTRY ROADS BOARD ROAD INVENTORY FILE (AVAILABLE FOR CBR CLASS 6 OR 7 ROADS ONLY)

Node numbers

Road numbers

Employment density zone

Functional class

Predominant land use

Intermediate intersections

Total intermediate intersections

Mid-block pedestrian crossings

Annual average daily traffic (AADT)

Year of AADT

Average traffic speed

Number of fatal accidents : day/night/total

Number of personal injury accidents : day/night/total

Table 2.8 details the data extracted from the CRB file.

2.3.2 The Random Site Survey

The random site survey was carried out to provide an estimate of the site characteristics associated with the population of all poles. Without this control information, few conclusions could be drawn from the accident data.

The accident sample was sub-divided into five 'data groups', according to accident type (intersection/non-intersection) and road class. The road classes were assigned according to the Commonwealth Bureau of Roads (1969) classification system ; Classes 6 and 7 refer to arterial and collector roads (denoted 'major' roads) and Class 8 refers to residential streets (denoted 'minor' roads). When the accident sample was so classified, the major roads accounted for the majority of accidents, although they represent only 18 percent of the total length of the urban road system.

To ensure that equivalent numbers of accident and random sites were investigated for each group, the random sample was stratified into the same five data groups. Had the random sample not been so stratified, the data obtained would have been predominantly for minor roads, and would not have provided adequate control data for the major roads on which most of the accidents occur. While this stratification did not provide an overall estimate of the distribution of the pole site population characteristics, it did ensure that subsequent statistical analysis was possible.

For the major road, non-intersection group and the intersection-of-major-roads group, the CRB road inventory file was used to generate the locations of pole sites for the random sample. For the data groups involving minor roads, randomly-generated street directory grid references were used to select the sites. Needless to say, the random survey area was identical to that covered by the accident survey (see Figure 2.1).

For non-intersection sites a 'random site generator' computer program provided a specific road location. In the field, the nearest pole to this selected location was chosen, with the toss of a coin making the final decision in the case of two candidate poles. 'Direction of travel' was also chosen randomly. For intersection sites, the pole nearest the tip of a randomly-generated radius vector from the intersection centre was the one selected. Once again, 'direction of entry to the intersection' was chosen randomly.

All of the measurements made at accident sites were repeated at the random sites except, of course, for damage details, weather, time of day, etc.

It should be noted that the random sites were selected from a road <u>segment</u> inventory, with the selected sites being evenly distributed over the road system. It was subsequently realized that this approach could introduce biases into the selection of poles. Their selection should strictly have been based on a <u>pole</u> inventory rather than a road segment inventory, thus ensuring that all poles had an equal chance of selection. Unfortunately, no such inventory was available. With the approach used, road segments with a high pole 'density' did not contribute any more poles than segments with low pole density. All else being equal, it would be expected that more pole accidents would occur in areas of greater pole density, than in areas of lower pole density, because of the greater number of exposed poles. However, the effect of neglecting pole density in the random site selection procedure was subsequently shown to be minimal. Fortuitously, only one data group was affected to any significant extent. Table 4.2 in Chapter 4 details the stratification of the accident and random samples.

2.3.3 'Randomly' Selected Vehicle Survey

As with site characteristics, little could be inferred from the data on accident-involved vehicles without some estimate of the 'population' characteristics. However, detailed information on the distribution of vehicle characteristics in the population is not available. The only published data were from the vehicle census at 30 September 1976 (Australian Bureau of Statistics, 1978b). This limited information provided distributions of vehicle year, make, body style and mass for the whole State of Victoria.

The most detailed control information obtained related to vehicle tyres. The tyre data obtained for accident-involved vehicles (shown in Table 2.4) were recorded again for randomly selected vehicles at five petrol stations around Melbourne. Vehicle make, model, year and body style were also noted. As all vehicles require refuelling, petrol stations were chosen for these observations in an attempt to avoid the sample bias that might be expected at inner-city carparks, recreational centres, etc. The stations chosen were spread over a variety of socio-economic areas, and ranged from residential to industrial regions. The sample size (627) was small in comparison with the vehicle population, but it was comparable with the accident sample and served to provide estimates of previously unknown population characteristics.

2.3.4 Accident Cost Information

The extent of the accident cost data collected in the present survey is covered in detail in Section 5.3 of Chapter 5. Table 2.9 presents a summary of the data obtained and their sources.

TABLE 2.9

ACCIDENT COST DATA COLLECTED IN THE PRESENT SURVEY

Cost Item	Source
Medical and hospital, by injury severity	Motor Accidents Board
Pole/utility damage	Supply Authorities
Vehicle damage	Vehicle repairers, tow-truck operators
Vehicle market value	National Auto Market Research (1977)

In addition, costs of various remedial programs were obtained from utility supply authorities, road authorities, councils and various equipment and materials suppliers (see Chapter 6).

2.3.5 Weather Information

The condition of the road surface (wet or dry) was recorded for all accident sites. Tow-truck operators were the primary source of this information. However, the Melbourne Metropolitan Board of Works (MMBW) has twenty pluviograph stations scattered over Melbourne, and the continuous records from these were used to cross-check all tow-truck driver's reports. Further, the pluviograph data were used to estimate the total number of wet road and dry road hours for the period of the accident survey, to provide a measure of the exposure of vehicles to wet roads.

2.3.6 Comparative Accident Data

The Road Safety and Traffic Authority (RoSTA) provided details of police-reported pole accidents for the Melbourne metropolitan area during the accident survey period. This information allowed estimates to be made of the level of accident coverage achieved in the present study. Data concerning all road accidents over the same period were also obtained to allow the pole accident sample to be put in perspective.

The Traffic Accident Research Unit of the Department of Motor Transport, New South Wales (TARU), provided data which allowed comparisons to be made of the severity of collisions with various types of fixed object. These data were obtained from New South Wales because the accident reporting threshold in that State was $50 property damage. For the Victorian (RoSTA) data the threshold is essentially at the casualty accident level. Both the TARU and RoSTA data are oriented towards the first object struck, and are derived from police accident report forms.

2.4 DATA ANALYSIS PROCEDURES

The data taken from the report forms, photographs and data sheets was coded onto computer punch sheets. This information was transferred to magnetic tape, which then formed the basic storage medium for the computer analysis. The computer system used was the

Control Data Corporation CYBER 73 Computer at the University of Melbourne. The statistical analysis package known as 'Statistical Package for the Social Sciences' (Nie et al., 1975) was used extensively for data manipulation and analysis. Details of the analyses undertaken are provided in subsequent Chapters.

CHAPTER 3

THE CHARACTERISTICS OF POLE ACCIDENTS

3.1 INTRODUCTION

This chapter contains a descriptive summary of the characteristics of the sample of 879 pole accidents (hereafter referred to as the 'accident sample') obtained over an eight-month survey period from 7 July 1976 to 7 March 1977. The information presented here provides a background for detailed analyses and statistical model derivations in Chapter 4. Where possible comparisons between the present study and other data sources are made, although comparable data are somewhat limited.

The most comprehensive published source of information on pole accidents in Australia is Vaughan's (1975) analysis of pole accidents reported to police in New South Wales in 1973. To supplement Vaughan's data the Road Safety and Traffic Authority (RoSTA) carried out a number of computer searches of their police-report-based accident files for this study. It should be noted that both RoSTA's and Vaughan's data are based on an accident classification scheme which considers the first, or primary, impact only. For example, in the case of a vehicle-to vehicle collision which results in one of the vehicles leaving the roadway and striking a pole (defined as a secondary pole impact) the accident would be classified and coded as a vehicle-to-vehicle collision. The present survey included secondary pole collisions and this factor should be considered when comparisons are made between studies.

3.2 NUMBERS OF ACCIDENTS AND CASUALTIES

3.2.1 RoSTA Data

Based on the RoSTA information, and statistics published by the Australian Bureau of Statistics (1977), primary collisions with poles accounted for 5.8 percent of road accident fatalities, and 4.6 percent of non-fatal injuries, for the whole of Victoria (urban and rural) in 1976. Similarly, pole accidents accounted for 5.9 percent of fatal accidents and 4.5 percent of injury accidents. For the Melbourne Metropolitan area, pole accidents recorded by RoSTA during the period of the present accident survey represented 8.6 percent of fatal accidents and 5.8 percent of injury accidents.

In terms of fixed-object collisions only, poles were involved in 22.2 percent of fatal accidents and 32.9 percent of injury accidents for the whole of the state during the survey period. In the Melbourne metropolitan area, pole accidents accounted for 45.3 percent of fatal fixed-object collisions and 51.9 percent of injury fixed-object collisions. Annually, primary pole accidents produce 55 fatalities and 810 injured persons for the whole state, with the Melbourne road system accounting for approximately 40 fatalities and 630 injured persons.

The RoSTA data for the survey period also showed that pole accidents were generally 1.5 times more severe than the average for all accident types, based on the number of fatal accidents per 100 casualty accidents.

3.2.2 The Accident Sample

The 879 pole accidents in the present sample resulted in 31 fatalities and 374 injured persons requiring ambulance transport. On the basis of primary pole collisions only, the sample included 30 fatalities and 310 injured persons. For almost the same period as the present survey, (1 July 1976 to 1 March 1977) RoSTA recorded 26 fatalities and 467 injuries. One reason for the difference between the two fatality figures lies in the definition of a fatality. RoSTA defines a fatality as death occurring within 30 days of the accident, whereas the 30 primary-collision fatalities in the accident sample include cases in which death occurred after 30 days. If the RoSTA definition is applied to the accident sample, the number of fatalities is reduced to 28, with a further reduction to 27 because one of the fatalities occurred outside the RoSTA data period.

While the numbers of fatalities are thus comparable, the number of injured persons in the accident sample remains well below the RoSTA figure. It would appear that the level of coverage of the present survey based on the number of injured persons is 66 percent. Based on the number of injury accidents, the figure is 65 percent. An alternative estimate of the level of coverage is made in Section 4.3.4, taking account of the size of the survey area and the level of tow truck company reporting. It is estimated that 70 percent of the Melbourne metropolitan area was covered by the notification system, and that the reporting rate within the area covered was 90 percent. This leads to an overall coverage estimate of 63 percent, which is in remarkable agreement with the RoSTA-based estimates. However the situation is complicated further when the statewide casualty figures of RoSTA are compared with the number of claims received by the Motor Accidents Board (MAB). The MAB, broadly speaking, provides no-fault compensation for road accident victims. The compensation covers medical and rehabilitation expenses as well as some loss of income. The number of claims received by the MAB in the 1976/77 financial year was approximately 34,500 compared with 18,600 casualties reported by RoSTA in the 1976 calendar year. Some of this discrepancy is no doubt explained by the relative benefits of reporting an accident to the MAB and the Police. Further, some injuries may appear some days after the accident and would therefore not appear on the RoSTA accident file. However, the MAB figure of 34,500 does not include cases covered by workers' compensation insurance and it is estimated by the MAB that these could number at least 2,000. Despite these uncertainties, it remains clear that the adoption of an overall coverage figure for the accident sample of 65 percent is likely to provide conservatively low estimates of the magnitude of the pole accident problem.

Taking the sample of fatalities to be complete and adopting the 65 percent coverage rate for non-fatal injuries, it is estimated that pole accidents in the Melbourne metropolitan area produce 45 fatalities and 785 injured persons annually.

3.3 CLASSIFICATION BY SEVERITY, COLLISION SEQUENCE AND ROAD FEATURES

3.3.1 Severity and Collision Sequence

The accident sample was classified according to whether the pole impact was the primary or a secondary collision, and according to the level of injury to the worst-injured occupant. Figure 3.1 shows this breakdown, with accident severity described as Fatal (F), personal injury only (PI) or property damage only (PDO). It can be seen that secondary collisions account for 15 percent of the accident sample, which is in agreement with the estimate of 14 percent made by Vaughan (1975). Secondary pole collisions appear to be only slightly less severe than primary collisions with 28.5 percent of secondary collisions resulting in occupant casualties compared with 30.1 percent of primary pole collisions. Figure 3.1 also shows that, even though pole accidents are more severe than most other urban accident types, the majority (70%) did not result in occupant death or injury. By way of comparison, Troy and Butlin (1971) reported that 90 percent of all accidents resulted in property damage only, in their cost study of road accidents in Canberra in 1965-6. Of the 374 persons recorded as injured and requiring ambulance transport to hospital in the present study, 34 either left the casualty ward without receiving treatment, or had files that could not be traced in the hospital. The 340 persons for whom records of medical treatment could be obtained were retained in the injury sample, the remaining 34 were reclassified as not injured.

Figure 3.2 shows the distribution of casualty occupants by severity and accident sequence. Primary pole collisions account for 84 percent of the casualty occupants.

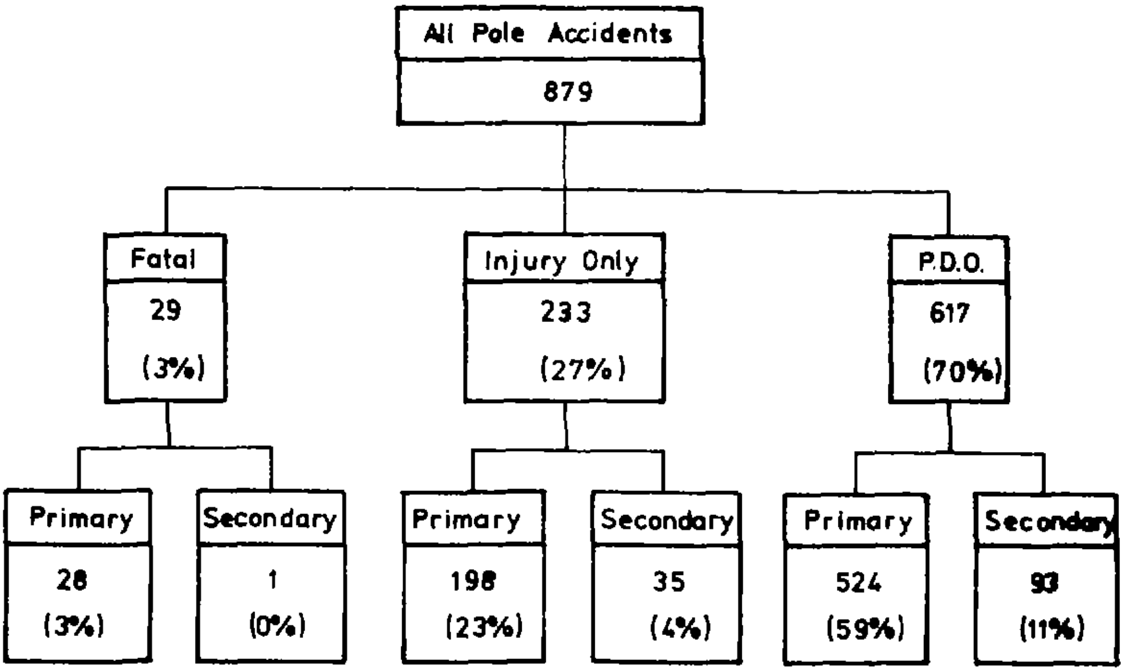


Figure 3.1. Distribution of pole accidents by accident severity.

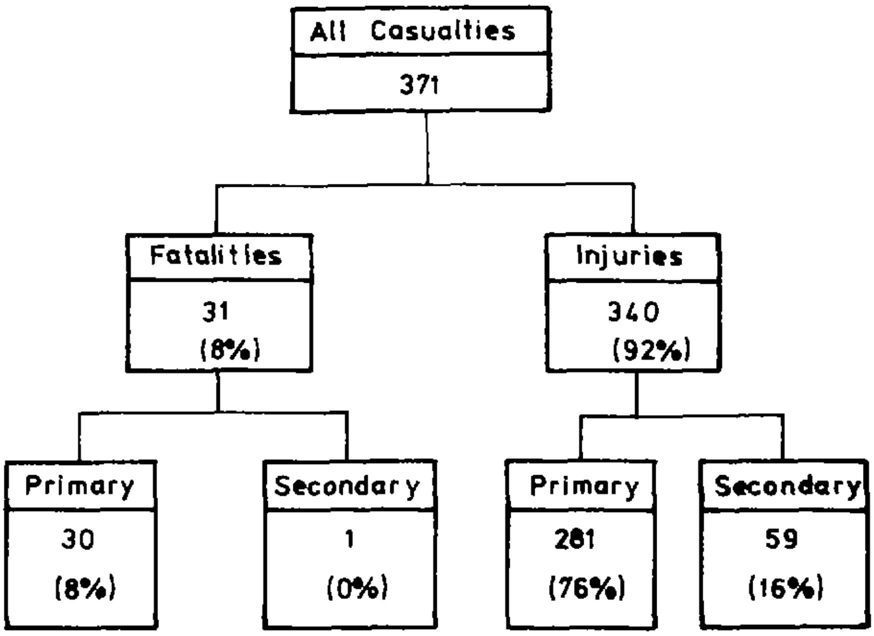


Figure 3.2. Distribution of casualty occupants by severity and impact sequence.

Table 3.1 compares the distributions of pole accident severity in the present accident sample with that reported by Vaughan. A rather significant difference can be seen in the personal injury and property damage only categories. Vaughan's reportings of a much lower percentage of PDO accidents could be partly explained by the inclusion in his data of rural accidents, which would be biased towards greater severity. It is also likely that the level of reporting (to police) of minor PDO accidents is lower than for more severe accidents. It is noted that in the present study a towaway criterion was employed for the PDO cases.

3.3.2 Road Features

The classification of the accident sample by road features is shown in Figure 3.3. One third of the accidents involved an intersection, with the majority of secondary collisions occurring in this category, particularly at cross type intersections. Unless the characteristics of the road system as a whole are known or can be estimated, the role of various road features in the accident process cannot be determined. The random pole survey was designed to provide such an estimate for this study. The detailed analysis of the influence of road features of pole accidents is presented in Chapter 4.

Table 3.2 compares the primary collisions from the accident sample with Vaughan's data in terms of road features. The influence of rural accidents in the Vaughan data is again indicated by the low percentage of signalised intersection cases compared with the present study. The overall percentage distributions by intersection, straight road and curved road are of the same order.

The distribution of pole accidents by road class (as defined by the Commonwealth Bureau of Roads, 1969) is shown in Figure 3.4. Classes 6 and 7 (denoted 'major' roads) refer to arterial and collector roads, while class 8 (denoted 'minor' roads) refers to residential streets. It can be seen that the largest sub-group is the major road non-intersection group, which accounts for 56% of

TABLE 3.1

DISTRIBUTION (%) OF POLE ACCIDENTS (PRIMARY IMPACTS) BY ACCIDENT SEVERITY.

Source	Accident Severity		
	Fatal	PI	PDO
Present Survey	3	27	70
Vaughan	3	50	47

TABLE 3.2

DISTRIBUTION OF PRIMARY POLE ACCIDENTS BY ROAD FEATURES

Road Feature	Source	
	Present Study	Vaughan
Signalised intersection	10.4	1.8
Non-signalised T intersection	9.5	15.8
Non-signalised Cross intersection	3.6	5.0
Non-signalised Multiple (other intersections)	0.7	2.8
Straight road	42.3	47.3
Curve	33.5	25.0

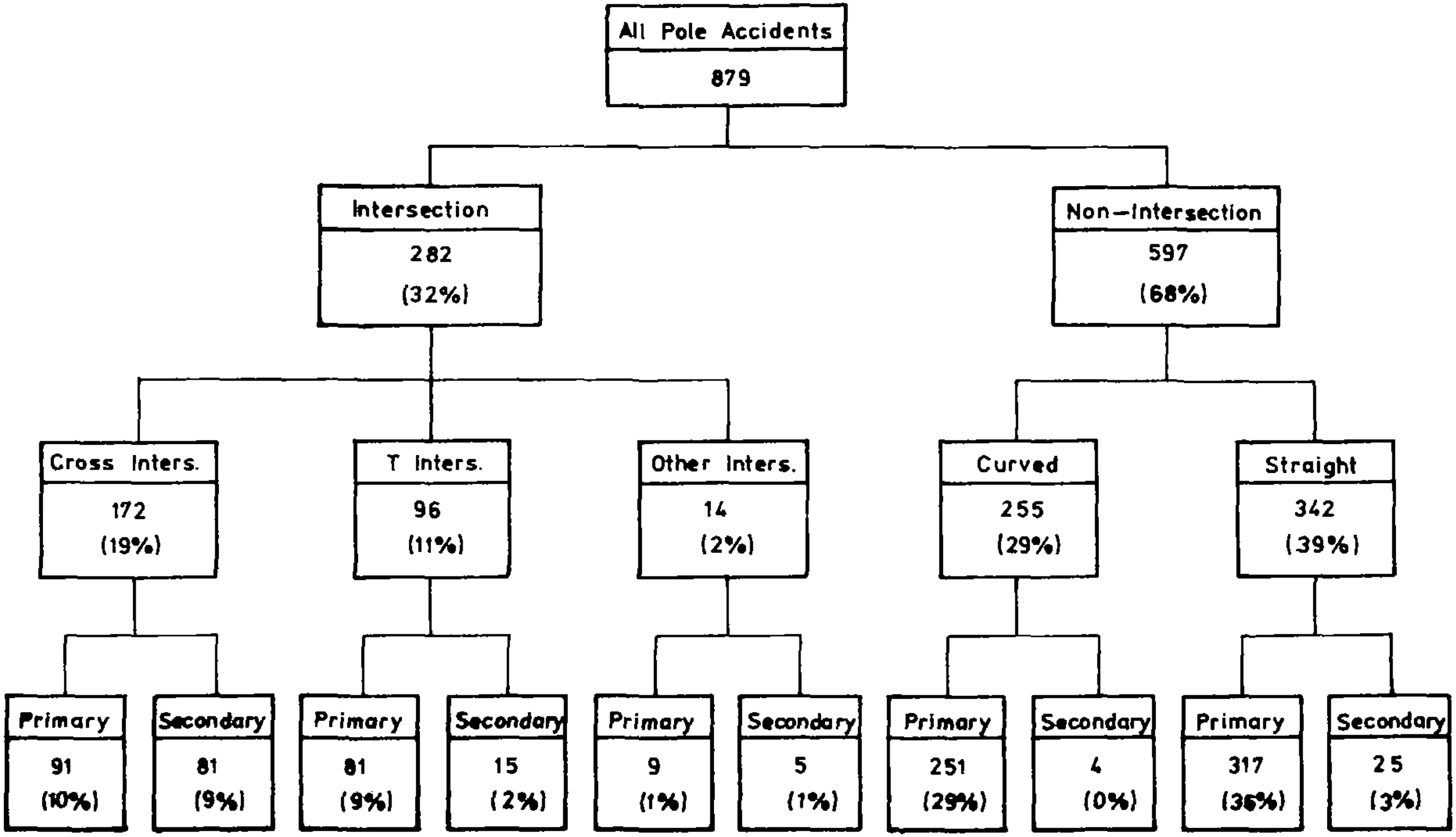


Figure 3.3. Distribution of pole accidents by road features and impact sequence.

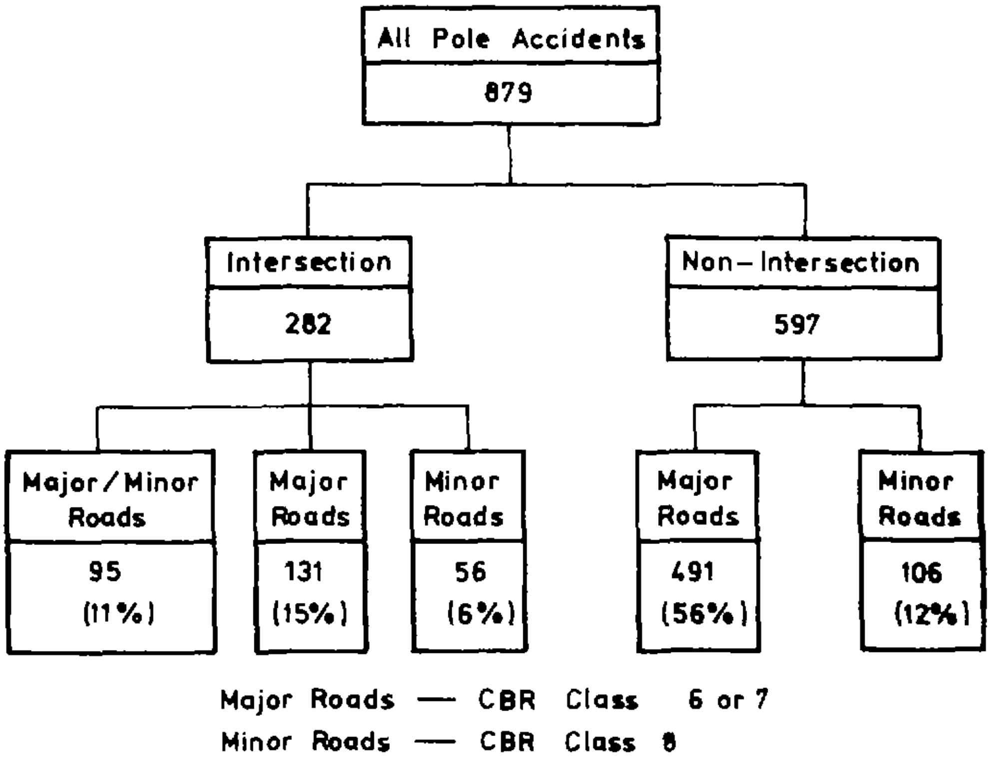


Figure 3.4. Distribution of pole accidents by Commonwealth Bureau of Roads (CBR) road class.

all pole accidents. The intersection of major roads group is the next highest group (15%), followed by minor road non-intersection (12%) the intersection of major and minor roads (11%) and the intersection of minor roads (6%).

The majority of the accident sites (90% of major road sites and 99% of minor road sites) were in 60 km/h speed limit zones. Eight percent of the major road accident sites were in 75 km/h speed limit zones with the remaining two percent being in 100 km/h speed limit zones.

3.4 CLASSIFICATION BY NON-ROAD FACTORS

3.4.1 Time of Day

Figure 3.5 shows the distribution of the accident sample by time of day and day of week, for all accident types and severity. There is a continuous background level of accidents throughout the week, with the numbers increasing within each day during the nightime hours. The number of accidents at night increases from Thursday night through to Saturday night, the peak occurring in the hours shortly after Saturday midnight, no doubt due to increased social and recreational traffic. The form of the distribution is identical to that reported by Vaughan, and in the data provided by RoSTA.

The variation of traffic volume with hour of week is shown in Figure 3.6, demonstrating that traffic volumes are at their lowest during the hours in which the accident rate is reaching its peak. Traffic volume data were obtained from the Victorian Country Roads Board (CRB) for eight sites around Melbourne which include a variety of road types. Figure 3.6 represents an average of those eight sites. To examine the hour by hour trend, Figure 3.7 shows the distribution of pole accident numbers and traffic volumes by hour of day for all accident classes for all days of the week. When the accident sample is split by accident type (curved road, T-intersection, etc) the variation of the numbers of each accident type with time of day is much the same as in Figure 3.7. A number of features of the accident distribution by time of day are interesting:

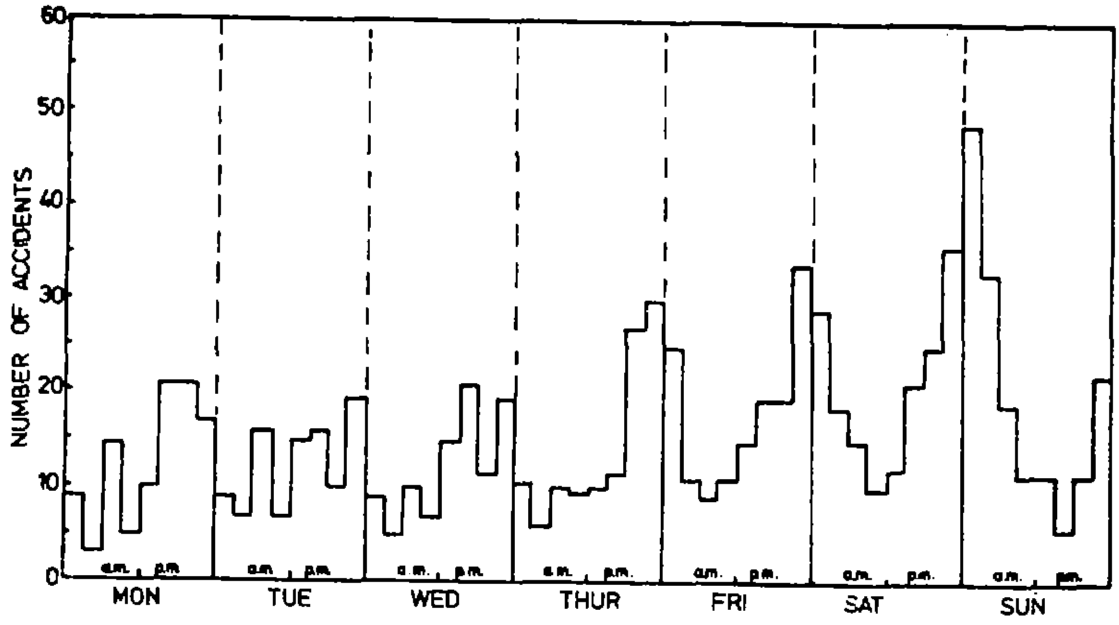


Figure 3.5. Distribution of pole accidents by time of week.

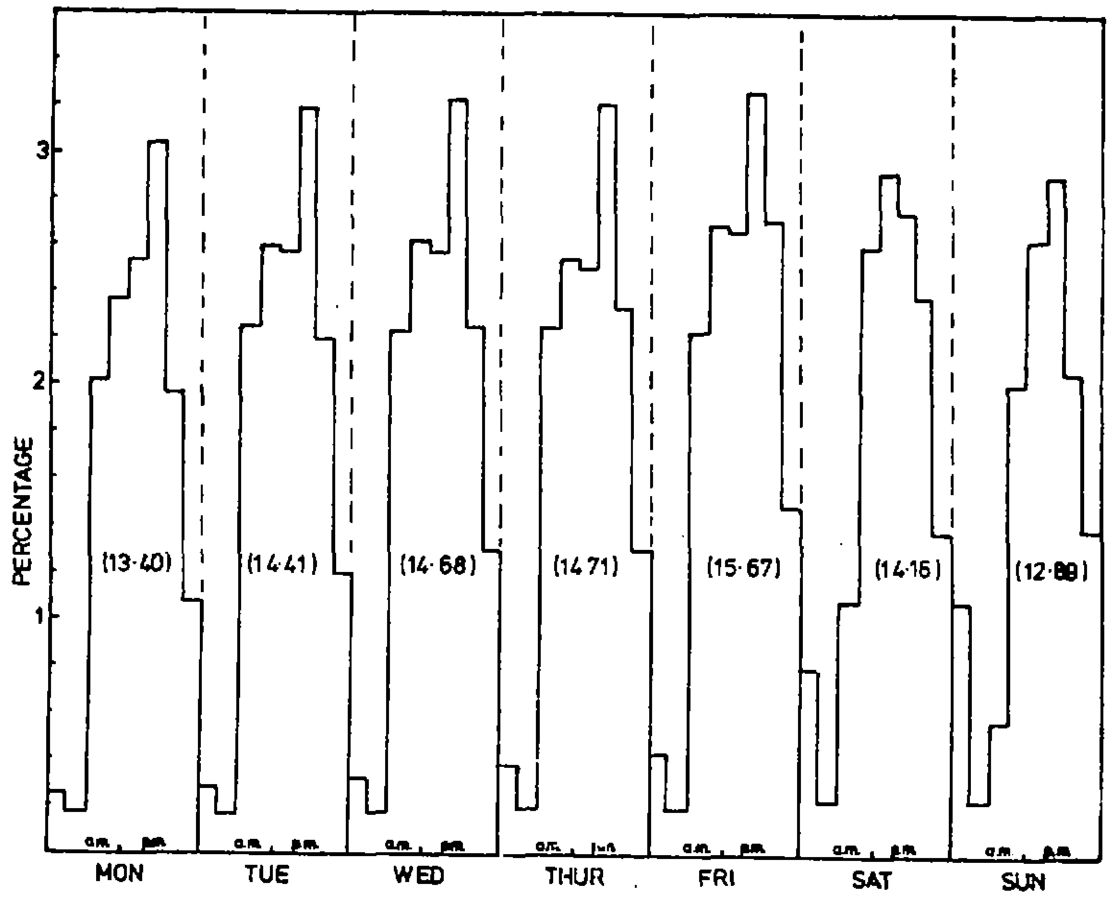


Figure 3.6. Distribution of traffic volume by time of week.

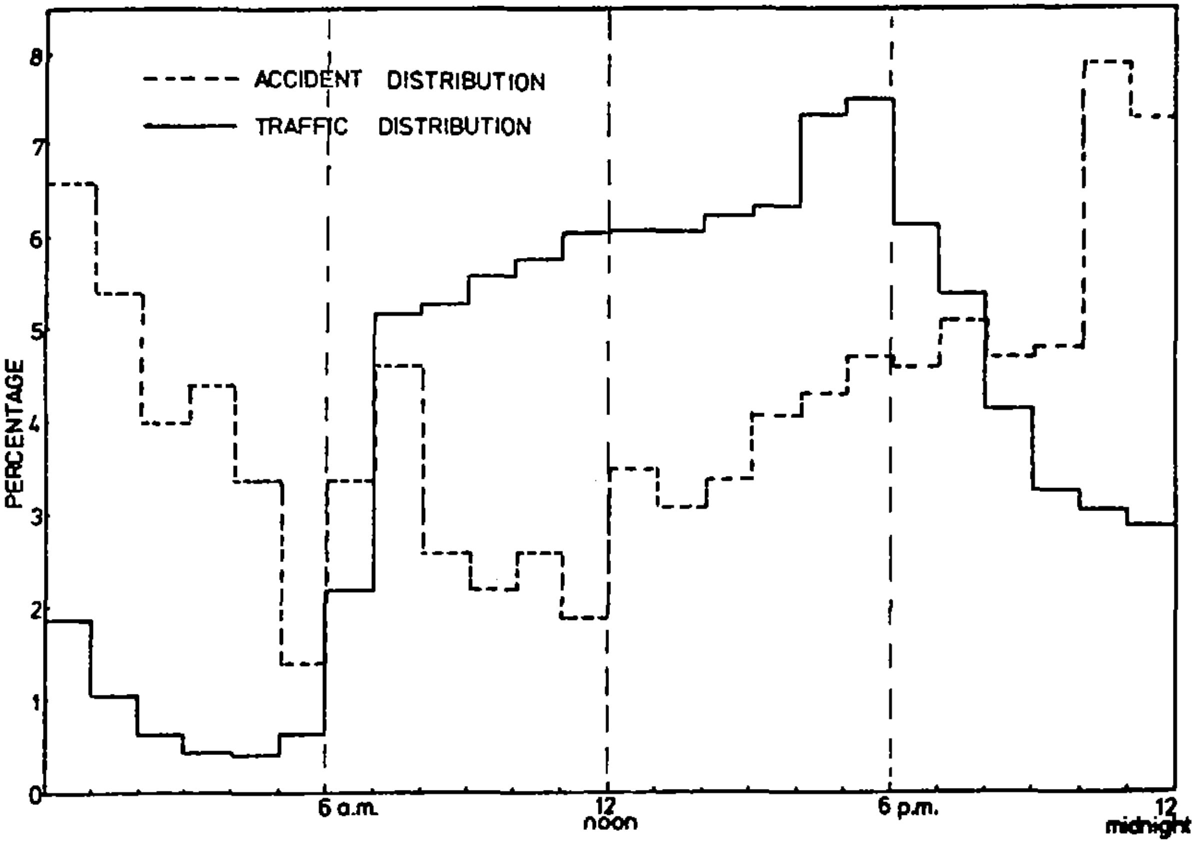


Figure 3.7. Distribution of pole accidents and traffic volume by hour of day, for all accident classes and days of the week.

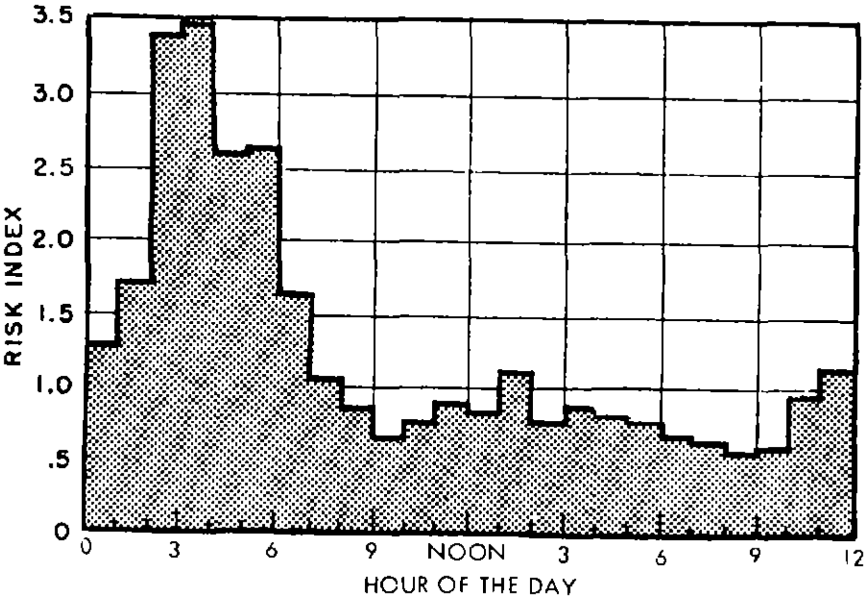


Figure 3.8. Risk index by hour of day for interstate highway accidents (Baker, 1967).

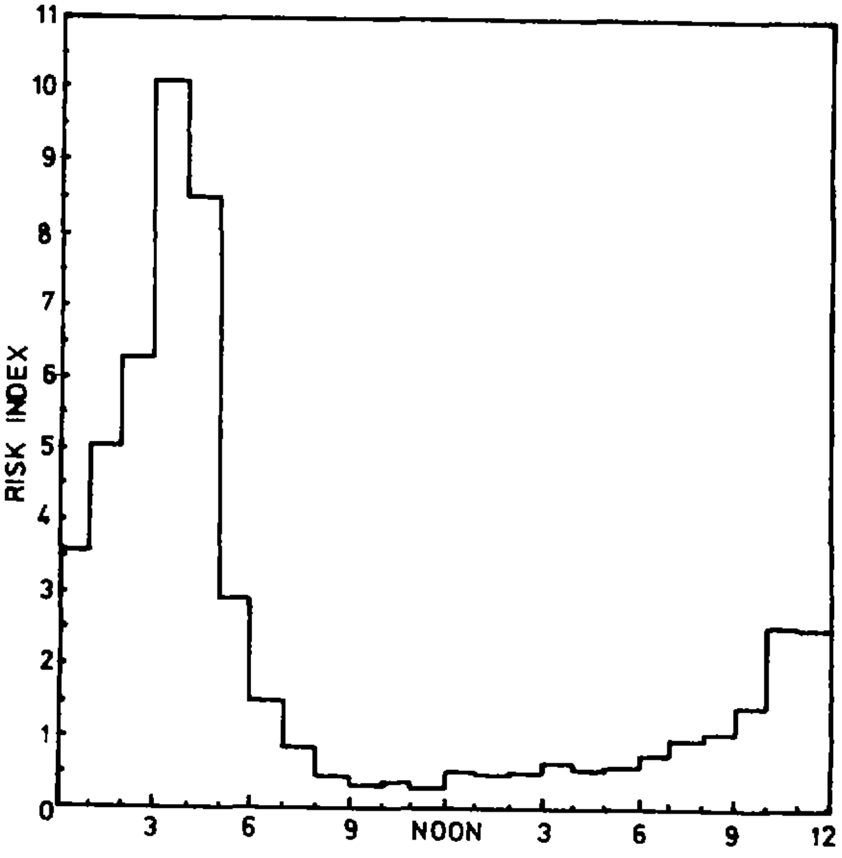


Figure 3. 9. Risk index by hour of day for pole accident sample.

(i) the peak occurs in the hour between 10 pm and 11 pm, which is the hour after hotel closing time.

(ii) the high accident rates occur during low traffic volume times.

(iii) there is a secondary peak in the accident distribution which corresponds to the morning rush period.

(iv) there is a general 'background' level of accidents throughout all hours of the day.

From the two distributions in Figure 3.7, a risk index-defined as the ratio of the proportion of accidents to the proportion of traffic per hour-can be determined. Such a risk index was derived by Baker (1967) for all accidents on an American interstate highway, with the results shown in Figure 3.8. The risk index curve calculated for the pole accident sample shown in Figure 3.9 is similar in form. The greatest accident risk per vehicle occurs in the hour between 3 am and 4 am. It is likely that fatigue and alcohol play a significant part in determining this peak.

3.4.2 Weather

The weather information collected for each accident case related primarily to the condition of the road surface. The tow truck driver attending the accident reported whether the road surface was wet or dry. The Melbourne Metropolitan Board of Works (MMBW) has twenty pluviograph stations spread over the Melbourne metropolitan area which provide uninterrupted strip chart recordings of rainfall. To crosscheck missing or doubtful tow-truck drivers rainfall reports, the pluviograph record for the time of the accident was obtained from the nearest recording station. In addition, complete records for the period of the survey were obtained from recording stations at the four points of the compass and a centrally-placed recording station. These records were averaged to provide an estimate of the wet versus dry hours of exposure. The road was deemed to be wet for a half an hour after rain had stopped.

Table 3.3 compares the numbers of wet and dry-road accidents with the hours of exposure of vehicles to wet and dry roads during the survey period. It is apparent that wet roads are associated with a disproportionately high number of pole accidents. In fact, assuming no difference in traffic volume or other relevant factors, a wet road is (338/541) ÷ (789/5019) = 4.0 times more likely to be associated with an accident than a dry road. In terms of the measure used extensively in Chapter 4 to denote relative risk, the probability of an accident on a wet road is 38/14 = 2.7 times higher than the mean probability for all road conditions. It is noted that the percentage of dry road accidents in the accident sample (62%) is a little different from the proportion reported for New South Wales by Vaughan (73%). The relative hours of exposure of dry roads in New South Wales and metropolitan Melbourne is not known however.

Road condition was found to have an interesting effect on the accident-producing mechanism on curved roads. Table 3.4 shows that the proportion of poles hit on the outside of the curve was reduced from 65 percent on dry roads to 54 percent when the road was wet.

It can be seen from Table 3.5 that this change was primarily due to a marked increase (from 10 to 37 percent) in the frequency of vehicles running off to the inside of right-hand bends when the roads were wet. There was also a small increase (from 64 to 67 percent) in the number running off to the inside of left-hand bends.

Notice from Table 3.5, also, that the majority of poles hit were on the left-hand side of the road, because of their generally closer proximity. (That this is the reason can be demonstrated by the fact that 70 percent of all mid-block pole crashes on major roads were on the left side. For undivided roads the figure was 79 percent, whereas the split was even for divided roads, for which

TABLE 3.3

DISTRIBUTION OF ACCIDENTS AND ROAD CONDITION EXPOSURE BY ROAD CONDITION

Road Condition	Accident Sample		Exposure	
	Number	Percent	Hours	Percent
Dry	541	62	5019	86
Wet	338	38	789	14

TABLE 3.4

PROPORTION OF POLES HIT ON OUTSIDE AND INSIDE OF ROAD CURVES, BY ROAD CONDITION (%)

Pole Location	Road Condition		
	Dry	Wet	Total
Outside of Curve	65	54	60
Inside of Curve	35	46	40

TABLE 3.5

PROPORTION OF POLES HIT ON LEFT AND RIGHT SIDE OF CURVED ROADS, BY DIRECTION OF BEND AND ROAD CONDITION (%)

Vehicle Movement	Left-Hand Bend			Right Hand Bend		
	Dry	Wet	Total	Dry	Wet	Total
	(inside)			(outside)		
Ran Off to Left	64	67	65	90	63	76
	(outside)			(inside)		
Ran Off to Right	36	33	35	10	37	24

the proximity of verge and median poles is roughly equal.)

The increase in frequency of vehicles running off to the inside of curves on wet roads suggests a change in the loss-of-control mechanism from spin-out, or drift-out, on dry roads towards an unstable, oscillatory form of steering control which increases the chances of finally leaving the road on the inside of the bend. Nevertheless, the predominant accident scenario on curves is running off to the outside of the bend (60 percent of all curved-road crashes). The distinctions between left and right are of interest in understanding the accident mechanism but of course, are of no value in selecting the most appropriate siting of poles on undivided roads.

3.4.3 Light Conditions

The other 'environmental' variable coded for the accident sample referred to light conditions. Table 3.6 shows that the majority of pole accidents occur at night. The difference between the figures for the two data groups included in Table 3.6 presumably stems from a difference in the interpretation of dusk or dawn compared with dark. (The RoSTA data are derived from police accident reports.)

The effect of artificial lighting on the initiation of the accidents event is difficult to determine, because the presence of lighting is directly related to the presence of poles. In fact, in comparing the street lighting in the accident sample to that in the random sample, the better-lit roads had more pole accidents than the less well lit roads. This clearly results from the relationship between lighting and pole density. Because of the nature of the accident and random pole samples it was not possible to separate the effects of pole density and the level of lighting.

3.4.4 Alcohol

The alcohol-related data collected in the present study was, on the whole, scant. The sources varied from tow truck driver hearsay to hospital-reported levels. In the majority of cases exact blood

TABLE 3.6

DISTRIBUTION (%) OF POLE ACCIDENTS BY LIGHT CONDITIONS

Light Conditions	Source	
	Present Study	RoSTA
Dawn/Dusk	17	4
Day	33	34
Night	50	64

TABLE 3.7

ATTENDING POLICE OFFICER'S OPINION OF DRIVER'S SOBRIETY FOR METROPOLITAN ROAD ACCIDENTS DURING SURVEY PERIOD *

Opinion of Sobriety	Pole Accidents		Other Accidents	
	No.	%	No.	%
Not Drinking	161	48	7634	83
Not Obvious Effect	46	14	249	3
Obviously Affected	129	38	1355	15
Sub-Total	336	100	9238	100
Not Known	116		1679	
Total	452		10917	

* Source: RoSTA

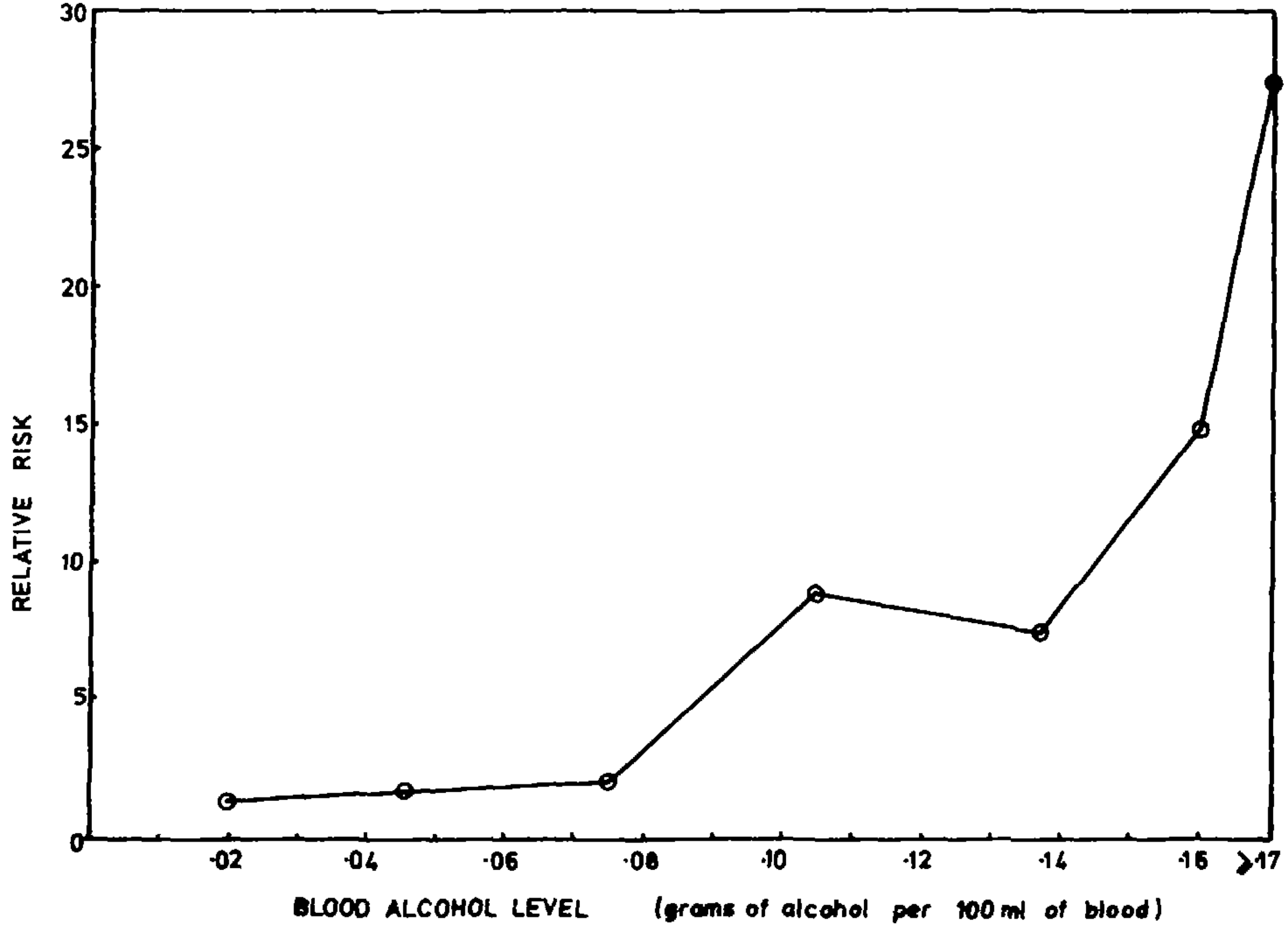


Figure 3. 10. Relative risk of being involved in an injury accident by blood alcohol level (Farris *et al*, 1977).

alcohol levels were not available. Of the 55 cases where hospital test results were available, 35 percent of those tested had not been drinking. This sample is biased towards more severe accidents, by the nature of the data source, and may not, therefore, be truly representative. The data available from RoSTA are also biased towards more severe accidents, and are based on the opinion of the attending police officer rather than chemical tests. However, given these inadequacies, it appears possible from the data in Table 3.7 that alcohol plays a stronger role in pole accidents than in other accident types.

The importance of alcohol in the precipitation of accidents has been well established. The results of a recent study by Farris, Malone and Kirkpatrick (1977), in which a sample of 2,415 accident drivers was compared with a random sample of 4,637 exposed drivers, are shown in Figure 3.10. It can be seen that the accident risk climbs sharply for blood alcohol levels higher than 0.08 grams per 100 millilitres of blood (usually expressed as 0.08%).

3.5 INJURIES AND DAMAGE TO VEHICLES, POLES AND UTILITIES

3.5.1 Direction of Impact on Vehicle

In this section the damage to the vehicle resulting from the pole impact only is considered. The role of vehicle characteristics in producing pole accidents is analysed in section 4.5.

Figure 3.11 presents the distribution of pole impacts by direction of impact relative to the vehicle. It is clear that the majority of impacts are frontal.

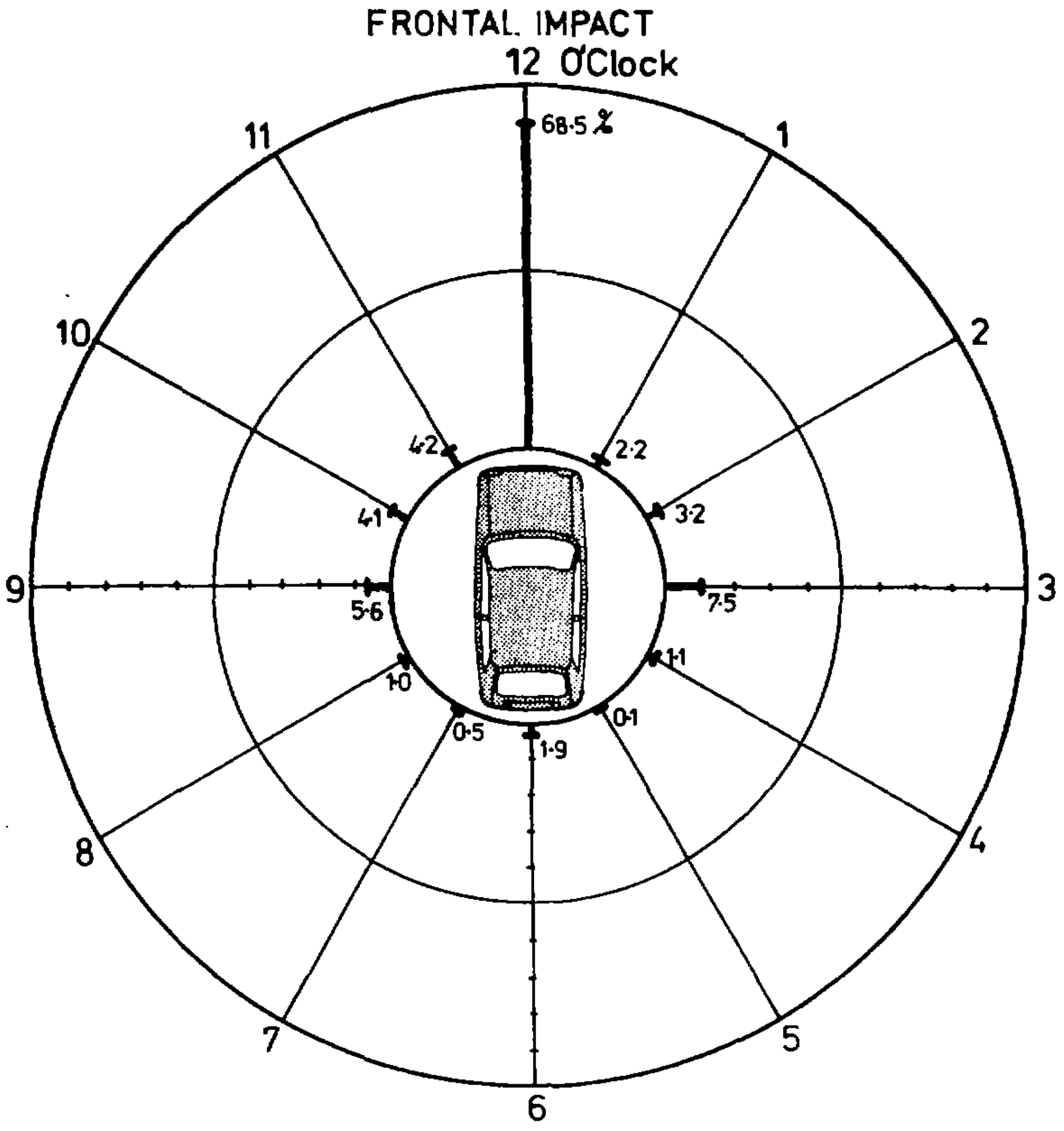


Figure 3. 11. Distribution (%) of pole accidents by direction of impact relative to the vehicle.

3.5.2 Relationship Between Vehicle Damage and Injuries

In terms of hazard to the vehicle occupants, the most important measure of impact severity is probably the amount of occupant space penetration, followed in importance by the total velocity change and peak deceleration levels suffered by the vehicle during the impact. Estimates of the latter two variables could not be made for the present analysis because of the lack of comprehensive data on vehicle damage resulting from controlled and instrumented pole impacts. To demonstrate the role of occupant space penetration in injury calculation, Figures 3.12 and 3.13 show the vehicle damage and occupant injury resulting from two pole crashes which involved similar amounts of deformation energy. Figure 3.12 shows how a side impact caused massive penetration of the driver space. The driver was killed instantly with severe chest and pelvic injuries. The frontal impact shown in Figure 3.13 would have produced a similar level of vehicle velocity change as in the previous collision. In this case, however, the occupant space penetration was minimal and the un-seatbelted occupants survived, despite being thrown out through the windscreen and tearing the dashboard from its mountings in the process. The injuries suffered by the driver of the vehicle shown in Figure 3.13, resulted from impacting the steering wheel and column, and the dashboard.

To further demonstrate the relationship between occupant space penetration and injury severity, Figure 3.14 shows the relationship between AIS score of the worst-injured occupant per accident and the amount of occupant space penetration. The more severe injuries are clearly associated with deeper occupant space intrusion, note that this increased injury severity is not necessarily due to deeper occupant space penetration only, as the deeper intrusions would also be associated with higher vehicle velocity changes and deceleration levels.

Sex M

Age 54 *

Time of Admission Killed instantly.

Expected length of hospitalization

INJURY SCHEMATIC

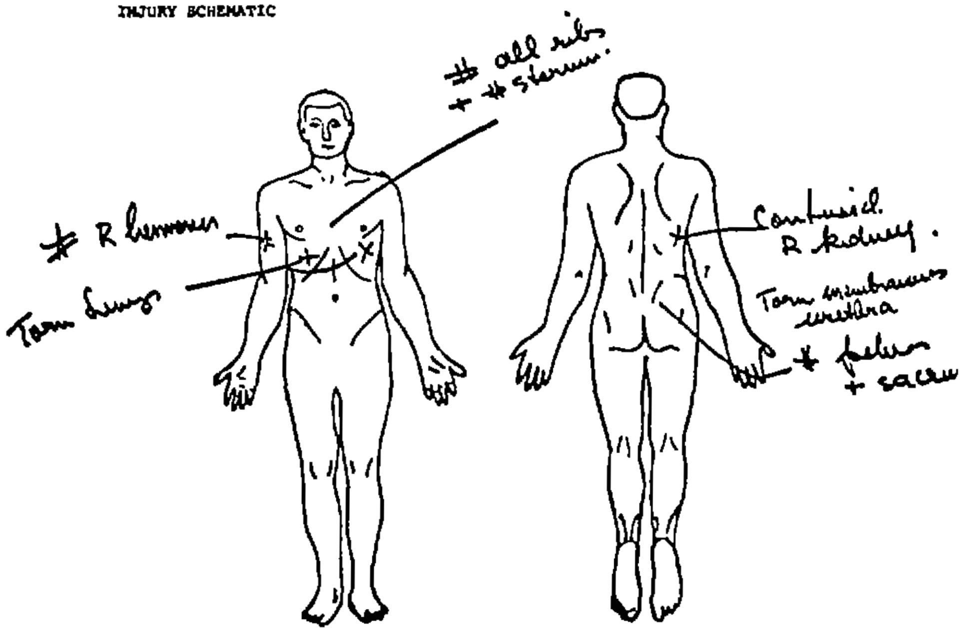
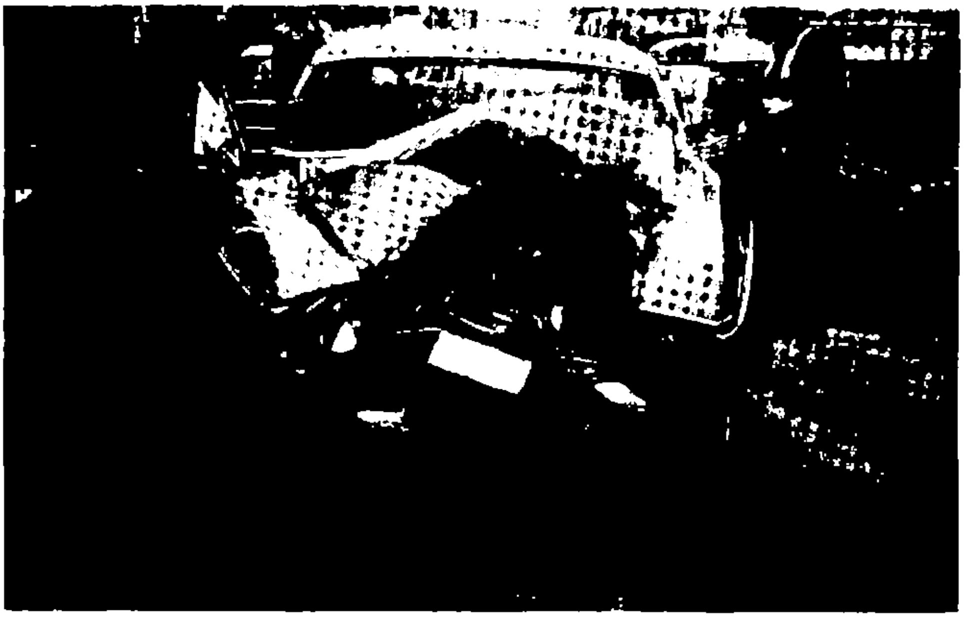


Figure 3.12. Vehicle damage and occupant injury resulting from a side impact with a pole.



Sex	M
Age	20
Time of Admission	2-9-78
Expected length of hospitalization	Released 3-4-78

INJURY SCHEMATIC

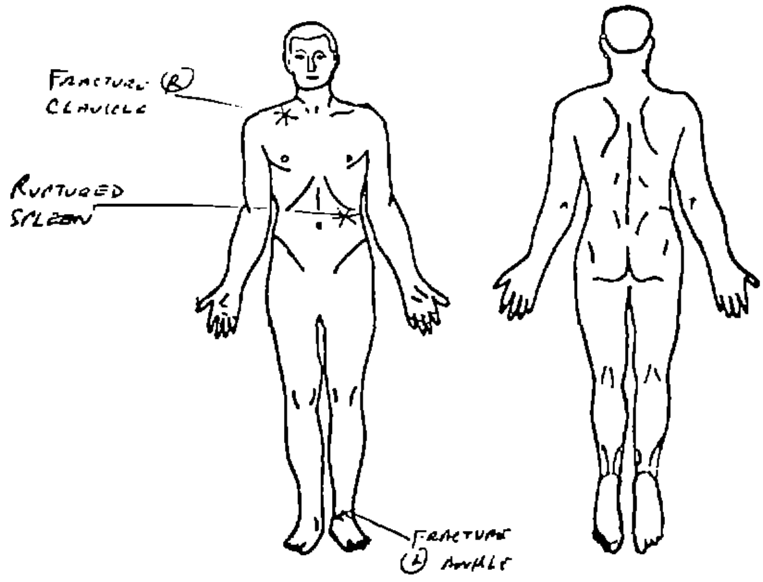


Figure 3.13. Vehicle damage and occupant injury resulting from a frontal impact with a pole.

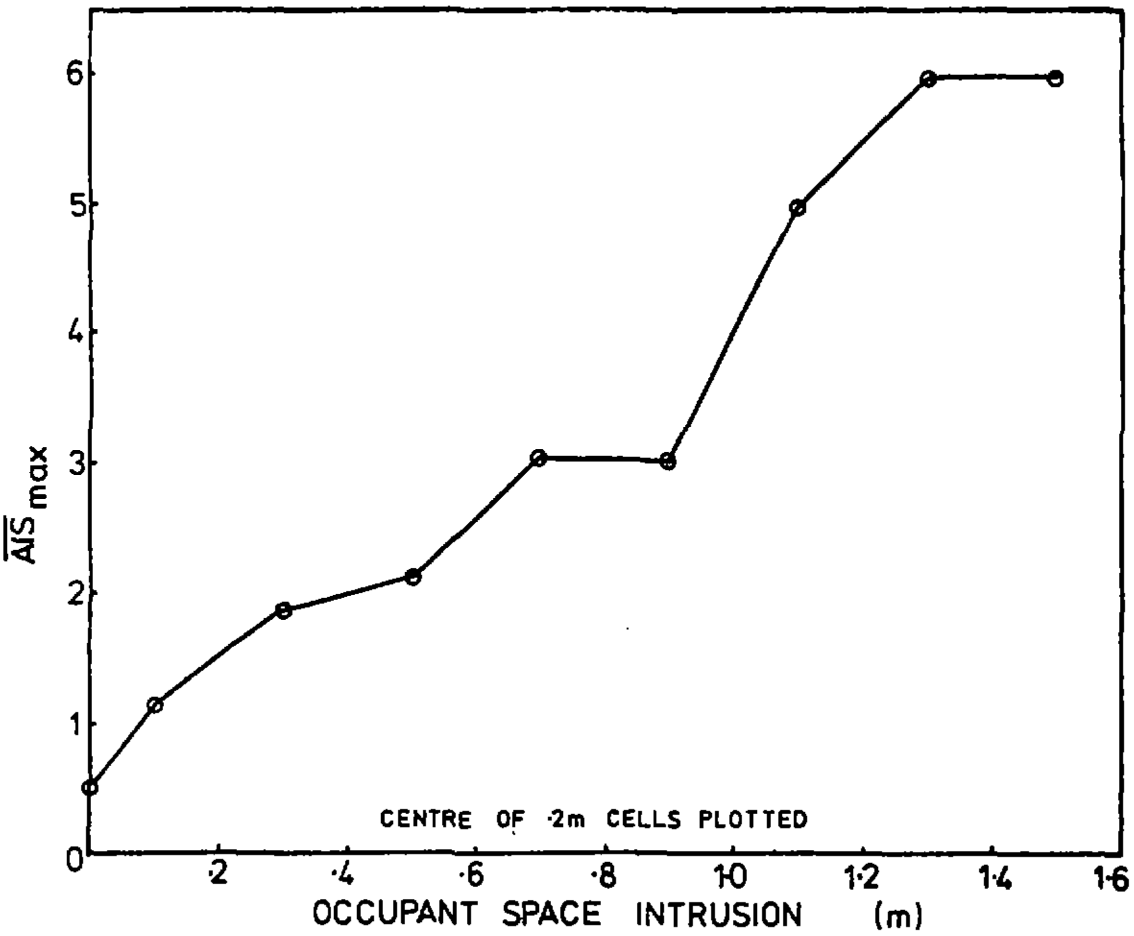


Figure 3.14. Mean AIS score of the worst-injured occupant per accident versus occupant space intrusion.

Figure 3.15 shows the distribution of mean occupant space penetration by direction of impact. As would be expected, the oblique and side impacts result in higher occupant space penetrations than frontal impacts. The distribution of the mean values of the highest AIS score per accident correspondingly follows a similar pattern, as shown in Figure 3.16.

Figure 3.17 shows another similar distribution of injury severity by impact direction. In this case injury severity is measured in terms of a modified form of the Injury Severity Score (ISS). Baker, O'Neill and Haddon (1974) originally proposed that the ISS should be calculated as the sum of the squares of the highest AIS level in each of the three most severely injured body areas. In the present study it was decided to calculate the ISS for each occupant on the basis of all recorded injuries (to a maximum of six). Contrary to Baker et al, all injuries in a particular body zone were counted. The latter approach was recommended by Nelson (1974), on the basis that the choice of body zones is somewhat arbitrary, and because a greater number of severe injuries intuitively implies a greater overall injury severity. Further, Nelson showed that the more body regions there were having major injuries, the longer was the stay in hospital and the higher the probability of dying. As it turned out, the decision to modify the ISS calculation had little effect on the results as the mean number of coded injuries per injured occupant was between three and four.

Despite the increased accident severity associated with side and oblique impact directions, the predominance of frontal impacts resulted in the majority of casualties arising from frontal impacts (Figure 3.18). As would be expected, the proportion of casualties associated with driver door impacts (Figure 3.18) is greater than the proportion of collisions associated with this impact direction (Figure 3.11).

Table 3.8 shows the relationship between the nature of the damage to the vehicle, and the resulting accident severity.

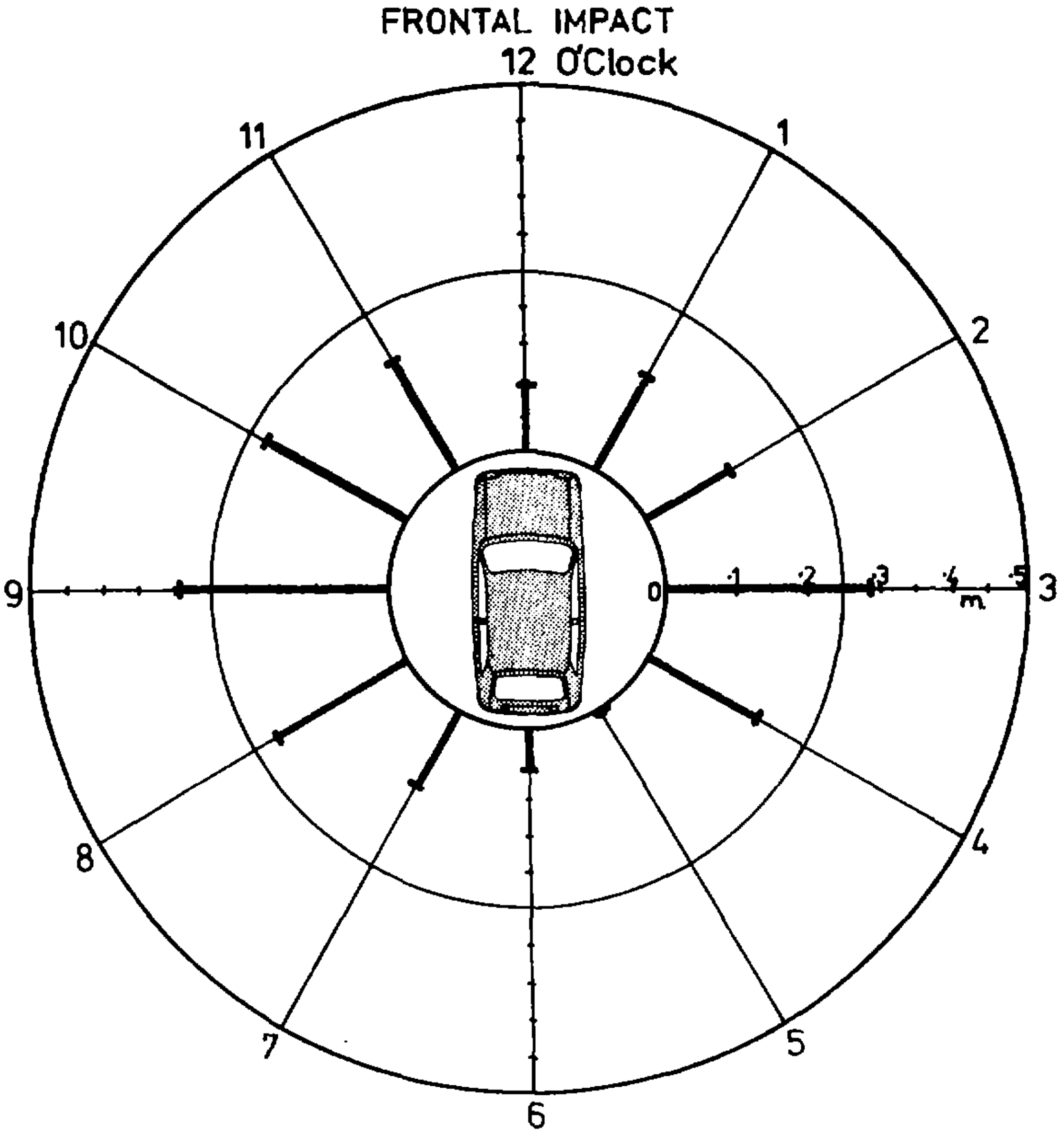


Figure 3.15. Distribution of mean occupant space penetration (m) by impact direction.

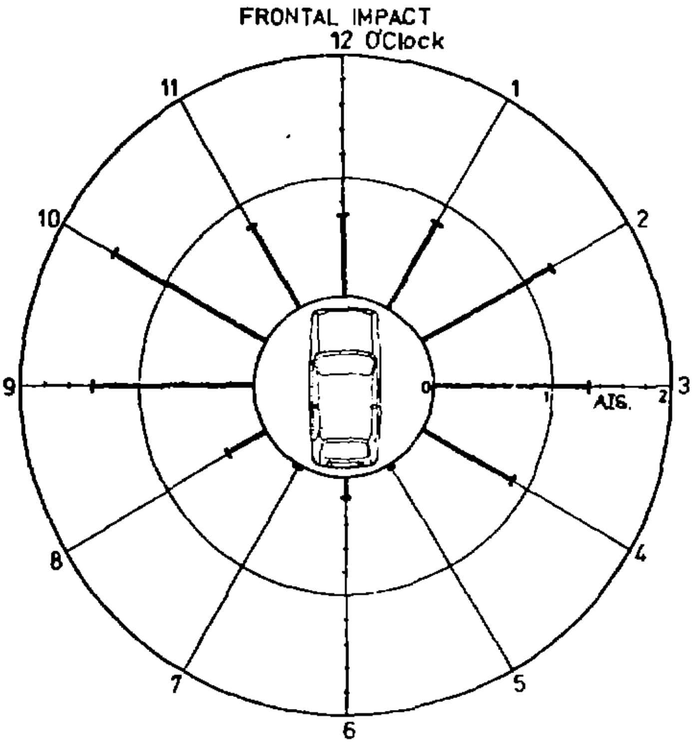


Figure 3.16. Distribution of the mean highest AIS score per accident by impact direction.

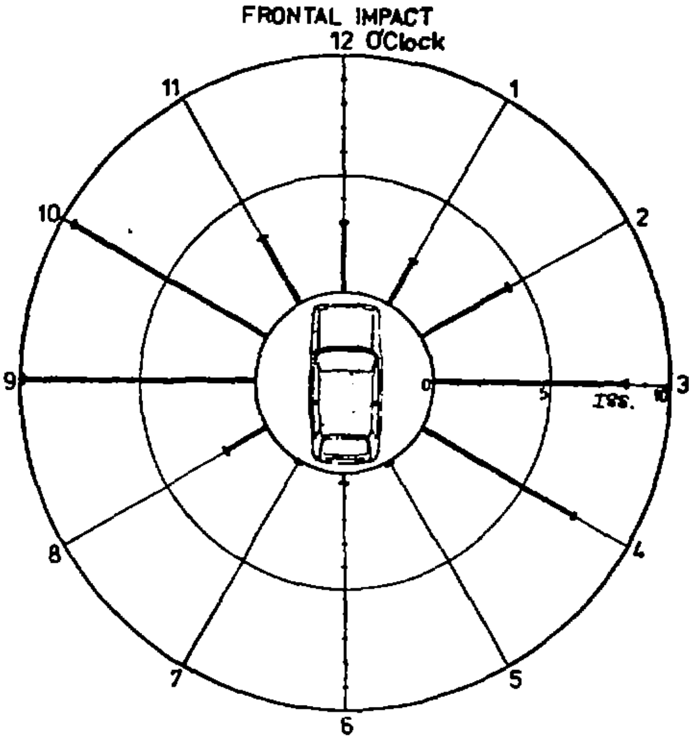


Figure 3.17. Distribution of the mean highest ISS **per accident** by impact direction.

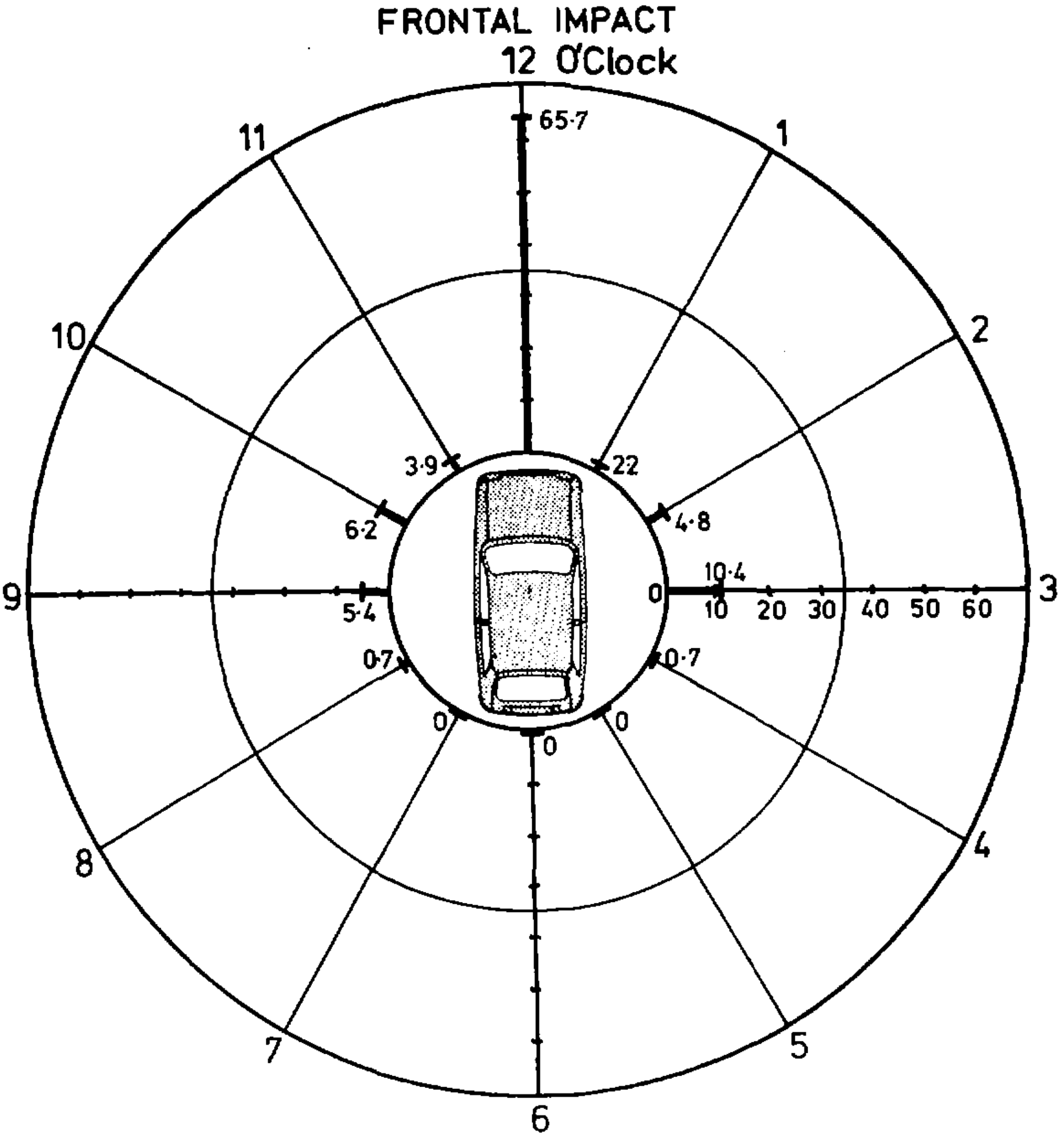


Figure 3.18. Distribution (%) of casualty occupants by impact direction.

TABLE 3.8

VEHICLE DAMAGE DESCRIPTION AND ACCIDENT SEVERITY

Damage Description	Accident Severity					
	Fatal		Personal Injury		P D O	
	No.	%	No.	%	No.	%
Wide Impact	0	0	0	0	2	0
Narrow Impact	26	90	178	79	355	67
Side-Swipe	0	0	7	3	58	11
Rollover	1	3	1	0	0	0
Corner Damage	2	7	41	18	118	22
Sub-Total	29	100	227	100	533	100
Unknown Damage	0		6		84	
Total	29		233		617	

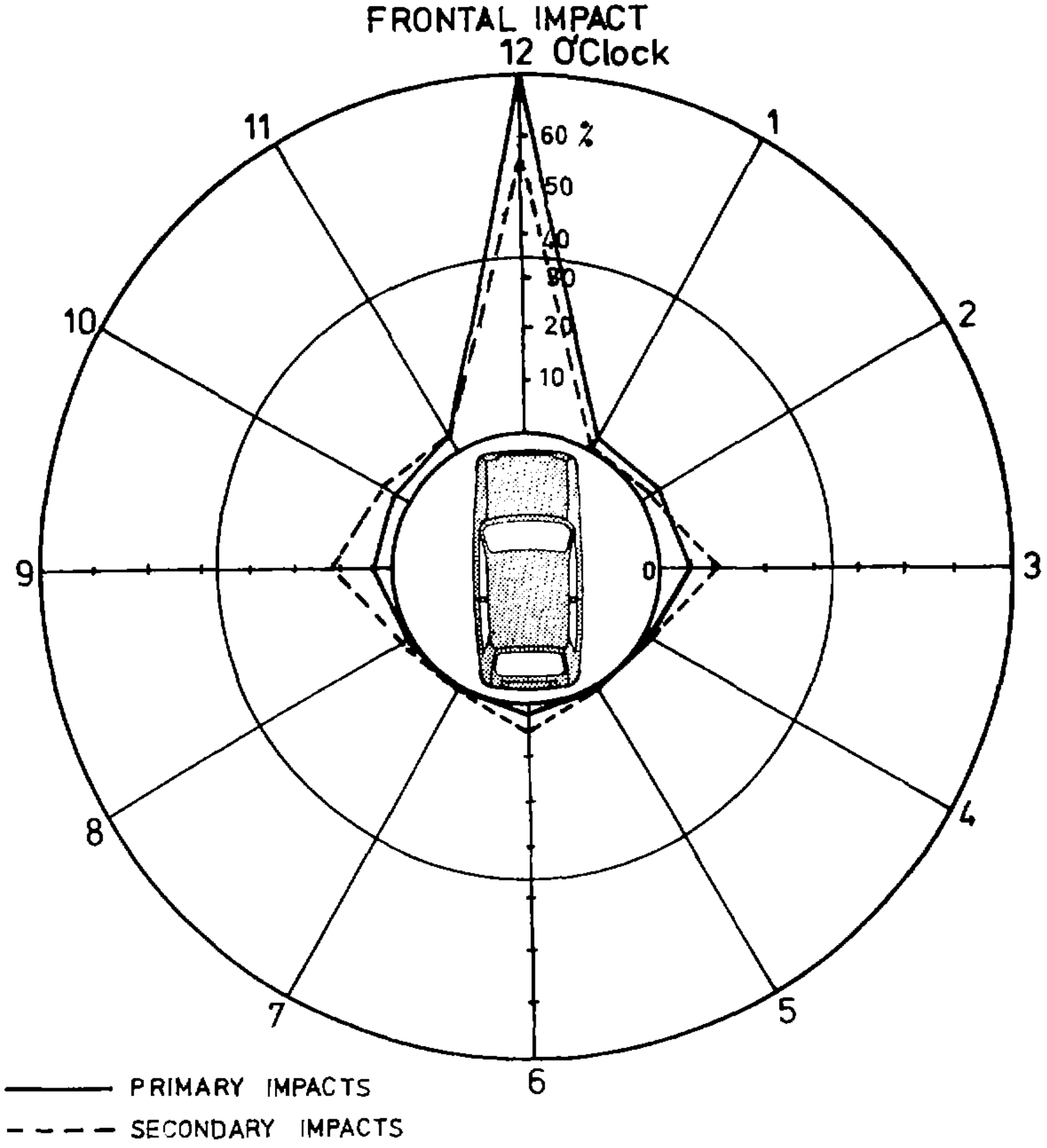


Figure 3.19. Distribution of direction of impact relative to the vehicle by pole impact sequence.

The damage description refers to the nature of the deformed zone of the vehicle. As was noted in Chapter 2, the vehicle damage was coded according to the Vehicle Deformation Index (Society of Automotive Engineers, 1972). The damage description categories in Table 3.8 are taken directly from that system. It can be seen that the majority of the impacts with poles resulted in narrow impact zones. Correspondingly, these concentrated impacts account for the great majority of the casualty accidents.

A further point to note from Table 3.8 is the retrieval rate, for damage assessment, of 90 percent of the accident-involved vehicles, Those that were missed are concentrated in the property-damage-only category. This was because many of these vehicles were towed home or directly to repairers, rather than to a towing yard first. Inspection of such vehicles was more likely to be denied by the owners.

It will be recalled from Section 3.3 that secondary pole collisions account for 15 percent of pole accidents, and are generally only slightly less severe than primary pole collisions. From Figure 3.19 it can be seen that secondary collisions involve a higher proportion of side impacts than primary collisions. As side impacts are generally the most severe, the slightly lower average accident severity of secondary pole impacts suggests somewhat lower impact velocities for such collisions, compared with primary collisions. It is noted that the majority of secondary impacts occurred at intersections (Figure 3.3).

3.5.3 Poles and Utilities

The distribution of pole types and materials in both the accident and random samples is shown in Table 3.9. It can be seen that there are no major differences in the two distributions, indicating that the pole classification has little bearing on the occurrence of pole accidents. The predominant pole type in both samples is the

TABLE 3.9

DISTRIBUTION OF POLES BY MATERIAL AND FUNCTION IN THE ACCIDENT AND RANDOM SAMPLES

Pole Material and Function	Accident		Random	
	No.	%	No.	%
Steel				
Luminaire	82	9.3	104	13.1
Tram	33	3.8	29	3.7
Traffic Light	81	9.2	46	5.8
Power	10	1.1	14	1.8
Power and Tram	29	3.3	22	2.8
Other	8	0.9	9	1.1
Concrete				
Luminaire	6	0.7	10	1.3
Tram	0	0	1	0.1
Power	10	1.1	3	0.4
Wood				
Luminaire	108	12.3	89	11.2
Tram	2	0.2	1	0.1
Traffic Light	1	0.1	0	0
Power	501	57.0	447	56.4
Power and Tram	2	0.2	11	1.4
Other	6	0.7	7	0.9

TABLE 3.10

DISTRIBUTION OF POLE TYPES BY ACCIDENT SEVERITY

Pole Material and Functions.	Accident Severity					
	Fatal		P I		P D O	
	No.	%	No.	%	No.	%
Steel						
Luminaire	3	3.7	18	22.0	61	74.4
Tram	2	6.1	9	27.3	22	66.7
Traffic light	3	3.7	23	28.4	55	67.9
Power	0	0	2	20.0	8	80.0
Power and tram	0	0	10	34.5	19	65.5
Other	0	0	1	12.5	7	84.5
Concrete						
Luminaire	0	0	3	50.0	3	50.0
Power	0	0	1	10.0	9	90.0
Timber						
Luminaire	5	4.6	34	31.5	69	63.9
Tram	0	0	2	100.0	0	0
Traffic light	0	0	1	100.0	0	0
Power	16	3.2	128	25.5	357	71.3
Power and tram	0	0	0	0	2	100.0
Other	0	0	1	16.7	5	83.3

timber power pole, which makes up 57 percent of the accident sample and 56 percent of the random sample

Section 4.6 contains a detailed analysis of the effect on pole and utility damage of pole material and function. An analysis of the severity of occupant injury as related to pole type is also presented in section 4.6. As an introduction to that analysis, Table 3.10 presents the distribution of pole type by accident severity. For the classifications with statistically reasonable levels of data, the distribution of severities varies only slightly across all pole types. If anything, steel tramways poles tend to result in the most severe accidents; steel luminaires the least.

3.6 *CHARACTERISTICS OF THE CASUALTY OCCUPANTS AND THEIR INJURIES*

3.6.1 Occupant Age and Sex

The age and sex distributions of the killed and injured occupants in the accident sample are very similar to those recorded for all road accidents by the Australian Bureau of Statistics (1977) and Nelson (1974). Sixty-one percent of the casualty occupants (killed and injured) were male, most frequently in the age group containing the late teens and the early twenties. Figures 3.20 and 3.21 show the distributions of male and female casualty occupants by age. Also plotted on the graphes are the male and female population distributions for the Melbourne Statistical Division. It is noted that the general population age distributions obtained from census data are not necessarily the same as for the population exposed. Also no information was available on the distances travelled by different age groups per annum. However given the lack of alternative data, the census distributions serve to demonstrate the bias towards particular ages and males in the casualty occupant age distributions. It is interesting to note that the peak in the female age distribution occurs at a younger age than that for the male distribution.

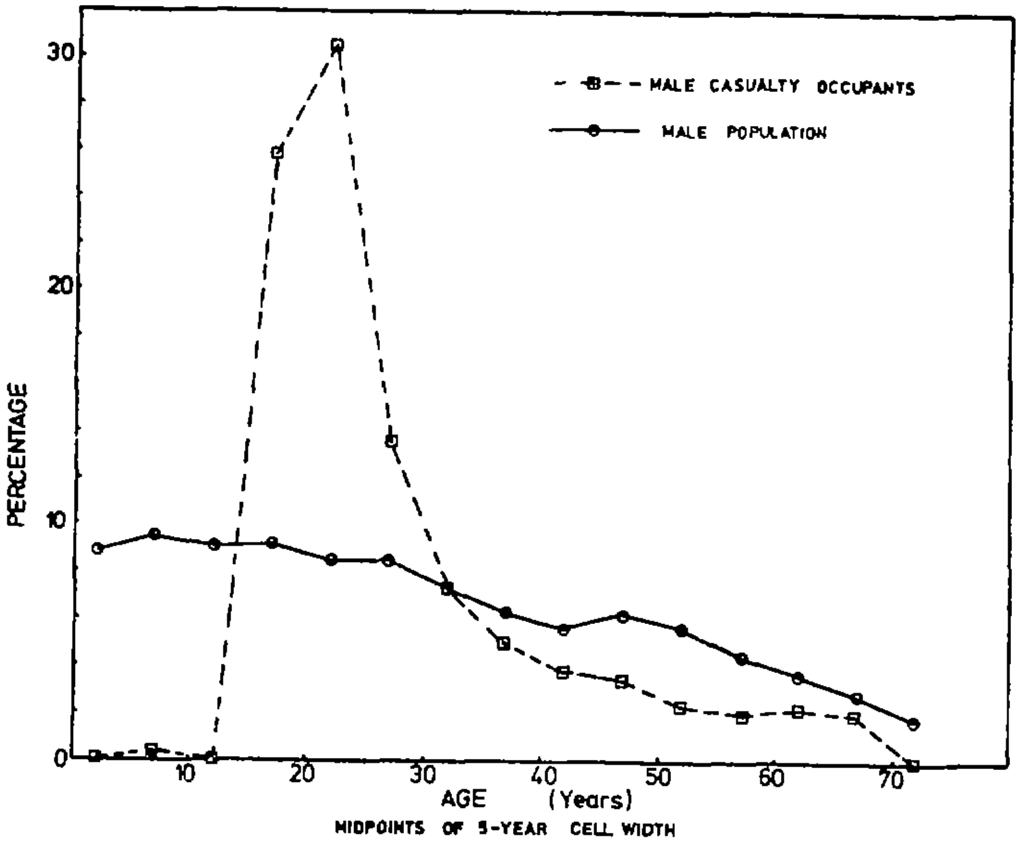


Figure 3.20. Distribution of male casualties by age.

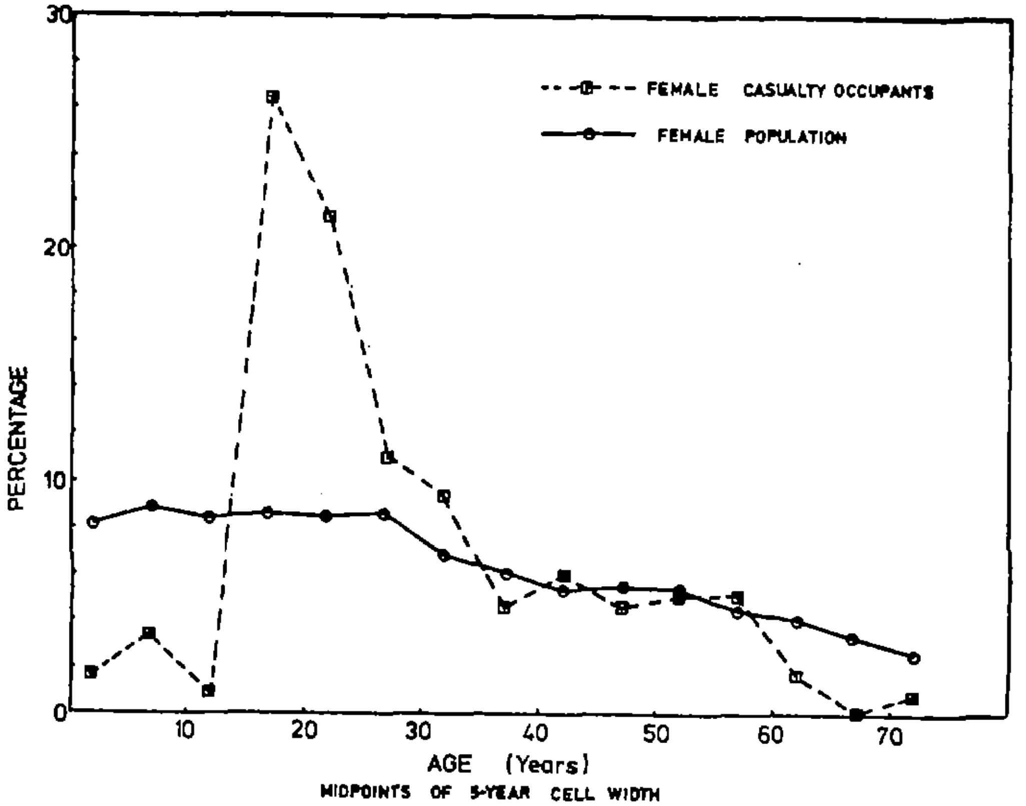


Figure 3.21. Distribution of female casualties by age.

3.6.2 Injury Characteristics

Detailed injury reports for 90 percent of the occupants were received from the hospitals. For property-damage-only accidents, the number of occupants was not always known; the number of uninjured occupants in casualty accidents was also generally unknown. For this reason, investigations of the distribution of injury severity were made (a) for the worst injury per accident or (b) for the casualty occupant group only. Figure 3.22 shows the distribution of AIS levels associated with the worst-injured occupant for all pole accident types. Clearly, the majority of accidents involved little or no occupant injury. Up to six separate injuries per casualty occupant were coded (after Marsh, 1973), which allowed the calculation of a Modified Injury Severity Score (as described in Section 3.5.2). Figures 3.23 and 3.24 show the distributions of AIS and ISS levels for the casualty occupant group.

Table 3.11 shows how injuries were distributed by body region. It can be seen that the majority of injuries were sustained in the head, face and neck regions, with the chest being the next most frequently injured zone. The distribution of lesions (nature of the injury) shown in Table 3.12 indicates that lacerations and fractures were the most common injury types. Similarly the body systems most frequently injured were the skin and the skeletal system, followed by the brain and respiratory system (Table 3.13). In general the injuries were minor (Table 3.14): AIS level 1 accounts for half of all the injuries.

To enable an analysis of injury locations by severity, and impact direction relative to the vehicle, the number of categories in Table 3.11 was reduced to seven, as indicated pictorially in Figure 3.25.

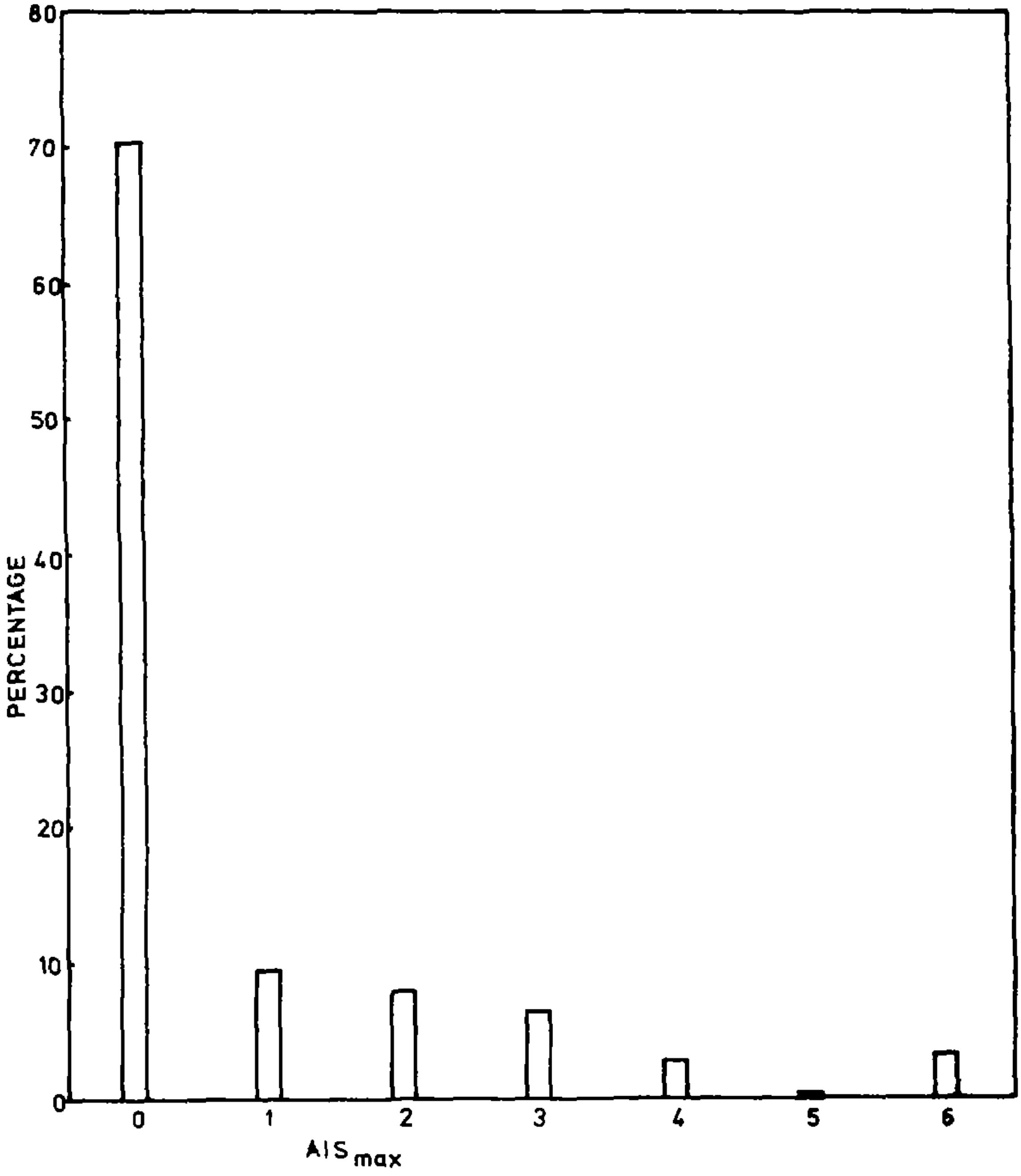


Figure 3.22. Distribution of the AIS score associated with the worst-injured occupant per accident for all pole accidents.

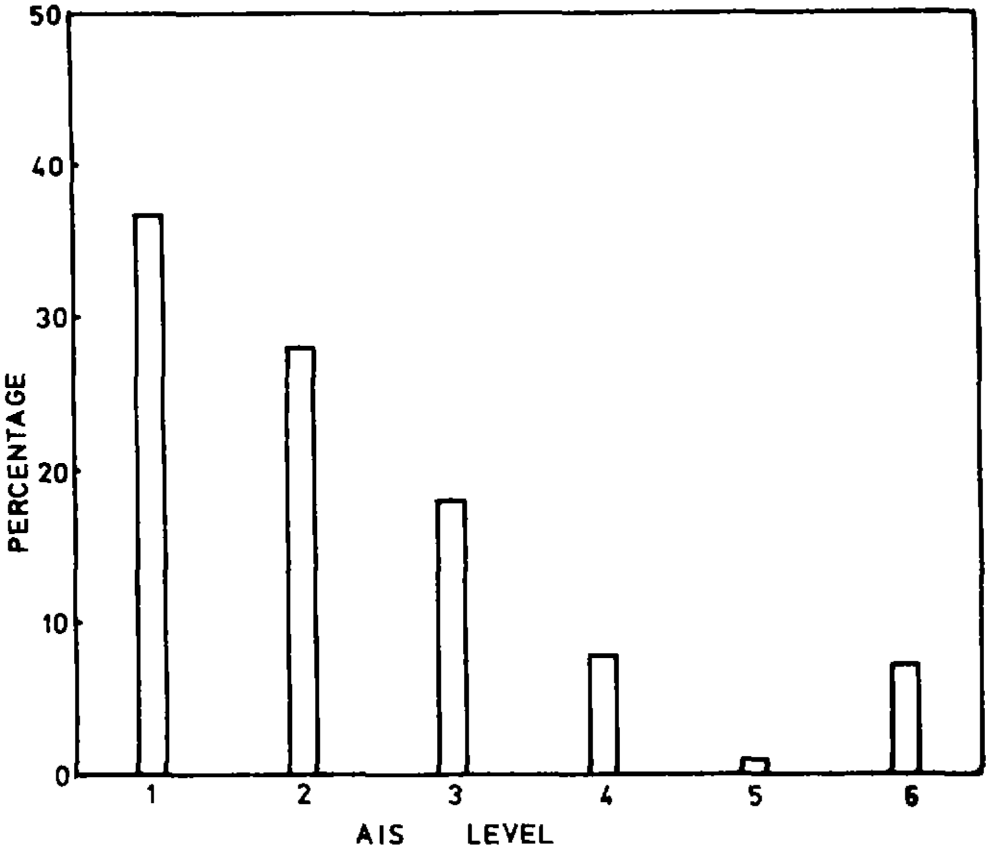


Figure 3.23. Distribution of AIS levels for casualty occupants.

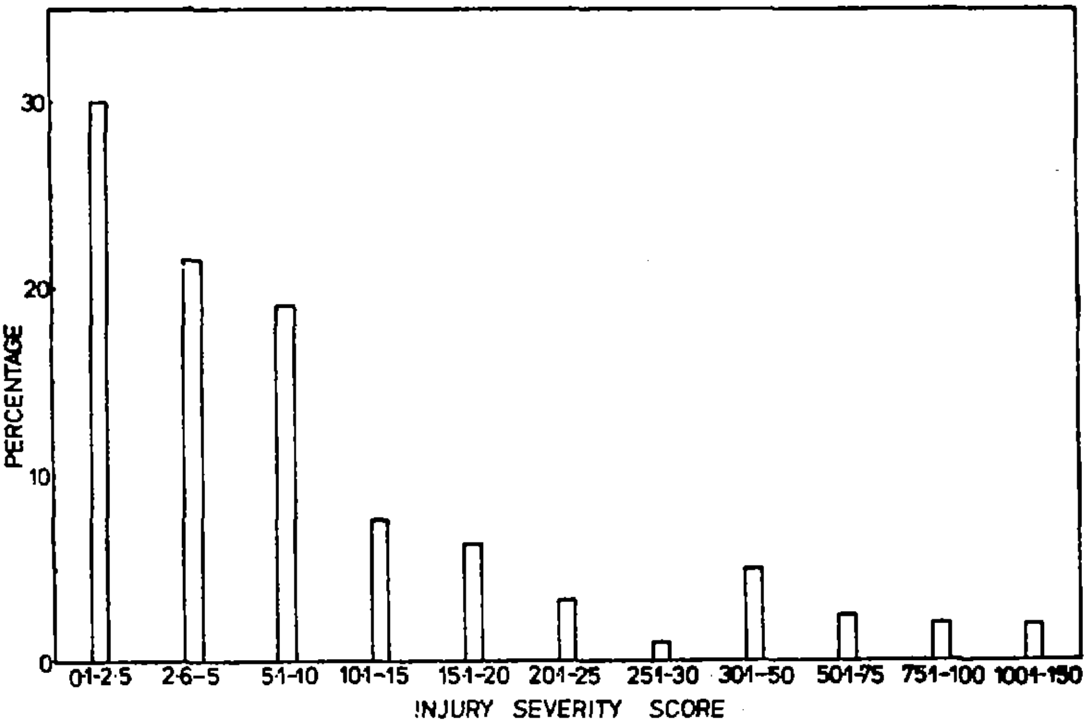


Figure 3.24. Distribution of modified ISS for casualty occupants.

TABLE 3.11

DISTRIBUTION OF INJURIES BY BODY REGION

Body Region		Number of Injuries	%
Head		138	15.2
Face		246	27.1
Neck		28	3.1
Shoulder	- right	15	1.7
	- left	17	1.9
Chest	- right	30	3.3
	- central	71	7.8
	- left	26	2.9
Arm	- right	34	3.7
	- left	33	3.6
Abdomen		42	4.6
Pelvis		39	4.3
Back - thoraco-lumbar			
Spine		15	1.7
Upper leg	- right	16	1.8
	- left	17	1.9
Knee	- right	17	1.9
	- left	25	2.8
Lower leg	- right	44	4.8
	- left	55	6.1

TABLE 3.12

DISTRIBUTION OF INJURIES BY LESION

Lesion	Number of Injuries	%
Laceration	254	27.4
Contusion	174	18.8
Abrasion	50	5.4
Fractures	243	26.2
Pain	39	4.2
Concussion	60	6.5
Haemorrhage	12	1.3
Avulsion	7	0.8
Rupture	44	4.8
Sprain	16	1.7
Dislocation	17	1.8
Crushing	1	0.1
Other	9	0.9

TABLE 3.13

DISTRIBUTION OF INJURIES BY BODY SYSTEM

System	Number of Injuries	%
Skeletal, bones and ligaments	261	29.9
Vertebrae	6	0.7
Joints	33	3.8
Liver	7	0.8
Nervous System	4	0.5
Brain	73	8.4
Spinal Cord	2	0.2
Eyes, ears	27	3.1
Arteries, Veins	6	0.7
Heart	4	0.5
Spleen	8	0.9
Urogenital	2	0.2
Kidneys	4	0.5
Respiratory	46	5.3
Pulmonary, Lungs	15	1.7
Muscles	51	5.8
Integumentary	325	37.2

TABLE 3.14

DISTRIBUTION OF INJURIES BY SEVERITY (AIS)

Severity	Number of Injuries	%
1	465	49.6
2	248	26.5
3	119	12.7
4	42	4.5
5	20	2.1
6	43	4.6

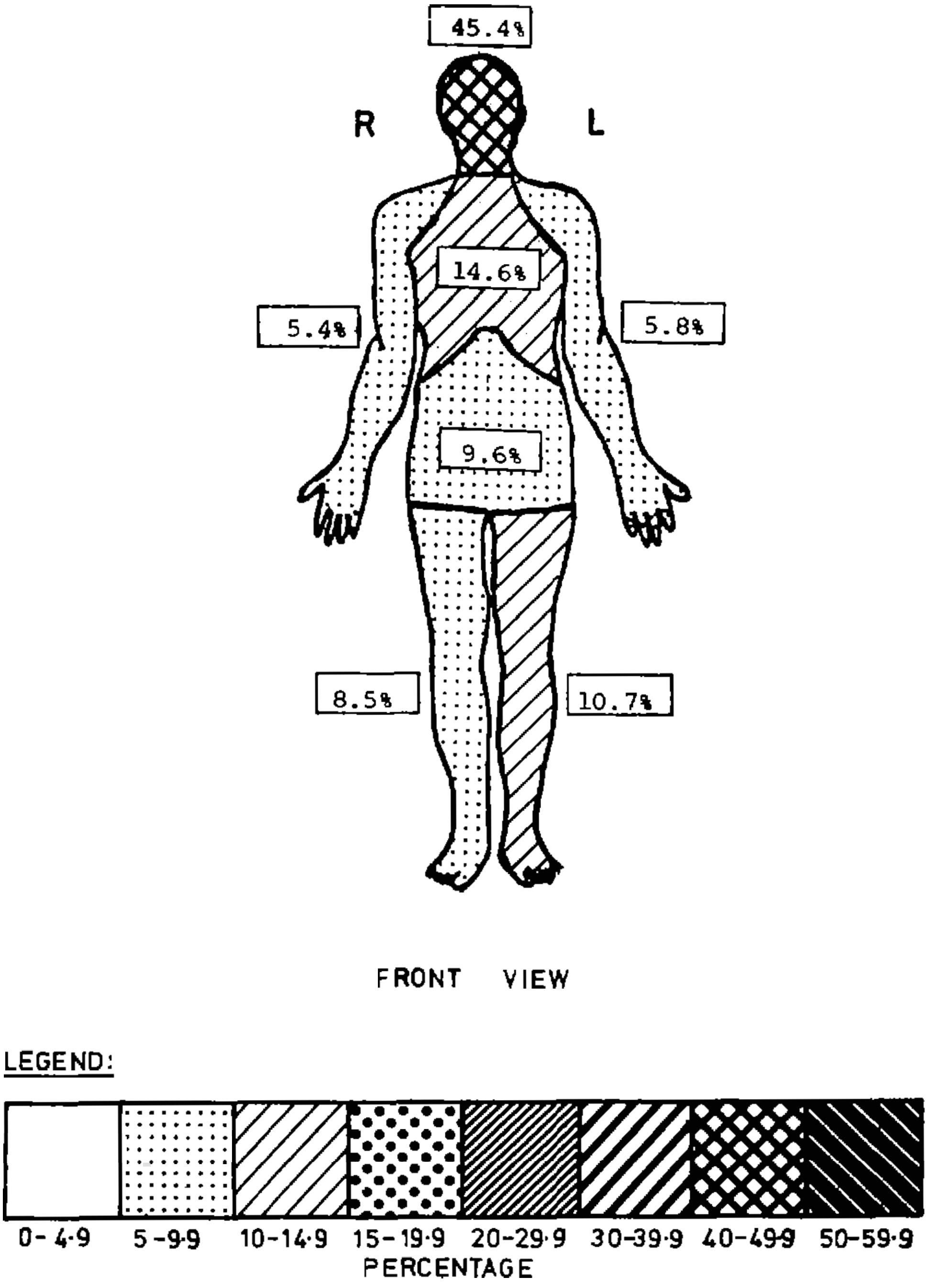


Figure 3.25. Distribution of injuries by body region.

The body regions shown are described as:

(i) Head, face and neck
(ii) Right arm and shoulder
(iii) Left arm and shoulder
(iv) Upper torso
(v) Abdomen and pelvis
(vi) Right leg
(vii) Left leg.

Figure 3.26 shows the distribution of injuries by body region for three levels of injury severity. For all levels of severity the head and neck region suffered the most injuries. The largest number of critical and fatal injuries were sustained to the head and neck, followed by the chest and then the abdomen.

Figure 3.27 presents the distribution of injuries by body region and injury severity for frontal collisions only. The injury patterns are much the same as those in Figure 3.26 for the minor and moderate injury categories. The critical and fatal injury distribution, however, is spread fairly evenly over the head and torso. Figure 3.28 shows the same information for side impacts. The most significant difference again occurs for critical and fatal injuries; for side impacts they are almost entirely concentrated in the head and upper torso. For the less severe but more numerous injuries, however, the proportion of head injuries is reduced in side impacts.

The decrease in the proportion of total head injuries relative to other body regions in side impacts is further demonstrated in Figure 3.29 which shows the distribution of injury location by direction of impact relative to the vehicle. Impacts from all directions result mostly in head injuries. For side impacts, however, there is a shift from the head region to increase the proportion of torso injuries, due to the increased occupant space penetration. As expected, driver side impacts result predominantly

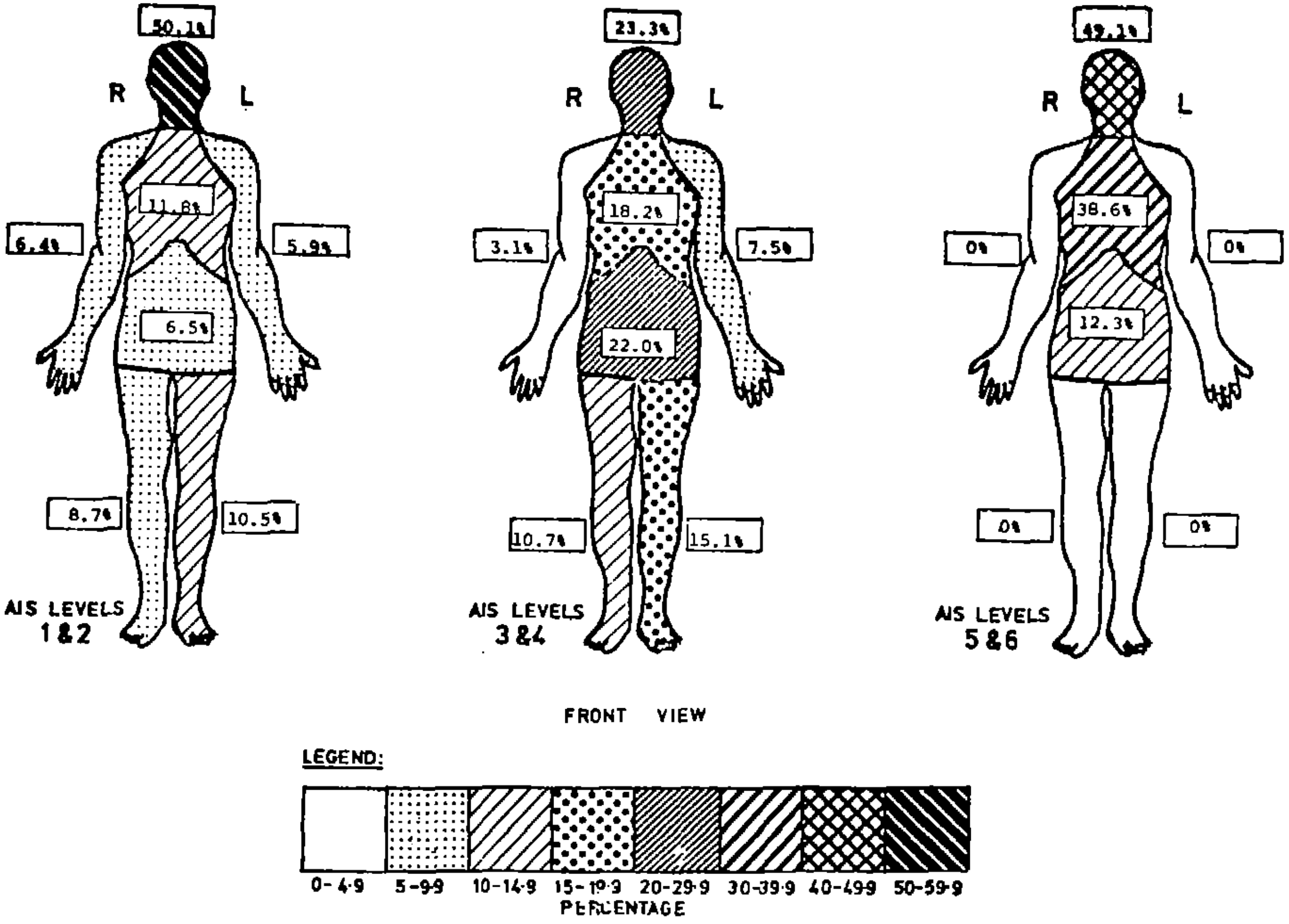


Figure 3.26. Distribution of injuries by body region for the three levels of injury severity.

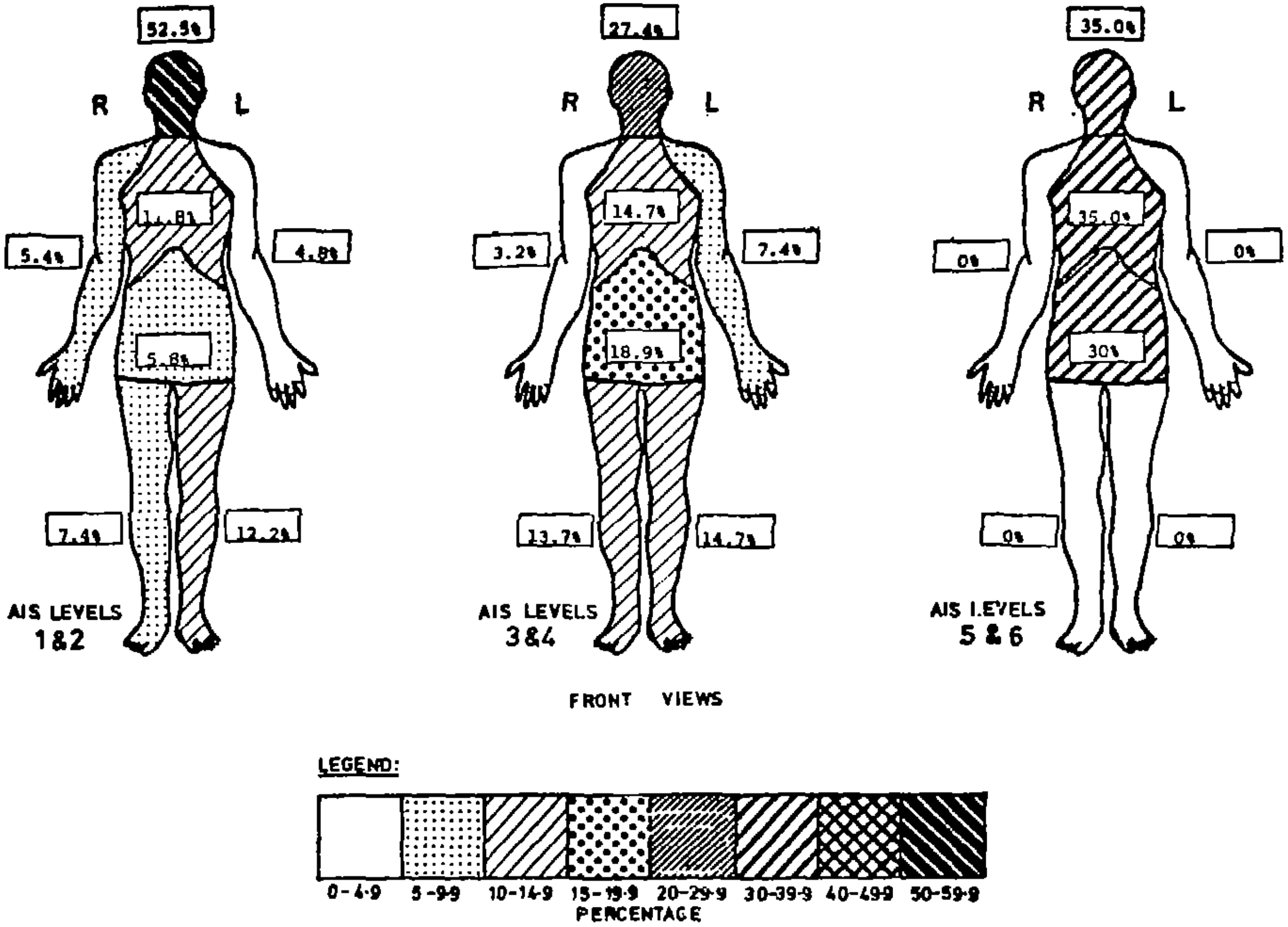


Figure 3.27. Distribution of injuries resulting from frontal impacts by location and severity.

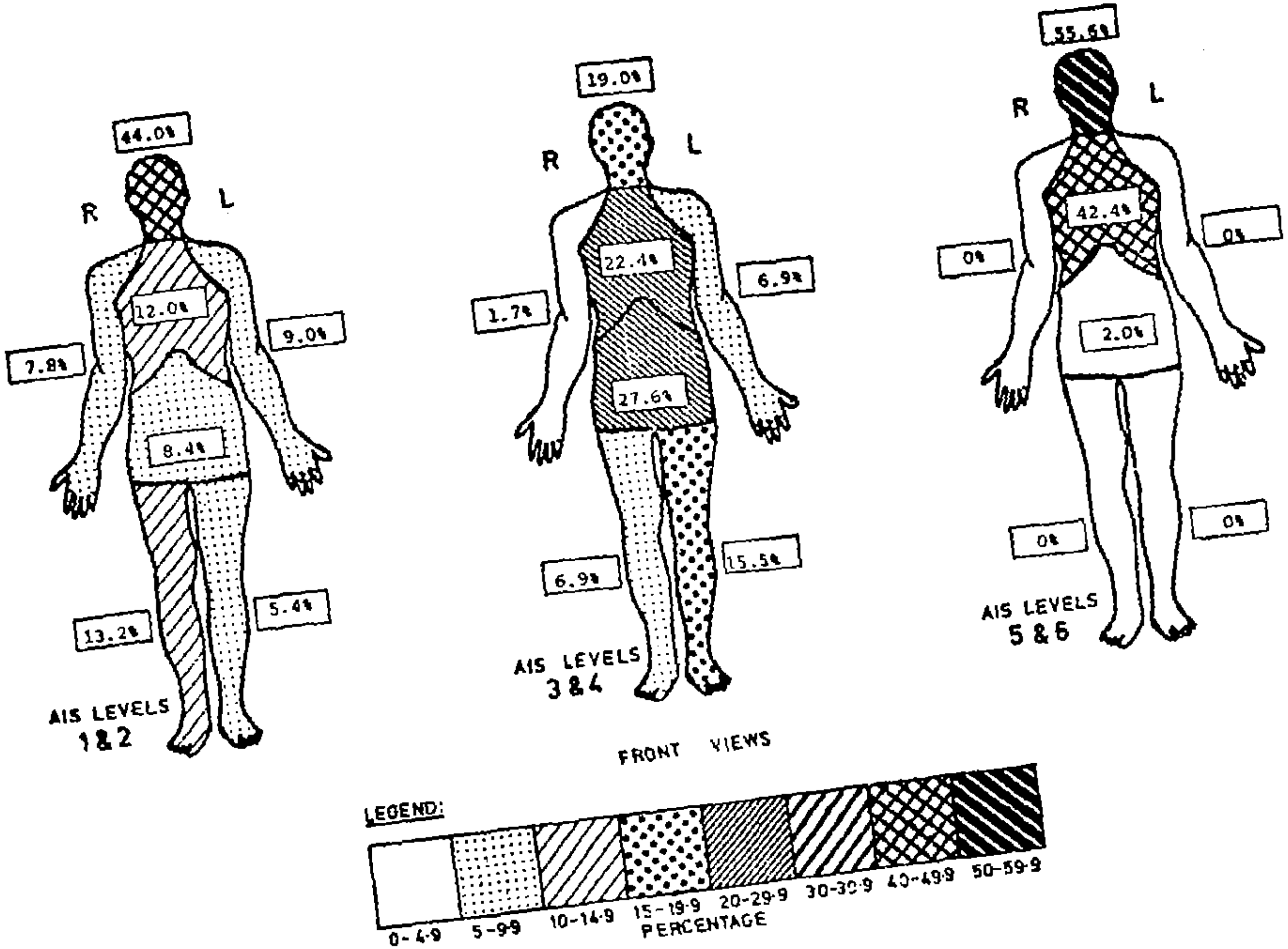


Figure 3.28. Distribution of injuries resulting from side impacts by location and severity.

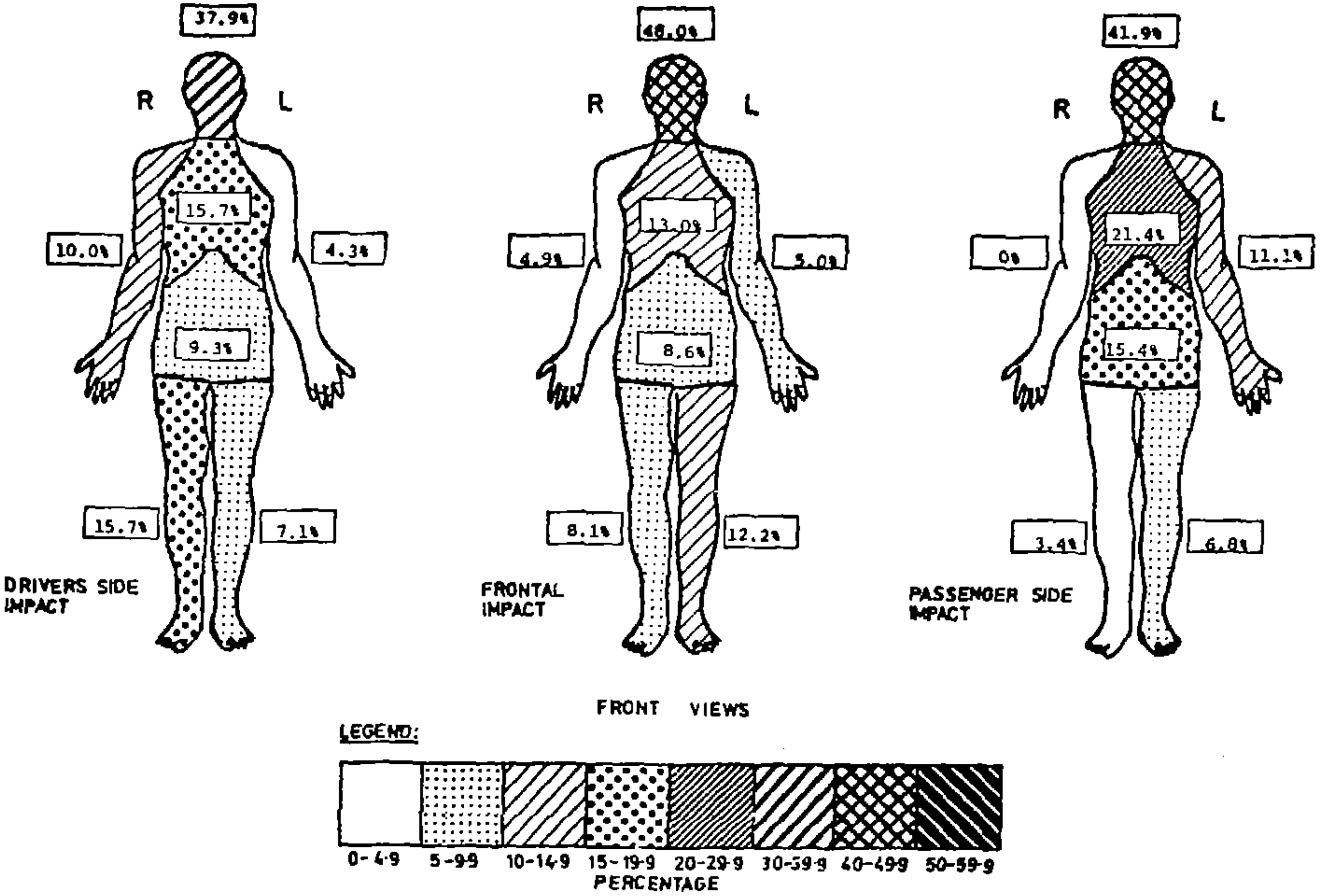


Figure 3.29. Distribution of injury location by direction of impact for all injury severities.

in right side injuries; passenger side impacts cause left side injuries.

The overall dominance of head injuries suggests that the wearing of helmets would greatly reduce the number of injuries. It is noted that this already has been suggested by Herbert and Corben (1976).

As no occupant interviews were attempted, no reliable information is available regarding the useage or effectiveness of seat belts in the accident sample. During the vehicle damage inspection, the belts were examined and evidence of occupant impact with the windscreen and/or the steering wheel was recorded. However, the information gained in this way is not considered reliable and is therefore not presented. It is noted that the effectiveness of seat belt wearing in reducing the incidence of road accident casualties is well established (eg. Vaughan, Wood and Croft, 1974; Cowley and Cameron, 1976; Marsh and Scott, 1976; Huelke, Lawson and Marsh, 1977). Herbert and Corben (1976) do point out, however, that seat belts appear to afford little protection against side impacts which result in large occupant space intrusions.

3.7 SUMMARY AND CONCLUSIONS

(i) On the basis of Road Safety and Traffic Authority (RoSTA) data for pole accidents involving casualties, the present survey achieved a 65 percent coverage of all metropolitan pole accidents. However, the number of injured persons recorded by RoSTA is almost exactly half that recorded by the Motor Accidents Board which suggests that the coverage of the less severe accidents may have been somewhat less than 65 percent. Within the study area the accident coverage was esti to be 90 percent.

(ii) The present sample of 879 pole accidents (obtained over eight months) included 31 fatalities and 374 injured persons. Seventy percent of the pole accidents studied resulted in property damage only.

(iii) Of the 879 cases in the accident sample, 85 percent involved the pole as the first object struck (primary collision). The remaining 15 percent involved the pole as the second object struck (secondary collision). Four out of five of these occurred at intersections.

(iv) According to RoSTA data (and definitions) primary collisions with poles accounted for 5.9 percent of all fatal road accidents and 4.5 percent of injury accidents in Victoria during 1976. In terms of primary fixed-object collisions, poles were involved in 22 percent of fatal accidents and 33 percent of injury accidents.

(v) In the Melbourne metropolitan area, during the eight-month survey period of this study (7 July 1976 to 7 March 1977), RoSTA data showed that primary pole accidents made up 8.6 percent of all fatal accidents and 5.8 percent of personal injury accidents. They accounted for 45 percent of fatal fixed-object collisions and 52 percent of personal injury fixed-object collisions.

(vi) Annually, the RoSTA data show that primary collisions with poles on Melbourne's urban road system result in approximately 40 fatalities and 630 injured persons. However, these figures understate the contribution to road trauma of collisions with poles because they do not account for secondary collisions. Also, the number of fatalities does not include the number of people who died from injuries more than 30 days after the accident.

(vii) From the results of the present eight month survey, which included secondary collisions and all fatalities, it is estimated that pole accidents in the Melbourne metropolitan area produce 45 fatalities and 785 injured persons annually.

(viii) Primary and secondary pole collisions result in much the same average accident severity.

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

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

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

(xii) More accidents occurred on Sunday morning between midnight and 3 am 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 am and 4 am. Fifty percent of the accidents studied occurred in the hours of darkness.

(xiii) 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.

(xiv) 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.

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

(xvi) 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 AIS level and depth of intrusion was found. Despite the increased severity of side and oblique impacts, 66 percent of casualties arose from frontal impacts.

(xvii) 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.

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

(xix) 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%).

(xx) 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.

Occupant injuries and vehicle damage are correlated, and a strong relationship between injury severity and occupant space intrusion is found. Although side impacts are generally the most severe, the great majority of injuries result from frontal collisions because of their greater frequency.

Information obtained on injuries and damage to vehicles, poles and utilities in the accident sample were used to make estimates of societal costs associated with various levels of injury, such estimates being previously unavailable for Australian conditions. When loss of societal welfare is measured in terms of consumption of current resources and foregone production, pole accidents in Melbourne cost at least $23 million annually. Benefit-cost calculations for a number of technically-proven means for reducing accident occurrence or severity show that remedial action is immediately warranted.

A complete project summary and list of recommendations is presented in Chapter 8. A user's guide for the accident predictor model is contained in Appendix B.

CHAPTER 4

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

4.1 INTRODUCTION

Pole accidents result from the interaction of a number of factors which can be broadly classified into five categories:

(a) Driver
(b) Vehicle
(c) Environment (weather, land usage)
(d) Roadway
(e) Roadside

The primary objective of this study is to investigate the engineering-related factors which contribute to the occurrence and severity of pole accidents, and in particular to develop a model to identify and rank specific pole sites in terms of accident risk (accident probability). The data collected have therefore been predominantly concerned with the roadway, the roadside and the vehicle.

The relationship between a number of vehicle characteristics and accident occurrence and severity has also been investigated. However, in the development of the accident predictor model, which relates accident risk to site-related variables, the driver and vehicle populations are taken as given.

4.2 POLE ACCIDENT OCCURRENCE AS A FUNCTION OF SITE CHARACTERISTICS

4.2.1 Previous Accident Prediction Models

A review of the literature related to accident prediction models revealed little of direct relevance to the present study.

Attempts to quantify accident risk have employed a number of predictor variables, ranging from driver record and background and environmental factors (Snyder, 1974), to roadway-related factors. One study even attempted to relate accident risk to the phases of the moon (without success Roer , 1974). Flynn (1977) presents a reasonably comprehensive review of studies using all these approaches.

The majority of work related to the present study has been carried out in the United States of America, and has concentrated on rural interstate highways. Typically, statistical models were derived from data which were obtained from a sample of road segments selected from the interstate highway system. Accident and roadway data for each segment were obtained, usually from extensive highway inventories. The method of sampling by road segment, made possible by the existence of such extensive inventories, meant that segment accident rates (accidents per mile or per vehicle - mile) could be related to highway variables, such as horizontal alignment, traffic volume, roadway width and grade, using multiple regression techniques. All accident types were included in the data base of the majority of studies. (Head 1958; Schoppert, 1957; Blensly and Head, 1960; Jorgensen, 1966; Cribbins, Arey and Donaldson, 1967; Cribbins, Horn, Beeson and Taylor 1967; Kihlberg and Tharp, 1968; Sparks 1968; Dart and Mann, 1970; Wright and Mak, 1972; Foody and Long, 1974; Dunlap, Fancher, Scott, McAdam and Segel, 1974; Agent and Deen, 1974;). Most studies concluded that traffic flow, curvature and grade were correlated (to varying degrees) with accident rate on rural highways.

The study by Wright and Mak (1972) was one of the few to investigate fixed object collisions on urban highways. Once again, road segments formed the basis of the data. It was concluded that total accidents per mile are related to speed limit, vertical alignment, number of intersections and traffic volume.

A number of investigations of roadside object collisions have used the median encroachment data of Hutchinson and Kennedy (1967) to evaluate roadside improvement programs particularly in relation to luminaire supports with frangible or slip bases (Edwards, Martinez, McFarland and Ross, 1969; Walton, Hirsch and Rowan, 1973; Glennon, 1974). The simple models developed in these studies are, however, only relevant to rural highways.

In a study of fatal fixed object collisions, Wright and Robertson (1976) recorded details of grade, curvature, superelevation, type of road and pavement, and shoulder widths in the vicinity of each crash site, and at locations 1.6 km upstream of the crash site. Comparisons between the crash and 'control' sites revealed that combinations of curvature and downhill grade were the most hazardous, and that the majority of fatal fixed object collisions occurred on non-local roads. The method used by Wright and Robertson was the most relevant to the present work, in that data from both crash and control sites were obtained.

4.2. 2 The Data Base of the Present Study

The 'road segment' method of deriving accident models requires the existence of extensive records, or sufficient time to allow a statistically meaningful number of accidents to occur within selected segments. Since neither were available in the present study, an alternative method was used. As has been discussed in detail in Chapter 2, site-related data concerning each pole accident location was collected. Such a sample, however, provides no information about the distribution of particular site characteristics in the population of all pole sites. Thus data from a sample of randomly-selected pole sites were also collected to provide the necessary exposure information. The random site sample was stratified according to accident type (intersection/ non-intersection), and road class, so that equivalent numbers of accident and random sites were investigated for each group. Table

4.1 details the stratification of the accident and random samples. A detailed description of the stratification approach was presented in Chapter 2.

Because of the large number of site variables in the data, only those variables that produced statistically significant effects, or that are thought to be particularly relevant to pole accidents, are included in the discussion which follows. All of the variables detailed in Chapter 2 were investigated in the course of the analysis, but many were discarded from the final model, and are therefore not discussed further.

TABLE 4.1

STRATIFICATION OF THE ACCIDENT AND RANDOM SITE SAMPLES

Data Group	Number in Accident sample	Number in Random Sample
Major Road non-intersection (MNI)	491	433
Minor Road non-intersection (MINI)	106	80
Intersection of major roads. (MJMJ)	131	130
Intersection of major and minor roads (MJMI)	95	100
Intersection of minor roads (MIMI)	56	50
TOTAL	879	793

Note: Major roads refer to arterial and collector roads. (CBR Functional Class 6 and 7). Minor roads refer to residential roads (Functional Class 8).

4.2.3 The Concept of Relative Risk

The analysis of the site data was carried out within the five data groups in Table 4.1. This is necessary because of the stratification of the random sample, with the implied possibility of differences in the accident mechanisms and the distribution of site characteristics, between data groups.

The first step in the analysis was to plot the percentage distribution of each variable in both the accident and random samples. The plotting of the distributions allowed a visual comparison of the samples to be made, and a preliminary sorting of significant variables to be undertaken. Figures 4.1 and 4.2 show two examples of such distributions: Figure 4.1 presents the British pendulum skid test results, while Figure 4.2 shows the grade of the road 30 metres upstream of the pole, both distributions being for major non-intersection cases. Clearly, there is a difference between the accident and random distributions of skid test, indicating that this variable should be included in the next stage of the analysis as a main, first-order effect. The grade results, on the other hand, show little difference between the two distributions, indicating that grade, by itself, has little bearing on the accident process. Despite apparent lack of significance as a first-order effect, however, it is always possible that a variable such as grade may interact significantly with a second variable. This preliminary analysis was designed to provide an initial 'feel' for the data, and to allow preliminary sorting of 'main' effect variables such as skid test, relative to those which may have secondary effects through interaction with other variables.

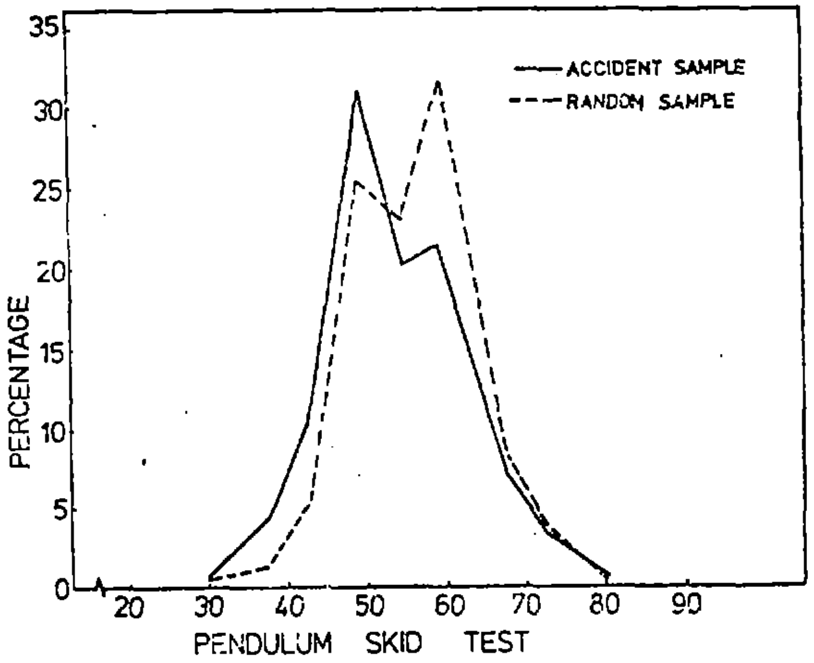


Figure 4.1 . Distribution of British pendulum skid test results for major road non-intersection cases (MNI data group)

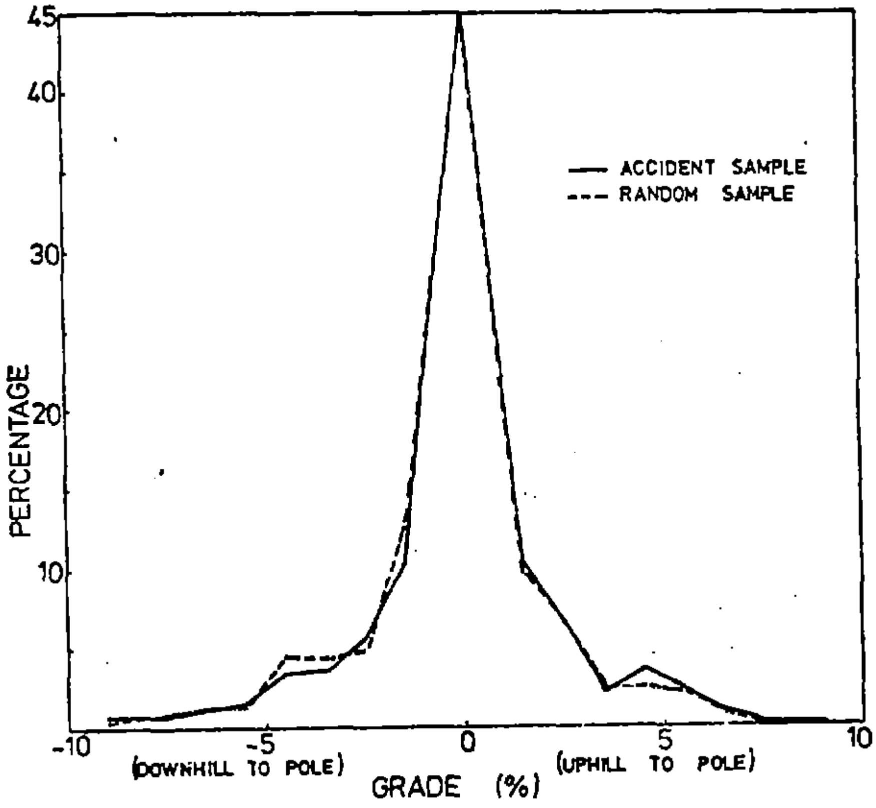


Figure 4.2. Distribution of grades at 30m upstream of the pole for major road non-intersection cases (MNI data group)

χ^2 (Chi-squared) two-way tests of independence were used to test the null hypothesis that the accident and random distributions of each variable are identical. For example, for the skid test distributions shown in Figure 4.1, the null hypothesis was rejected, with a probability of a Type I error $p < 0.0028$. On the other hand the null hypothesis for grade (Figure 4.2), could not be rejected ($p < 0.98$).

It should be noted that statistical significance does not necessarily imply practical significance. The outcome of the χ^2 test is affected by the size of the sample, and the majority of specific null hypotheses can be rejected given a large enough sample (Wonnacott and Wonnacott, 1977). Therefore, the results of such tests should be interpreted with caution and should not be used as the only basis for judgements concerning the inclusion or rejection of variables in the final model.

The derivation of the accident predictor model is based on two concepts:

(a) trials
(b) relative risk

A trial is defined as an event or a time period in which the outcome is either a 'failure' (occurrence of an accident) or a success (no accident), the outcome of a particular trial being independent of those in all other trials.

For the current analysis, a trial is defined as a pole being exposed for a short period of time. The duration of the trial is conceived of as being sufficiently short so that only one accident ('failure') could possibly occur at that pole during the trial period. A time period of a second is conceptually satisfactory for this purpose, so that a trial is referred to as a 'pole-second'.

The relative risk (RR) associated with some attribute is defined as the ratio of the probability, P, that a 'pole-second' with this attribute will result in a 'failure' (accident), to the mean failure probability, $\bar{P}$, for all poles in the population. That is,

$$RR = \frac{P}{\bar{P}}$$

Thus, if the relative risk for a particular pole can be determined, taking account of all its relevant attributes, and the mean failure probability for all poles is known, then the expected number of accidents in a given period at that pole can be predicted from the total number of trials that would occur during that period. The aim of the present analysis of data from the accident and random samples of poles, therefore, is to determine the relative risks associated with all attributes which significantly effect the occurrence of pole crashes.

Let the population of N poles in the study area be described by two attributes x_1 and x_2, say, and let the number of accident sample and random sample poles with the i-th level of attribute x_1 and the j-th level of attribute x_2 by a_{ij} and r_{ij}, respectively. Over the study period T, the N_{ij} poles in the population generate N_{ij} (T/ΔT) 'trials', where ΔT (= 1 second, say) is the duration of a trial, chosen short enough so that the only possible outcomes of a trial are 'success' (no accident) and 'failure' (one accident at the trial pole).

For a pole with characteristics ij, the probability P_{ij} of a trial resulting in an accident is therefore estimated by

$$P_{ij} \hat{=} \frac{a_{ij}}{N_{ij} T/\Delta T}$$

The random sample of r poles is used to estimate the proportion of all poles in the population which have the characteristic ij. Thus, N_{ij} is estimated as

$$N_{ij} \hat{=} \left(\frac{r_{ij}}{r}\right) N$$

Hence

$$P_{ij} = \frac{a_{ij}\ r}{r_{ij}\ NT/\Delta T} \tag{4.1}$$

The mean failure probability, for trials involving all poles, is estimated by

$$\overline{P} \hat{=} \frac{a}{NT/\Delta T} \tag{4.2}$$

where a is the total number of accidents for the accident pole sample.

The relative risk associated with characteristics ij is defined as

$$RR = P_{ij}/\overline{P} \tag{4.3}$$

Hence, using equations (4.1) and (4.2),

$$RR = \frac{a_{ij}/a}{r_{ij}/r} \tag{4.4}$$

That is, relative risk is equal to the ratio of the proportion of accident cases with characteristics ij to the proportion of random cases with characteristics ij.

A relative risk of 1, means that the pole has an 'average' probability of being involved in an accident; a relative risk greater than 1 implies above 'average' accident probability; less than one, below average.

An alternative interpretation of the null hypothesis for the χ^2 independence test is that, taken overall, the relative risks associated with the different levels of a variable are not different from unity.

Figures 4.3 and 4.4 show relative risk plots derived from the data in Figures 4.1 and 4.2, for the British pendulum skid test and the grade at 30m upstream from the pole for the MNI data group (see Table 4.1 for a list of data group abbreviations).

As expected the relative risks for the skid test results depart quite markedly from unity, whereas the grade relative risks do not.

To further illustrate the concept of relative risk, it can be seen from Figure 4.3 that the relative risk for sites with a skid resistance of 30 is 2.8, whereas the relative risk for sites with a skid resistance of 65 is only 0.7. On the basis of skid resistance alone, therefore, the probability of an accident at an MNI site with skid resistance of 30 is four times higher than at a site with a skid resistance of 65. Relative risk is simply a ratio of probabilities.

A *second method of derivation of relative risk arises* if a trial is defined as the passage of one vehicle past a pole (a 'vehicle-pole pass'). Let V_{ijk} be the total traffic flow during the study period past the k th pole in the random sample with characteristics ij. Then the number of trials for the k th random pole, according to this new definition, is also given by V_{ijk}. The total number of trials in the random sample for poles with characteristics ij is then

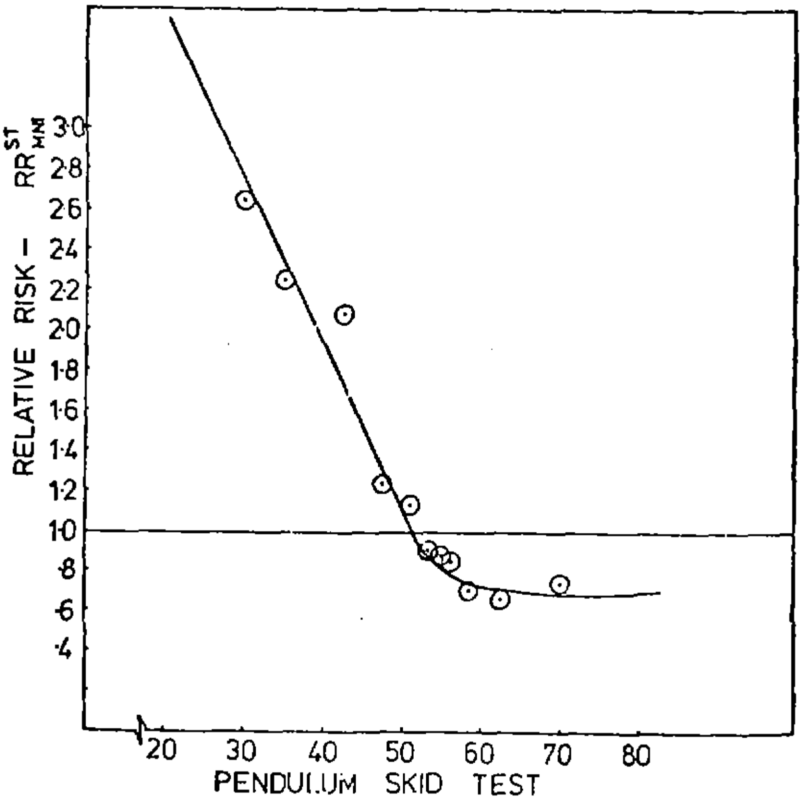


Figure 4.3. Relative risk versus British pendulum skid test levels for the MNI data group

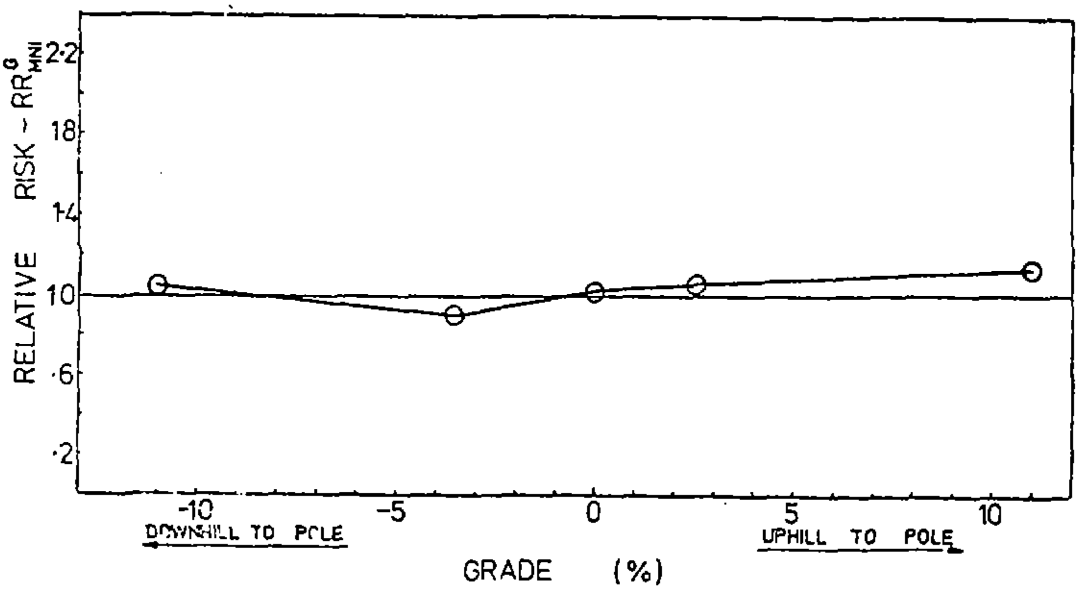


Figure 4.4. Relative risk versus grade 30m upstream from the pole for the MNI data group

$$t_{ij} = \sum_{k-1}^{r_{ij}} V_{ijk} = r_{ij} \overline{V}_{ij} \qquad (4.5)$$

where $\overline{V}_{ij}$ is the mean traffic flow (per pole) for characteristics ij. The proportion of trials in the random sample with characteristics ij, p_{ij}, is

$$p_{ij} = \frac{t_{ij}}{\underset{ij}{\Sigma\Sigma} t_{ij}} = \frac{t_{ij}}{t} \qquad (4.6)$$

where the total number of trials for the random sample is

$$t = \underset{ij}{\Sigma\Sigma}\, t_{ij}$$

An estimate of the total number of trials in the population over the study period is

$$T \mathrel{\hat{=}} \left(\frac{N}{r}\right) t$$

where N is the total number of poles in the population and r is the total number of poles in the random sample.

Thus an estimate of the number of trials in the population over the study period for poles with characteristics ij is

$$T_{ij} \mathrel{\hat{=}} p_{ij}\, N \frac{t}{r} \qquad (4.7)$$

The trial failure probability for a pole with characteristics ij, is estimated by

$$P_{ij} \mathrel{\hat{=}} \frac{a_{ij}}{T_{ij}} \qquad (4.8)$$

Inserting equations (4.6) and (4.7) into equation (4.8) gives

$$p_{ij} = \frac{a_{ij}\,r}{t_{ij}\,N} \tag{4.9}$$

The mean failure probability for trials involving all poles is estimated as

$$\bar{p} \;\hat{=}\; \frac{a}{N\frac{t}{r}} \tag{4.10}$$

The relative risk is again given by

$$RR = \frac{p_{ij}}{\bar{p}}$$

Inserting equations (4.9) and (4.10) gives

$$RR = \frac{a_{ij}/a}{t_{ij}/t} \tag{4.11}$$

The relative risk defined by equation (4.11) is termed the 'weighted relative risk', because the random sample poles have been 'weighted' by the traffic flows past them. The unweighted relative risk in equation (4.4) is concerned with equal-time-interval trials, and its magnitude for a given pole will depend on the exposure of the pole to traffic. Thus, all other risk-producing factors being similar, a pole exposed to only a few vehicles per day would be expected to have a much lower unweighted relative risk than a pole beside a heavily-trafficked road. On the other hand, the weighted relative risk in equation (4.11) is on a per vehicle basis, so that the weighted relative risks for the two poles just mentioned would be expected to have similar magnitudes.

Of course, if there was no correlation between traffic flow and the particular characteristics ij, the relative risks calculated from equations (4.4) and (4.11) would be the same: In this case the mean traffic flow $\bar{V}_{ij}$ (equation (4.5)) would be the same for all characteristics ij, so that $\bar{V}_{ij} = \bar{V}$, say, where $\bar{V}$ is the overall mean traffic flow per pole in the random sample. Then

$$t_{ij} = r_{ij}\bar{V}$$

$$t = r\bar{V}$$

so that equation (4.11) becomes

$$RR = \frac{a_{ij}/a}{(r_{ij}\bar{V})/(r\bar{V})} = \frac{a_{ij}/a}{r_{ij}/r}$$

as in equation (4.4).

The difference between the weighted and unweighted relative risks, when traffic flows are not the same over all levels of the attribute, is best illustrated by the RR for traffic flow itself as an attribute. Figures 4.5 and 4.6 show the relative risk plots for average annual daily traffic (AADT) for major road non-intersection (MNI) cases. Figure 4.5 is for the unweighted relative risk, while Figure 4.6 is the weighted relative risk plot.

The relative risk notation used on the ordinate of these figures (RR_{MNI}^{AADT}), and in the subsequent text, is to be interpreted as the relative risk for AADT given that the pole is in data group MNI. Similarly RR_{K}^{e} would be interpreted as the relative risk for e (superelevation) given K (curvature).

The two relative risk plots for AADT in Figures 4.5 and 4.6 appear quite different.

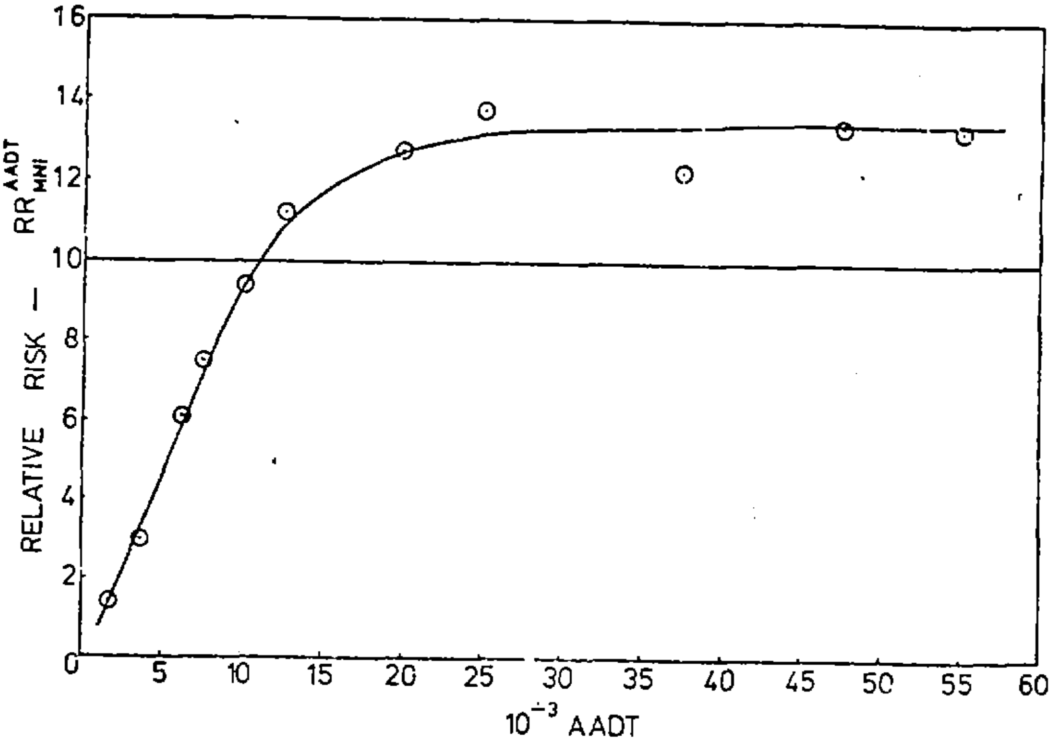


Figure 4.5. Unweighted relative risk versus AADT-MNI data group

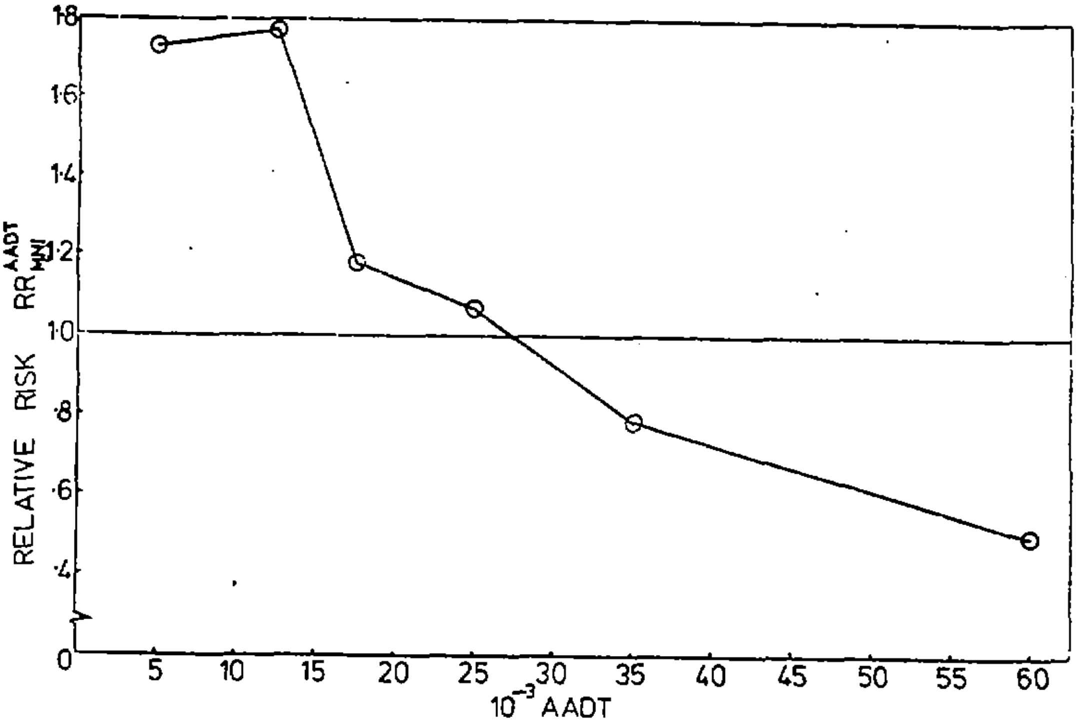


Figure 4.6. Weighted relative risk versus AADT-MNI data group

Figure 4.5 shows that the unweighted relative risk increases with traffic flow until an AADT of 25000, after which it levels off. If risk were a function of exposure only, then the relative risk would be expected to increase linearly with AADT over the whole range of traffic flows. This is clearly not the case. It is apparent that, whereas at low flows, risk increases with exposure, at higher traffic levels the unweighted relative risk saturates. This could be the result of traffic congestion with resultant lower speeds, or possibly reflects improved roadway design standards for higher traffic flow roads. The former seems somewhat unlikely as the majority of pole accidents occur at times of low traffic volume (section 3.4).

Figure 4.6 is consistent with this interpretation: At low volumes the per-vehicle, weighted relative risk is roughly constant. For higher values of AADT the per-vehicle risk steadily decreases.

The choice of which relative risk calculation method to use is somewhat arbitrary, as they both lead to the same predictions concerning pole accident numbers at a given site.

Because of the lack of traffic flow data for minor roads, however, it was decided to use the unweighted relative risk, so that a consistent approach could be used throughout the analysis. The weighted relative risk also suffers from the disadvantages that the errors in estimation of AADT at each site would increase the variability of the relative risks calculated, and the disparity between the numbers of vehicle-pole passes and the numbers of accidents would mean that the χ^2 test of independence would no longer be an appropriate test of significance of the data.

4.2.4 Derivation of the Major Road Non-Intersection (MNI) Data Group Model.

(a) Elimination of Variables.

Visual sorting and χ^2 independence tests of the data left the variables listed in Table 4.2 for inclusion in the second stage of the model derivation. The primary or 'main effect' variables were those which were significant in their own right. The secondary variables were those which were included for interaction tests, but were not significant by themselves. Symbols for each of the variables are also included in Table 4.2.

(b) Confidence intervals for estimates of relative risk

Relative risk plots for the majority of the variables were generated. In attempting to decide the relative merits of the plots it became apparent that some measure of variability or the 'confidence' that could be placed in the plotted points was required. The method of maximum likelihood was used to find the maximum likelihood estimate of the standard deviation of the estimates of relative risk. Figure 4.9 shows the relative risk plot for absolute maximum curvature upstream of the pole with plus and minus one standard deviation limits indicated for each plotted point. The calculation of these 'limits' takes account of the proportion of the data contributing to a particular estimate of relative risk, as well as the total amount data in the sample. Derivation of these 'confidence' limits is contained in Appendix A. If the relative risk estimates for a particular level of a site characteristic were distributed normally (which they aren't) the one standard derivation limits plotted would represent 68% 'confidence intervals. The 'confidence' limits are shown to give some indication of the likely variability of the estimates of relative risk and to assist in assessments of the significance of apparent differences in relative risks - from each other and from unity.

(c) The effect of pole density

An additional variable to those listed in Table 4.2 which has significant χ^2 was pole spacing. This was defined as the average distance between poles in the vicinity of the subject pole, on the same side of the road. The relative risk plot for this variable,

TABLE 4.2

VARIABLES INCLUDED IN THE SECOND STAGE OF THE MODEL DERIVATION - MNI DATA GROUP.

Variable Group	Variable Discription	Symbol
Primary		
	Modulus of maximum curvature	$\lvert K_{MAX} \rvert$
	Annual average daily traffic	AADT
	British pendulum skid test	ST
	Pole lateral offset	LO
	Road width	W
	Pavement deficiencies	PD
	Side friction margin	SM
	Road divided/undivided	DV
	Curvature	K
	Side friction factor	SDFF
	Modulus of side friction factor	$\lvert SDFF \rvert$
	Inside or outside of bend	IOB
Secondary		
	Distance from curve start	DC
	Superelevation at curve	e
	Grade	G
	Distance to point of maximum curvature	DM

shown in Figure 4.7, revealed a flaw in the method of selection of random poles. The selection method consisted of going out to a location which had been randomly chosen from a road system inventory, and then selecting the nearest pole to that point. In other words, each segment of road had an equal change of selection, rather than each pole. Thus, segments of roads with a high 'density' of poles did not contribute any more poles to the random sample than segments with a low pole density. The data collection method was orientated to the collection of information relating to specific poles rather than groups of poles or road segments. Similarly the statistical model being developed is aimed at being able to predict the probability of an accident occuring at a particular pole. Ideally, therefore, the method of selection would have been based on an inventory of all poles, so that every pole had an equal chance of selection.

Now pole spacing or pole 'density' should not affect the probability of a particular pole being hit, unless pole density has some subtle effect on driver behaviour, or is correlated with another significant variable. All else being equal, it would be expected that more pole accidents would occur in areas of greater pole density than in areas of lower pole density, simply because of the greater number of exposed poles. Because the random sample did not take account of pole density, therefore, poles in higher density areas would appear to have a relative risk greater than unity; those in lower density zones less than unity. The relative risks calculated from equation (4.4) for each value of pole spacing should therefore be adjusted to take account of the different pole density associated with each pole spacing.

A review of the site diagrams for the random cases in this data group revealed that the majority of sites (75%) had poles on both sides of the road, and the pole spacing did not vary greatly from one side to the other. The inverse of pole spacing therefore provides a crude estimate of pole density. Using this basis for estimating pole density, therefore, the 'apparent' relative risk associated with a given pole spacing is predicted to be the ratio of the mean pole spacing for all MNI road segments to the given pole spacing. Relative risks predicted on this basis are plotted as the curve in Figure 4.7. It can be seen that the experimental points are in reasonable agreement with the predicted curve. Hence it was concluded that, if some candidate predictor variable proved to be strongly correlated with pole spacing, the spurious relative risks associated with the variation of pole spacing could be compensated for by multiplying the apparent relative risk by the ratio of the appropriate pole spacing to the overall mean pole spacing.

It is noted here that this simple correction is not valid for the relative risk comparison of 'divided' versus 'undivided' road, since the divided roads typically have poles on the median strip as well as on the house sides. This problem is discussed in more detail subsequently.

Using two-way χ^2 independence tests, scattergrams and linear regressions, correlations between candidate predictor variables and pole spacing were investigated using the random site data.

One variable which was weakly correlated with pole spacing was horizontal curvature of the road. The appropriate corrections for this correlation caused such a small shift in the affected points as to be negligible (see Figure 4.9). Other variables which were correlated with pole density were 'road width', 'road divided/ undivided' and 'pavement deficiencies'. These correlations will be dealt with in detail during the derivation of the relative risk associated with each variable.

(d) Correlated and interacting variables.

A distinction is made here between the terms 'correlation' and 'interaction' as applied to predictor variables. The presence of correlation means a degree of a linear relationship between two

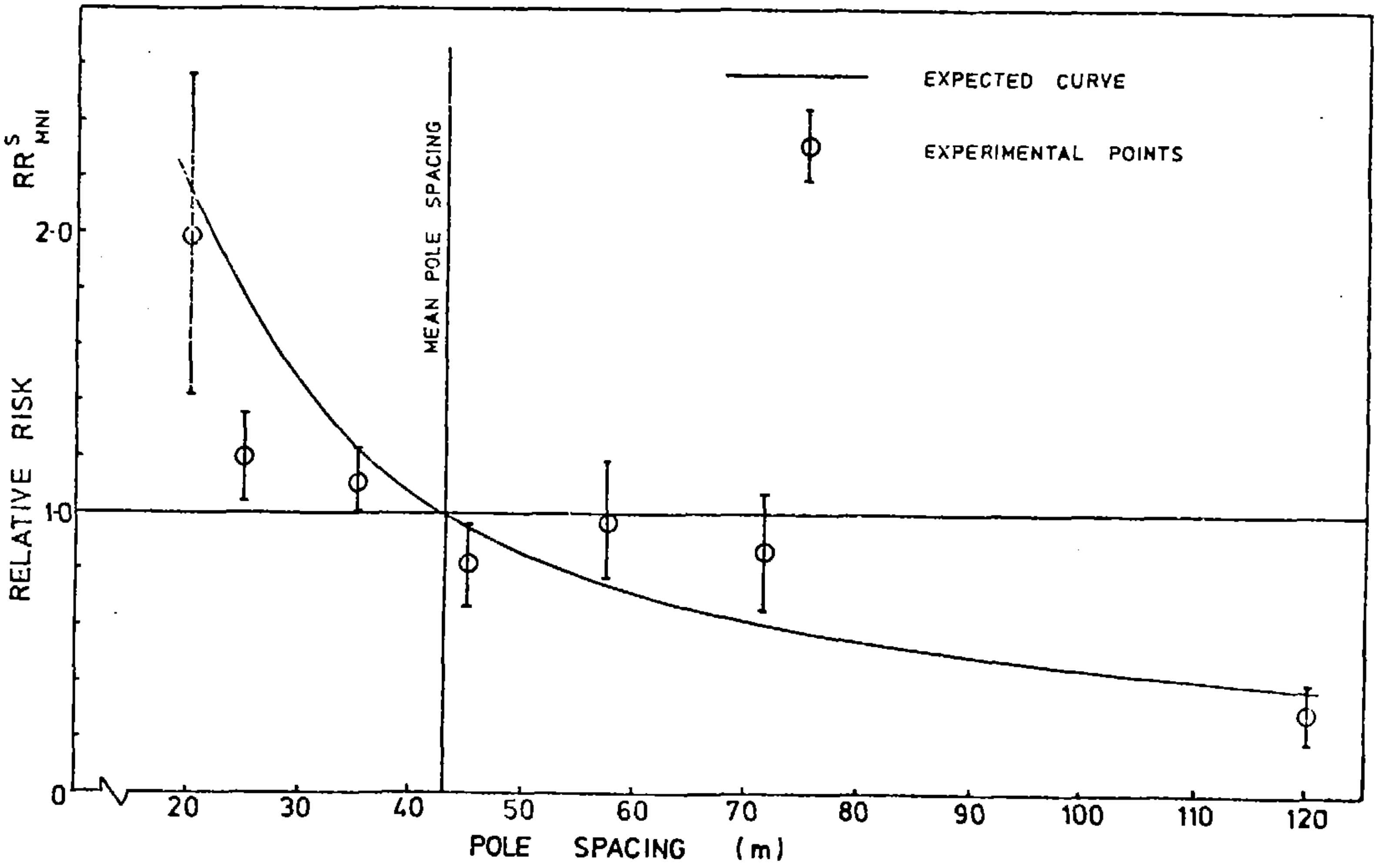


Figure 4.7. Raw relative risk versus pole spacing - MNI data group

predictor variables in the population of pole sites, and is tested for using only the random sample. For example, road width and traffic flow are positively correlated so that higher traffic flows tend to be associated with higher road widths. Interaction on the other hand, refers to the situation when the value of one predictor variable influences the effect of another (not necessarily correlated) predictor variable on the probability of an accident. An example of this is the interaction between the degree of curvature and the location of the pole with respect to that curve. These two variables are not correlated, but interact to result in higher relative risks for poles in certain zones of a curve. Relative risks for correlated variables, or variables which interact, should be plotted as a family of curves where the effect of one variable is displayed for various constant values of the other.

All of the variables were put through correlation and interaction tests Chi-square tests for three-way contigency tables were used to test for interactions (Lancaster, 1951; Lewis, 1962; Kendall and Stuart, 1973). As noted above, two-way χ^2 independence tests and linear regressions of one variable on another were used to check for correlations between variables. The search for interactions was limited to pairs of variables and did not investigate higher order relationships.

If two variables were found to be related, then relative risk plots for one of the variables, controlling for the other, were generated to investigate the practical significance of the relationship. For example, it was found that skid test was correlated with traffic flow in such a way that higher traffic flows implied lower skid resistances. The scattergram indicated that, although the correlation was statistically significant, the variation of skid resistance across the range of traffic flows was relatively small. Figure 4.8 shows plots of the relative risk associated with the skid test result, given that the traffic flow lies within one of two ranges. Because of the limited sample

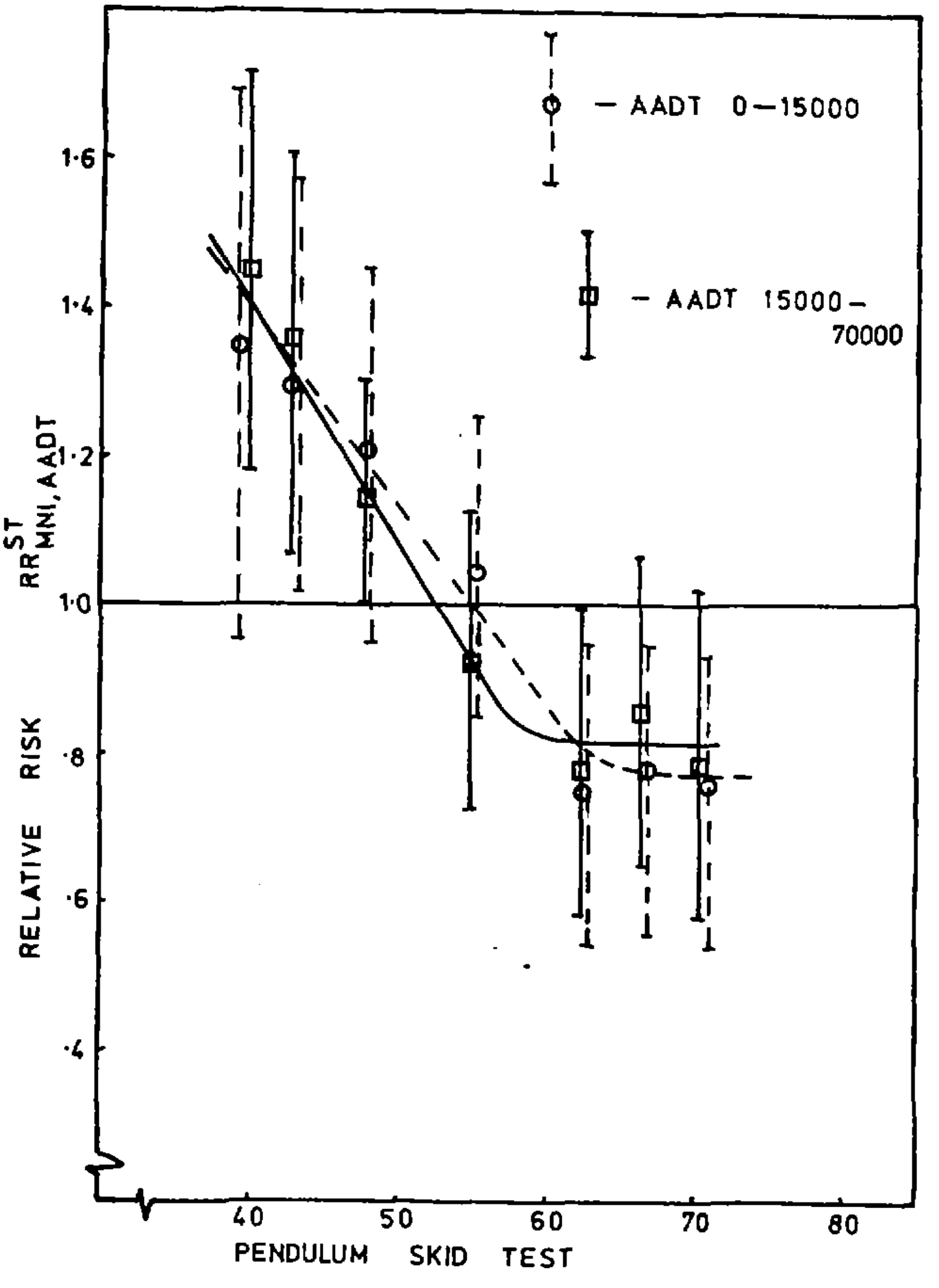


Figure 4.8. Relative risk versus British pendulum skid test results for two levels of annual average daily traffic - MNI data group

size, and the need to control the variability of the estimates of relative risk, it was only possible to divide the data into two traffic flow groups. It can be seen that the two plots are not significantly different given the considerable overlapping of the 'confidence' limits. This is confirmed by the three-way contingency table test which in effect tests how different each of the members of the family of relative risk plots are from one another.

This procedure was carried out for the remaining variables, and it was found that the only practically significant interactions were between the following pairs of variables: superelevation and curvature; curvature and location of the pole with respect to the curve; road width and road divided/undivided. No interaction between curvature and grade was found, in contrast to the results of the studies of Kihlberg and Tharp (1968), and Wright and Robertson (1976). Similarly traffic flow and curvature were not correlated for the roads in this study, a finding which differs from the situation found by Dart and Mann (1970) and Wright and Mak (1974).

The analysis of this data group was simplified by the fact that few significant correlations or interactions existed among the key variables. Also, the pole density effects introduced by the method of selection of random poles proved unimportant.

(e) The effect of horizontal curvature of the road.

Relative risk for absolute maximum curvature is shown in Figure 4.9. This variable produced the widest range of relative risk of any of the primary variables. However, definition of the relationship between curvature and relative risk suffered somewhat from lack of data. The number of sites involving curvature in the accident sample was 4·7 times higher than in the random sample. While this was a highly favourable result, in terms of discriminating between poles at risk, when it came to assigning relative risks to particular levels of curvature, the small amount of random site

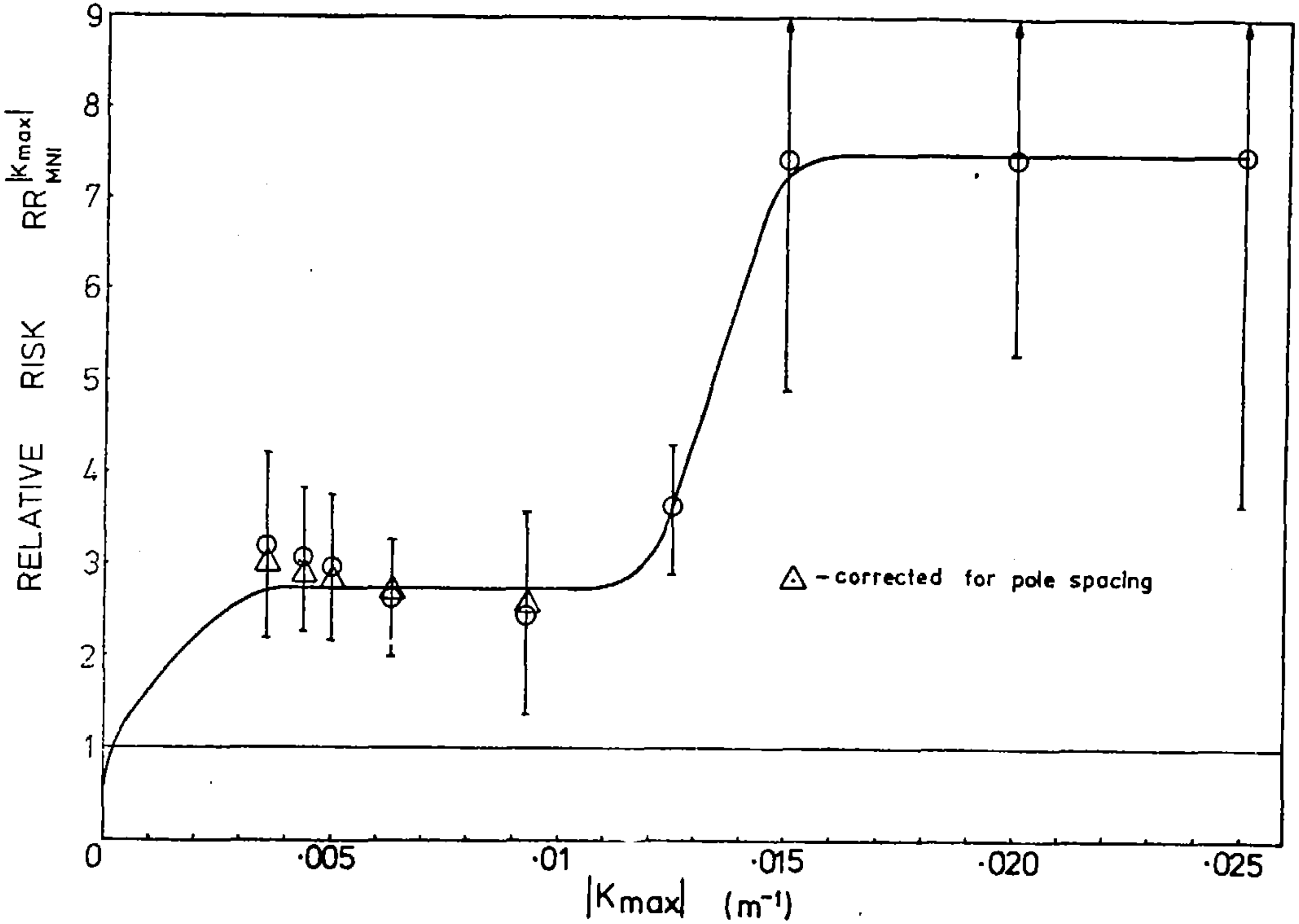


Figure 4.9. Relative risk versus absolute maximum curvature upstream of the pole - MNI data group

curvature data was somewhat restrictive. To alleviate this problem, curvature data for left and right hand curves were pooled. As the difference in relative risk between left and right hand curves appears negligible, no significant loss of information resulted from this pooling. (If anything, right hand bends had a slightly higher relative risk than left hand bends, a result which is consistent with the Victorian Road Safety and Traffic Authority (RoSTA) data presented in Chapter 3. However, the respective relative risks are extremely close to one (1.05 and 0.95).

The lack of curved random site data led to 'confidence' intervals on the Figure 4.9 plot of $RR_{MNI}^{|K_{MAX}|}$ being relatively large, although the three levels of relative risk corresponding to zero curvature, low to moderate curvature and high curvature are clearly defined. The overall effect of curvature is consistent with the findings of studies by Hillier and Wardrop (1966), Kihlberg and Tharp (1968), Dart and Mann (1970), Leisch and Associates (1971), Dunlap _et al_ (1974) and Wright and Robertson (1976).

(f) The effect of traffic flow rate.

The derivation of the relative risk curve for AADT was discussed in detail in section 4.2.3. The curve is replotted in Figure 4.10 with 'confidence' limits shown. To briefly reiterate the discussion in section 4.2.3, it appears that whereas at low traffic flows RR increases at higher flows the RR 'saturates'. This 'rolling off' of relative risk for high levels of AADT could be a function of reduced traffic speed with increasing congestion, although this seems unlikely in view of the fact that the majority of accidents occur in low traffic volume periods (section 3.4). It could also be a function of generally improved road design standards on the higher traffic volume roads. In any case, the effect of AADT shown in Figure 4.10 is consistent with the results reported by Khilberg and Tharp (1968), Chapman (1969), and Slatterly and Cleveland (1969). They all reported decreasing single vehicle accident rates with increasing AADT, the single vehicle accident being representative of the majority of pole accidents observed in the present study.

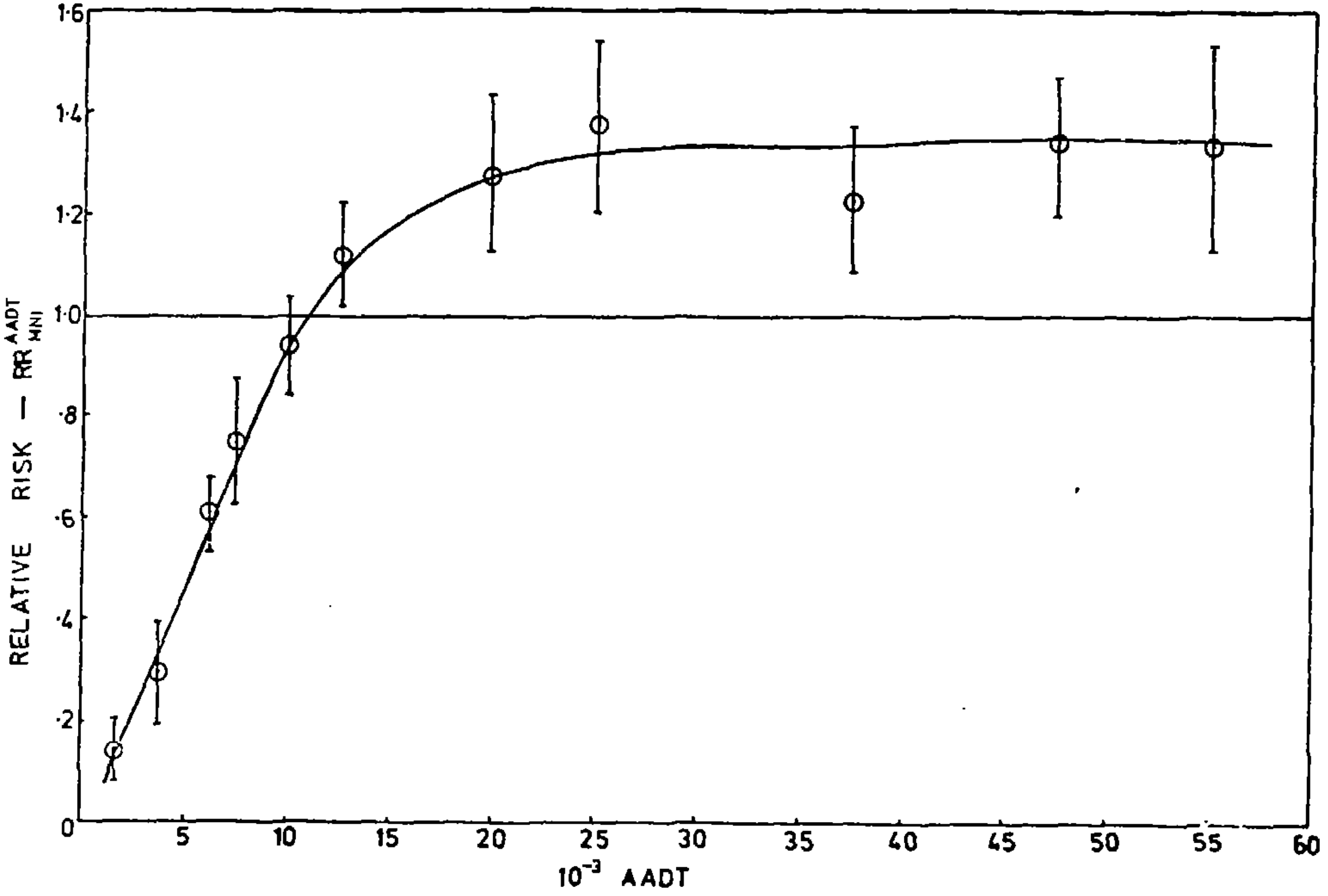


Figure 4.10.Relative risk versus AADT - MNI data group

(g) The effect of skid resistance

Another variable which produced a significant range of relative risks is the British pendulum skid test result (Figure 4.11). Low skid resistance values resulted in high relative risks, RR diminished rapidly with increasing skid resistance until a skid resistance value of 55, with little further return being achieved for skid resistances higher than this value.

While some criticism has been levelled at the accuracy and relevance of the pendulum skid test results (Forde, Birse and Fraser, 1976), they have proved here to be an excellent discriminator of risk. It is noted also that pendulum skid test results have been compared with the results of other methods of determining pavement friction (Kummer and Meyer, 1967);(Runkle and Mahone, 1977) and have shown good correspondence.

For the purposes of the current project the pendulum test has proved to be more than adequate.

The results of Giles, Sabey and Cardew (1964) (Figure 4.12) and Rizenbergs, Burchett and Warren (1977) (Figure 4.13) demonstrate very similar characteristics to the skid resistance relative risk depicted in Figure 4.11. The Giles et al results are directly comparable to Figure 4.11, in that the curve was derived from a sample of accident sites and a sample of random sites and has relative risk as the dependent variable. While the curve is very similar in form, the slope of the linear section of the Giles et al, results is higher. The accident data used by Giles et al were for wet road skidding accidents only, whereas the data for Figure 4.11 includes both wet and dry accident cases. It is to be expected therefore that the slopes would be different with Giles et al results having the greater slope.

Figure 4.13 which shows a plot of the ratio of wet to dry accidents against skid number, cannot be directly compared with

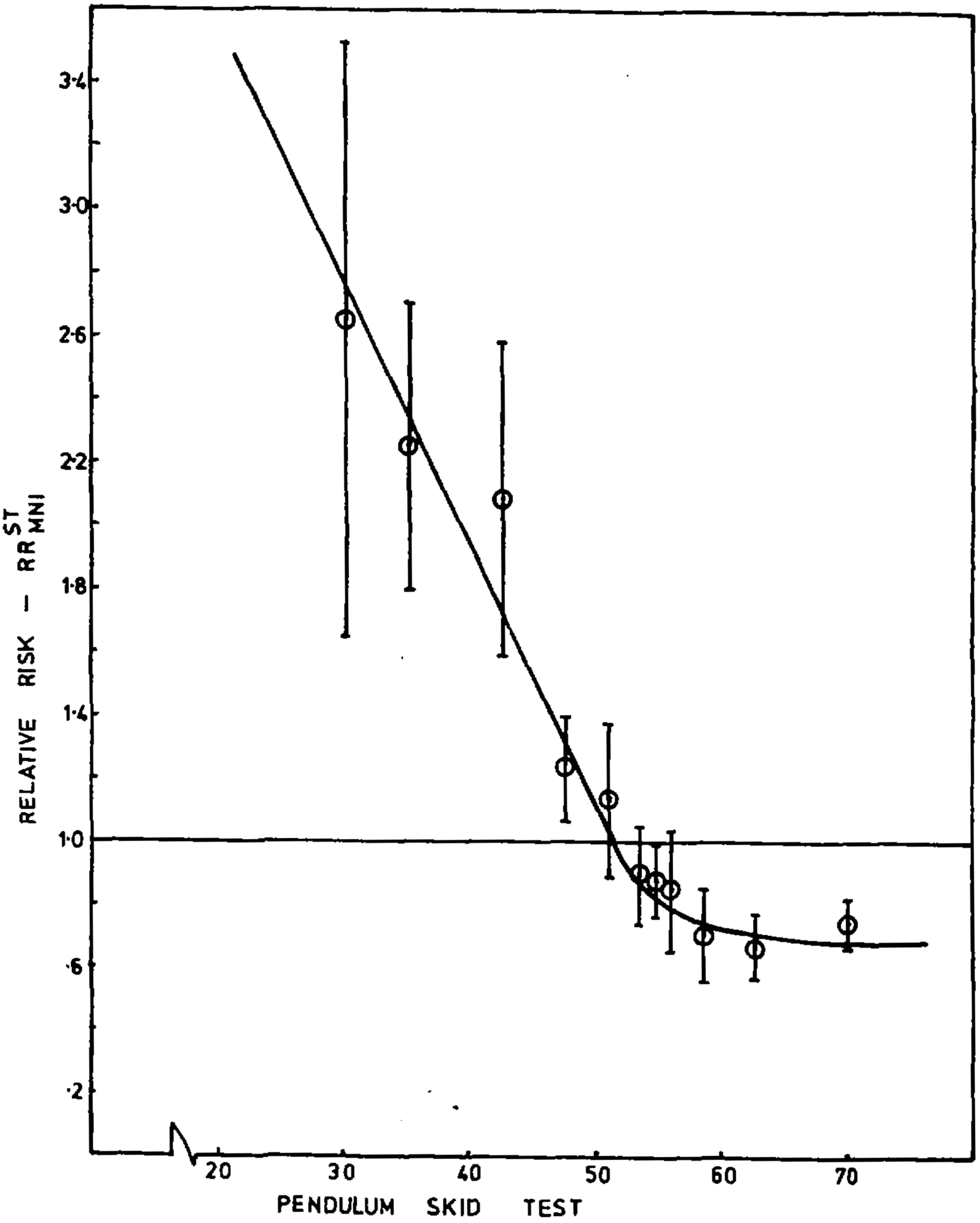


Figure 4.11.Relative risk versus British pendulum skid test - MNI data group

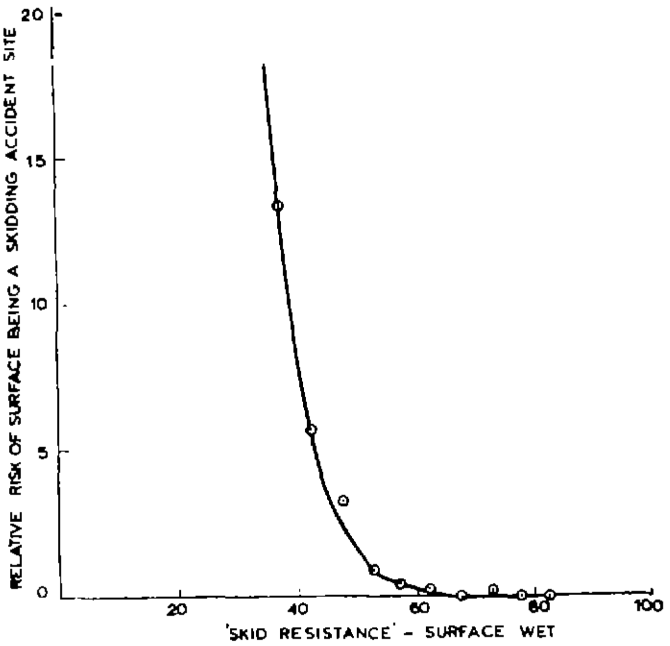


Figure 4.12. Relative risk of a surface being a skidding accident site (Giles, Sabey and Cardew, 1964)

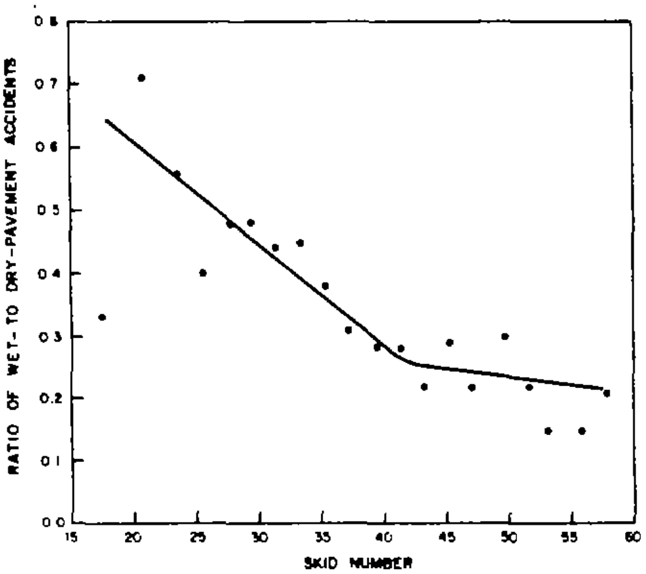


Figure 4.13. Average ratio of wet to dry pavement accidents versus skid numbers (Rizenbergs, Burchett and Warren, 1977)

the relative risk plots. Skid number is a different measure of pavement friction to the pendulum skid test number, although the results can be related (Runkle and Mahone, 1977). The curve does, however, demonstrate a similar 'break point' above which there is a diminishing return for higher skid resistance values.

(h) The effect of lateral offset

The lateral offset of the pole, defined as the distance between the pole and the curb, or shoulder edge if there was no curb, was also a strong discriminator of risk, as shown in Figure 4.14. As with skid resistance, there is a clearly defined region of high return in terms of risk reduction, after which the predicted return is almost zero. The results indicate that the probability of an accident involving poles at the pavement edge is 3.5 times higher than for poles which are set 3 m back from the road edge (Figure 4.14). They also show that little further reduction in accident probability is achieved by moving the pole back from 3 m to a 12 m offset.

Jorgensen (1966) proposed an exponential relationship between risk (defined as the accident potential index, A_f) and lateral offset, based on data collected from a number of studies (Figure 4.15). The relative risk curve obtained for lateral offset in Figure 4.14 is strongly suggestive of a similar relationship, although on a different scale because of the different classes of road involved. Just such a scale change was suggested by the Highway Research Board (1969), who recommended that the design offset of hazards be related to road type and vehicle speed, as indicated in Figure 4.16.

(i) The effect of road width

The analysis of the effect of road width was divided into two parts, the first dealing with the divided road cases, the second with undivided roads, because of the correlation between pole density and roadway divided/undivided. Road width was defined as the distance between curbs, so that for divided roads it was the 'one-way' width, while for undivided roads it was the total road width.

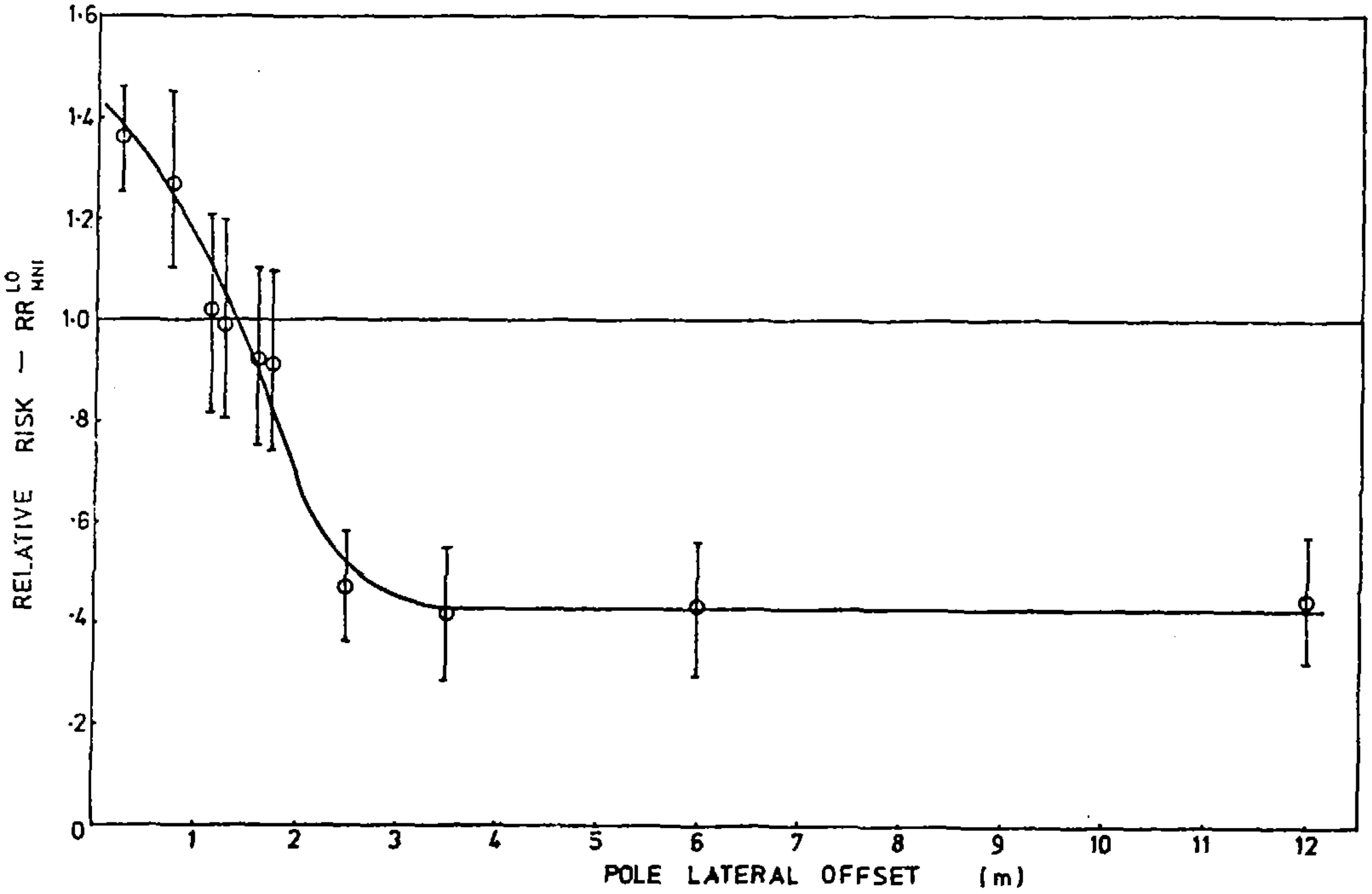


Figure 4.14. Relative risk versus pole lateral offset - MNI data group

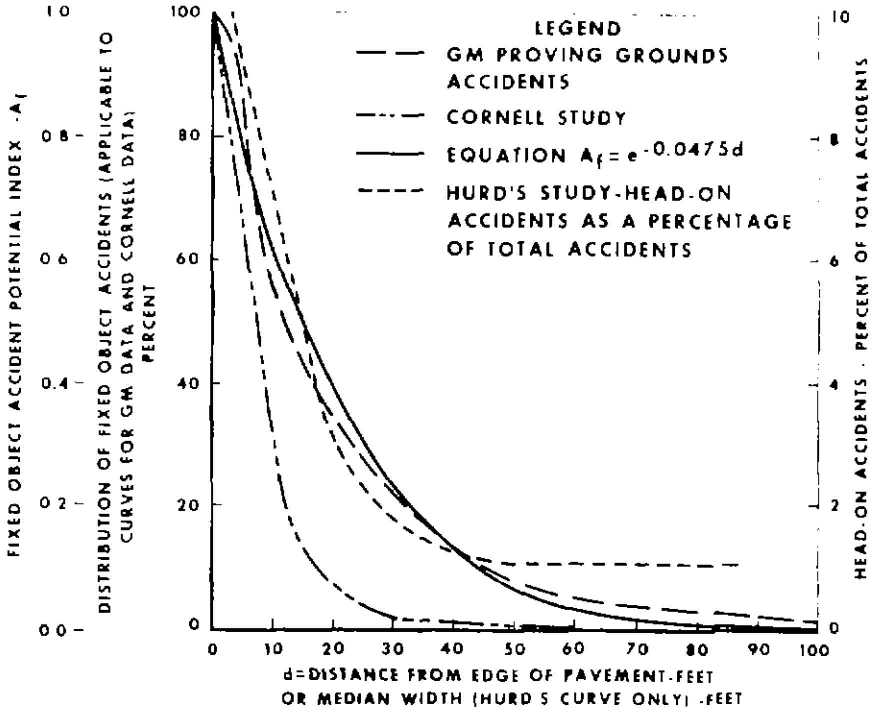


Figure 4.15. Accident potential index versus lateral offset (Jorgensen, 1966)

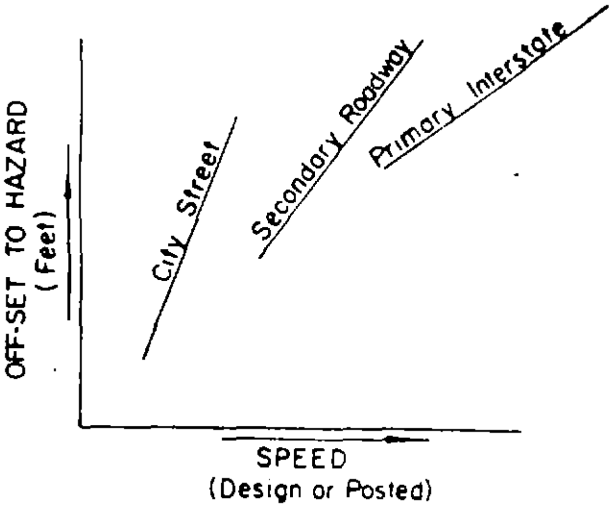


Figure 4.16. Relationship between speed, type of roadway and offset to hazard (Highway Research Board, 1969)

The two-way χ^2 test of independance failed to show any difference between the accident and random sample distributions of divided road width. Correspondingly, on the plot of relative risk for divided road width in Figure 4.17, all the 'confidence' intervals include a relative risk of unity. The slight increase in relative risk with road width is most likely due to the correlation between road width and AADT. After controlling for AADT, divided road width shows no effect on relative risk. This variable was therefore discarded as a predictor.

A different result was obtained for undivided road width (Figure 4.18). It was found that, unlike divided road width, undivided road width was strongly correlated with both pole spacing and AADT. Plotting the relative risk curves for two levels of traffic revealed that the curves were identical in form and, within the confidence limits, were the same. Appropriate corrections (see Figure 4.18) were made for the correlation with pole density which was such as to associate low road widths with high pole spacing (low density), and vice versa. No explanation for the final curve shown in Figure 4.18 can be advanced. The peak in relative risk occurs at a road width equivalent to a four lane undivided road. However, an analysis based on number of lanes did not produce clean cut results. Despite the lack of rationale the Figure 4.18 curve clearly explains some of the data, so this variable was retained for testing in the final model.

(j) The effect of favourable and adverse superelevation

Three variables which interacted with curvature were analysed. The first of these was the superelevation e . Because of the shortage of curvature data in the random sample, the analysis had to be at a fairly crude level. In testing the superelevation effect, the data was restricted to left or right bends and positive or negative superelevation. Despite this restriction the trend was pronounced : bends with incorrect superelevation have a higher relative risk. The results are presented in Table 4.3, as are the values adopted for use in the final model.

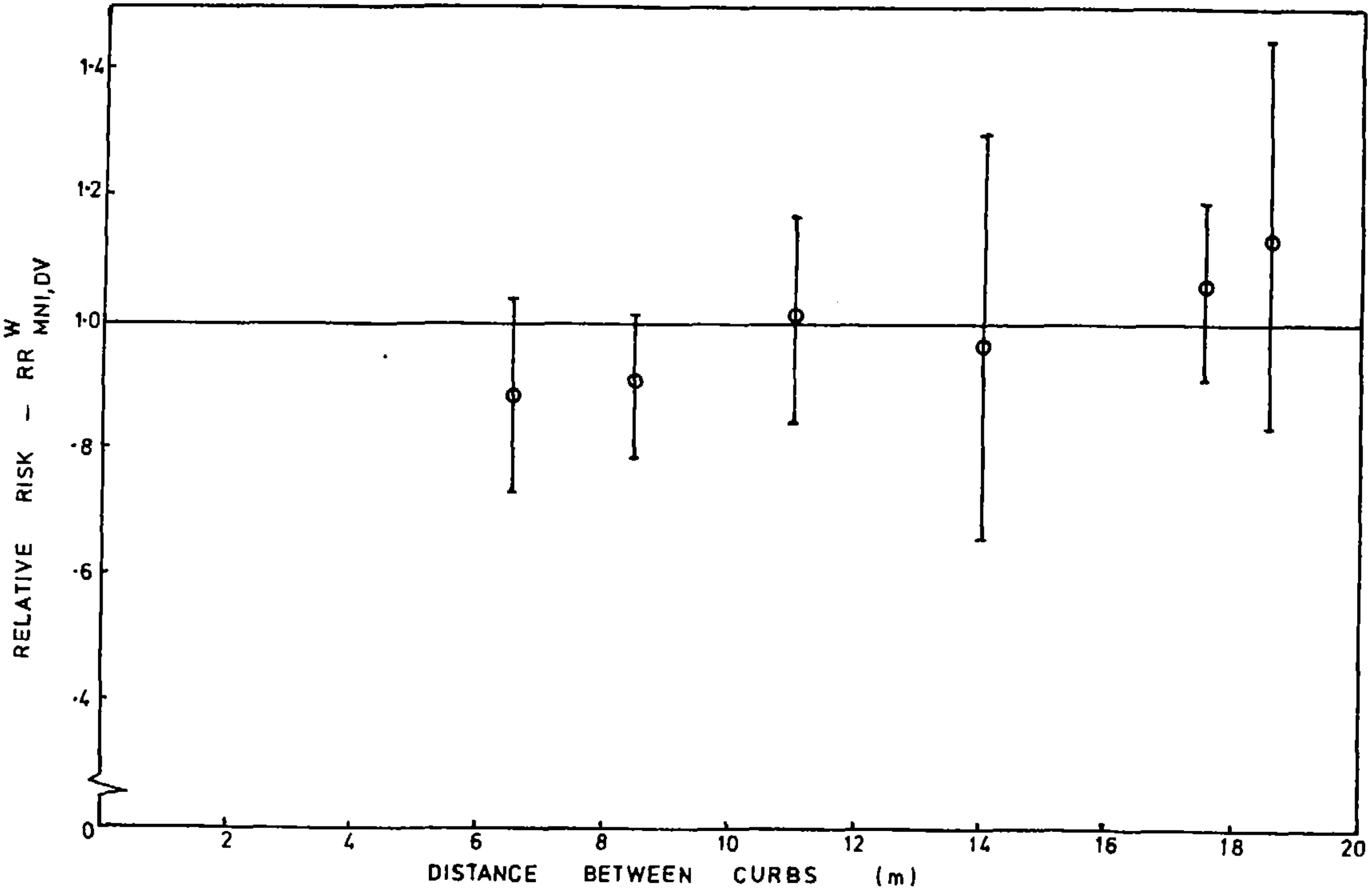


Figure 4.17. Relative risk versus distance between curbs (road width) for divided roads only - MNI data group

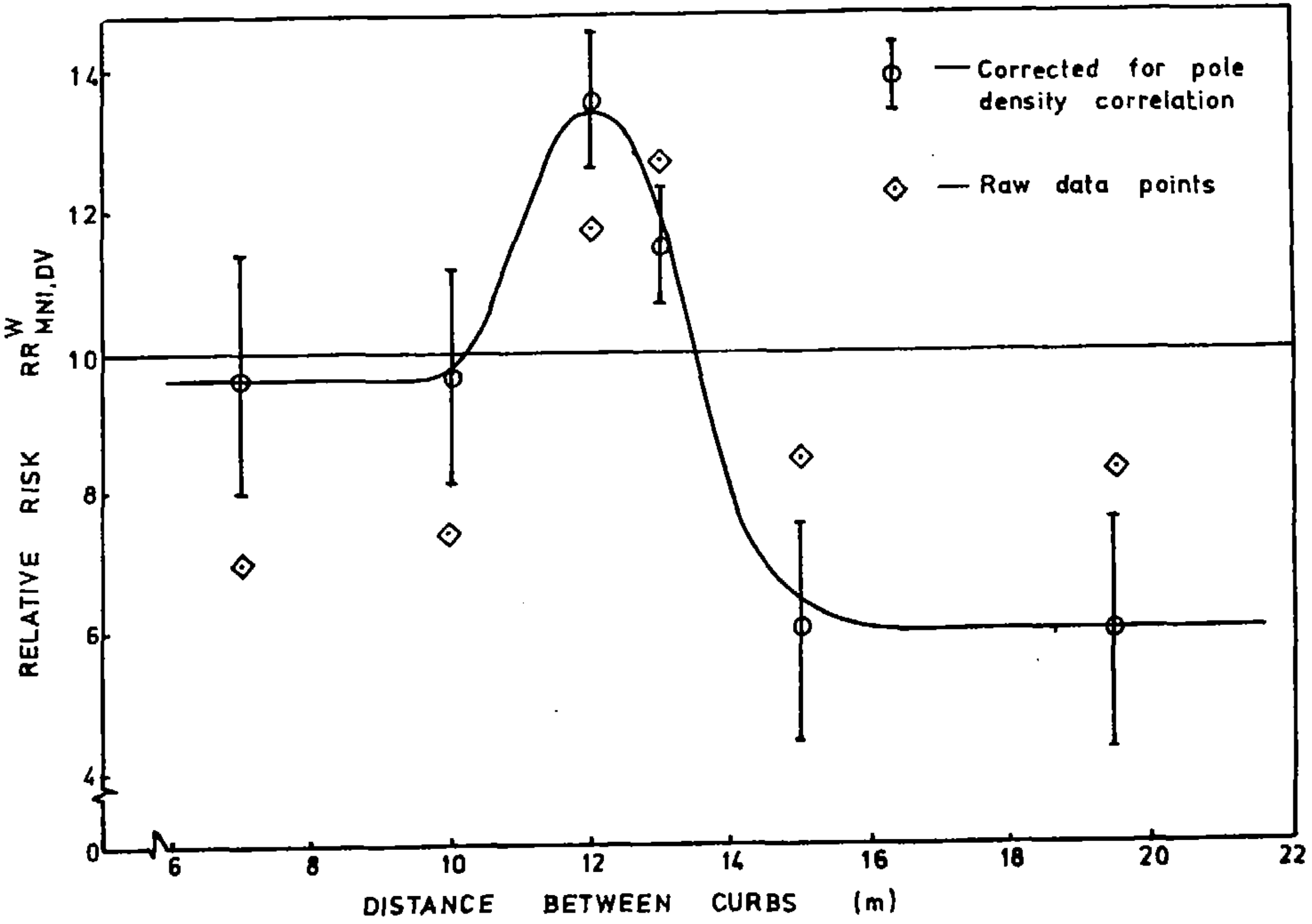


Figure 4.18. Relative risk versus distance between curbs (road width) for undivided roads - MNI data group

TABLE 4.3

RELATIVE RISK FOR SUPERELEVATION GIVEN CURVATURE
$(RR^{e}_{MNI,K})$ - MNI DATA GROUP

Curvature	Calculated RR Superelevation(1)		Adopted RR Superelevation(1)	
	-	+	-	+
Left	0.93	1.23	0.9	1.2
Right	1.22	0.78	1.2	0.9

(1) A positive superelevation is defined as clockwise rotation of the road surface from horizontal looking in the direction of travel of the vehicle.

(k) The effect of poles on the inside or outside of a bend

The data was again separated into divided road cases and undivided road cases for the derivation of the relative risks associated with poles being on the inside or the outside of a bend (OIB). It was thought that the proximity of median strip poles on divided roads may affect the outcome of the relative risk. However both sets of data were consistent in revealing a slightly higher relative risk for poles on the outside of bends compared with those on the inside. That is, poles placed on the right hand side of the road on left hand curves, and those on the left hand side of the road for right hand bends have a slightly higher probability of being hit. Readers are referred to Section 3.4 for a discussion on the effect of road condition on this aspect of collisions involving curvature. Table 4.4 details the adopted relative risks.

TABLE 4.4

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

(ℓ) The effect of pole location in relation to a road curve

Measurements of curvature were recorded at the point of maximum curvature, and for distances of 0 , 20 and 50 metres upstream from the pole. It was apparent from the percentage distributions of curvature at these locations, that the position of the pole with respect to the curve was important. It can be seen from Figures 4.19 to 4.21, that the accident site curvature distribution 'shrinks' towards the random site distribution as the point of measurement moves towards the pole.

Clearly, if there is some critical point during negotiation of a curve at which loss of control is most likely to occur, then poles a short distance downstream from this point will be most at risk. Two possible curve reference points were investigated : the start of the curve and the point of maximum curvature. Neither the distance of poles from the curve start, DC, nor the distance from the maximum curvature point, DM, had a significant effect on accidents by itself, but both interacted significantly with curvature. Of the two, DC had the stronger effect and so was retained for inclusion in the model. As might be expected, the data show that as the maximum curvature of the bend decreases, the distance from the curve start to the region of maximum risk increases.

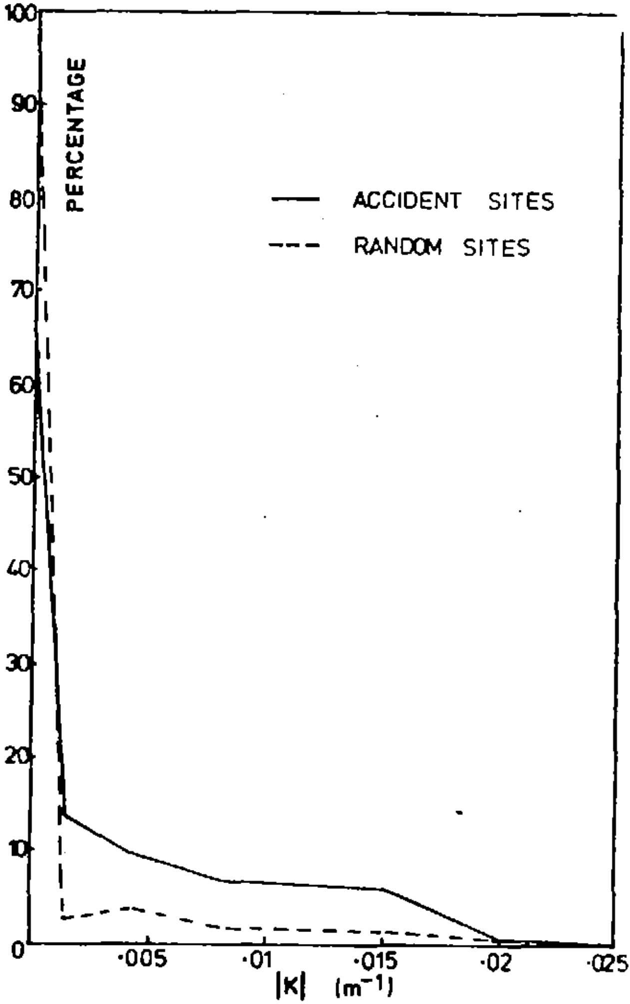


Figure 4.19. Distribution of curvature 50m upstream of the pole

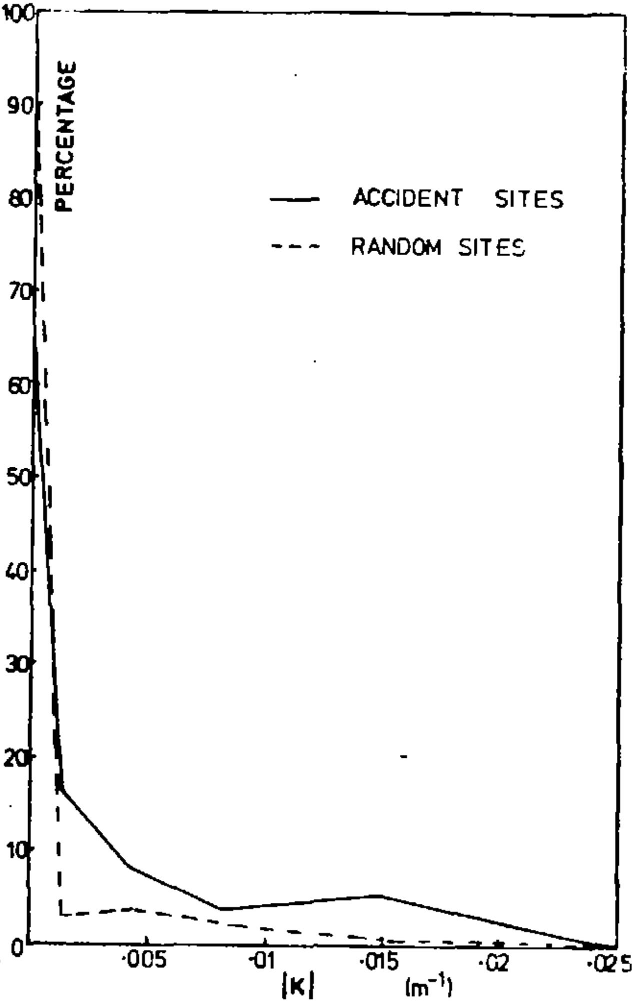


Figure 4.20. Distribution of curvature 20m upstream of the pole

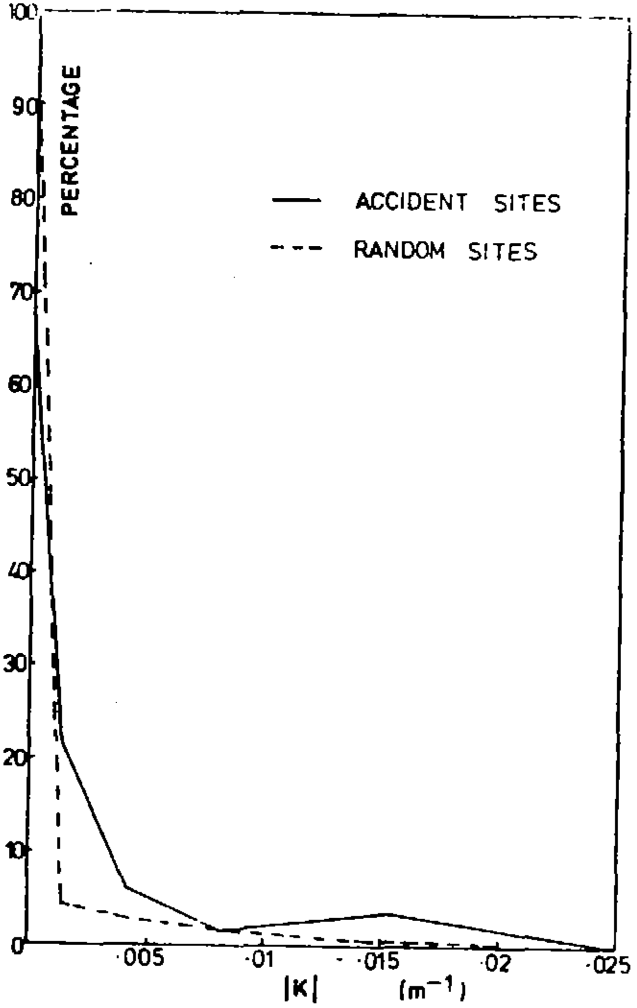


Figure 4.21. Distribution of curvature 0m upstream of the pole

Figure 4.22 shows relative risk against distance from curve start for three levels of maximum curvature. The results show that for low curvature sites, poles close to the start of the curve have a low relative risk, which increases with increasing distance from the start of the curve. For sites with moderate curvature, poles close to the curve start have a low relative risk which rises to a maximum at about 120 m , and then decreases for poles further out of the curve. Poles close to the curve start have a relative risk greater than unity for high curvature bends, with risk decreasing for poles beyond 50 m from the curve start. Straight lines have been arbitrarily drawn between the experimental points because the lack of data (particularly in the random sample) prohibits any better definition of the relationship. While the results demonstrate clearly defined trends, some reservations remain with respect to the exact values of relative risk, as indicated by the 'confidence' limits. However given the strength of the effect this variable was retained for the final model.

(m) The effect of pavement deficiencies

The presence of pavement deficiencies also led to a relative risk that departed from unity. Pavement deficiencies (PD) coded in the data included corrugations and holes, tram tracks and the presence of a dip or crest. The calculated relative risks are shown in Table 4.5.

TABLE 4.5

RELATIVE RISK ASSOCIATED 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

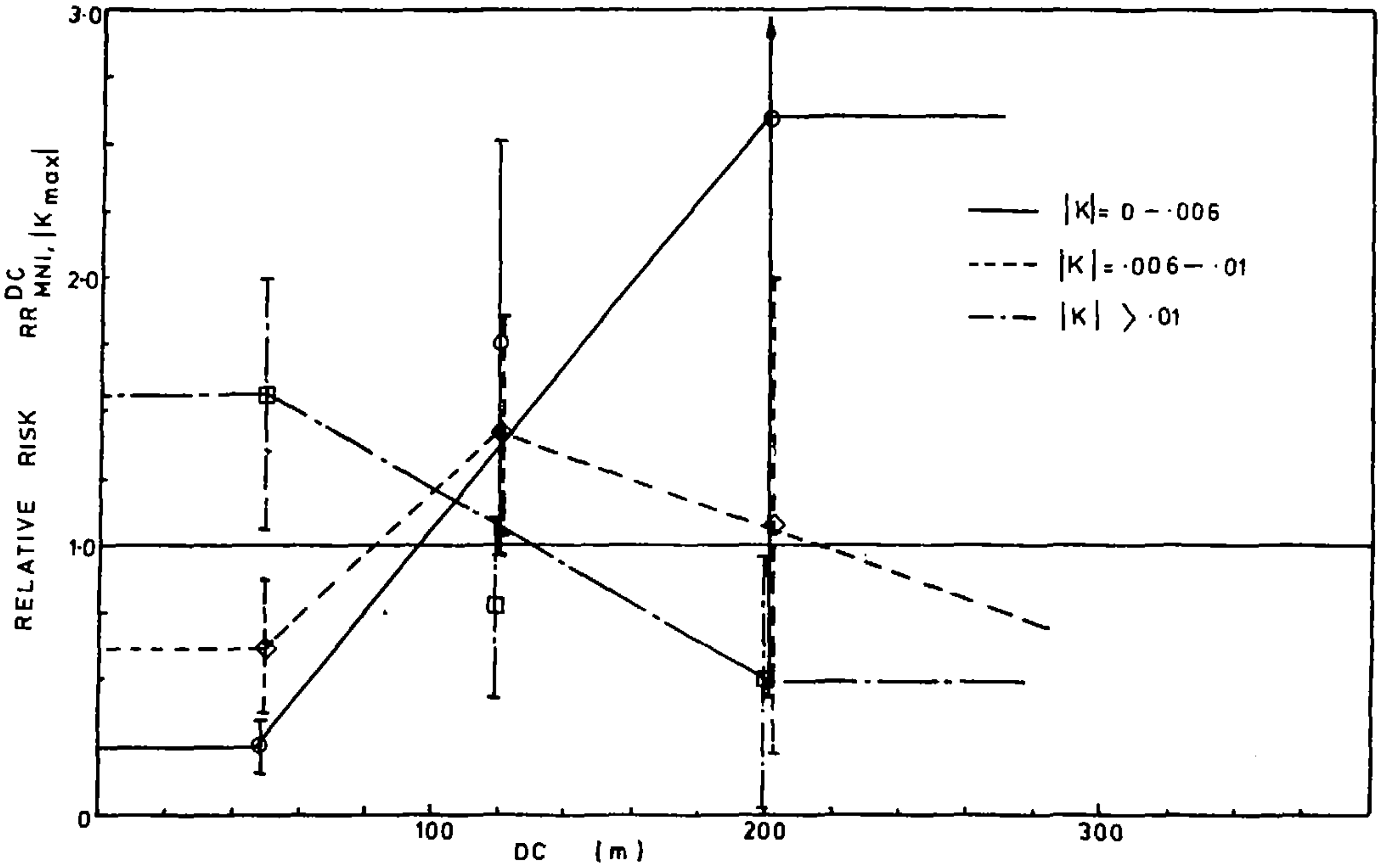


Figure 4.22. Relative risk versus distance from curve start controlling for absolute maximum curvature – MNI data group

The presence of tram tracks immediately implies the presence of tram poles. Such poles typically have a pole spacing lower than the sample mean, and a lateral offset of near zero. It was decided that, as this category of pavement deficiencies was so 'polluted' by its correlations with other variables, a relative risk of 1.0 would be assigned. A relatively small percentage of cases involved pavement deficiencies, so that this variable had only a small bearing on the final model results.

(n) The effect of divided versus undivided roads

As was discussed earlier, higher pole densities are associated with divided roads than undivided roads. Higher traffic flows are also associated with divided roads so that the raw relative risks listed below require modification to compensate for both these effects.

$$RR_{MNI}^{DIV} = 1.30$$

$$RR_{MNI}^{UNDIV} = 0.70$$

The majority of roads in this data group have poles on both 'house-sides' of the road. Divided roads generally have additional poles on the median strips, giving a higher pole density. Higher traffic volume results in greater site exposure, an effect which is already accounted for in the AADT relative risk. The corrections for each of these correlations involve a reduction of the relative risk associated with divided roads and an increase in undivided road relative risk. Although difficult to quantify accurately, consideration of typical site characteristics suggests that the pole density correction for the divided road relative risk is of the order 0.85. The difference in mean traffic flows leads to an AADT correction of 0.90. The resulting relative risk for both types of road is approximately unity. This dichotomous variable was therefore discarded as a useful predictor of risk. It is noted that for divided roads no difference in risk was detected between house-side poles and median strip poles. The question of higher risk for one side of the road or the other for two-way undivided roads is, of course, meaningless.

(o) The effect of the margin between pavement friction supply and demand

A cornering vehicle makes a 'demand' for lateral friction forces. The extent to which the 'demands' made by most drivers approach the 'available' skid resistance can be expected to contribute to the risk of an accident.

Figure 4.23 shows a plot of relative risk against 'friction margin' which is a crude measure of the differences between the available pavement friction and the maximum side friction requirement. The side friction requirements were calculated from the posted speed of the curve (the legal speed limit or advisory speed sign value), superelevation or crossfall, and the maximum curvature upstream of the pole. The pendulum skid test provided the pavement friction estimate. On straight roads, the friction margin simply represents the difference between the skid resistance and the friction necessary to overcome the normal crossfall of the road. It was thought that this composite variable might be more closely related to the mechanism of vehicle control failures than curvature and skid resistance by themselves. Figure 4.23 shows that skid margin does indeed discriminate strongly between poles in terms of relative risk.

If friction margin were to be used as a predictor variable in the final model, its relative risk would have to replace the relative risks associated with the individual variables used in its calculation.

(p) Summary of predictor variables retained for model

The variables surviving the analyses described above and considered for inclusion in the final predictor model are :

(i) Maximum curvature
(ii) Annual average daily traffic
(iii) Pendulum skid test
(iv) Pole lateral offset

continued -

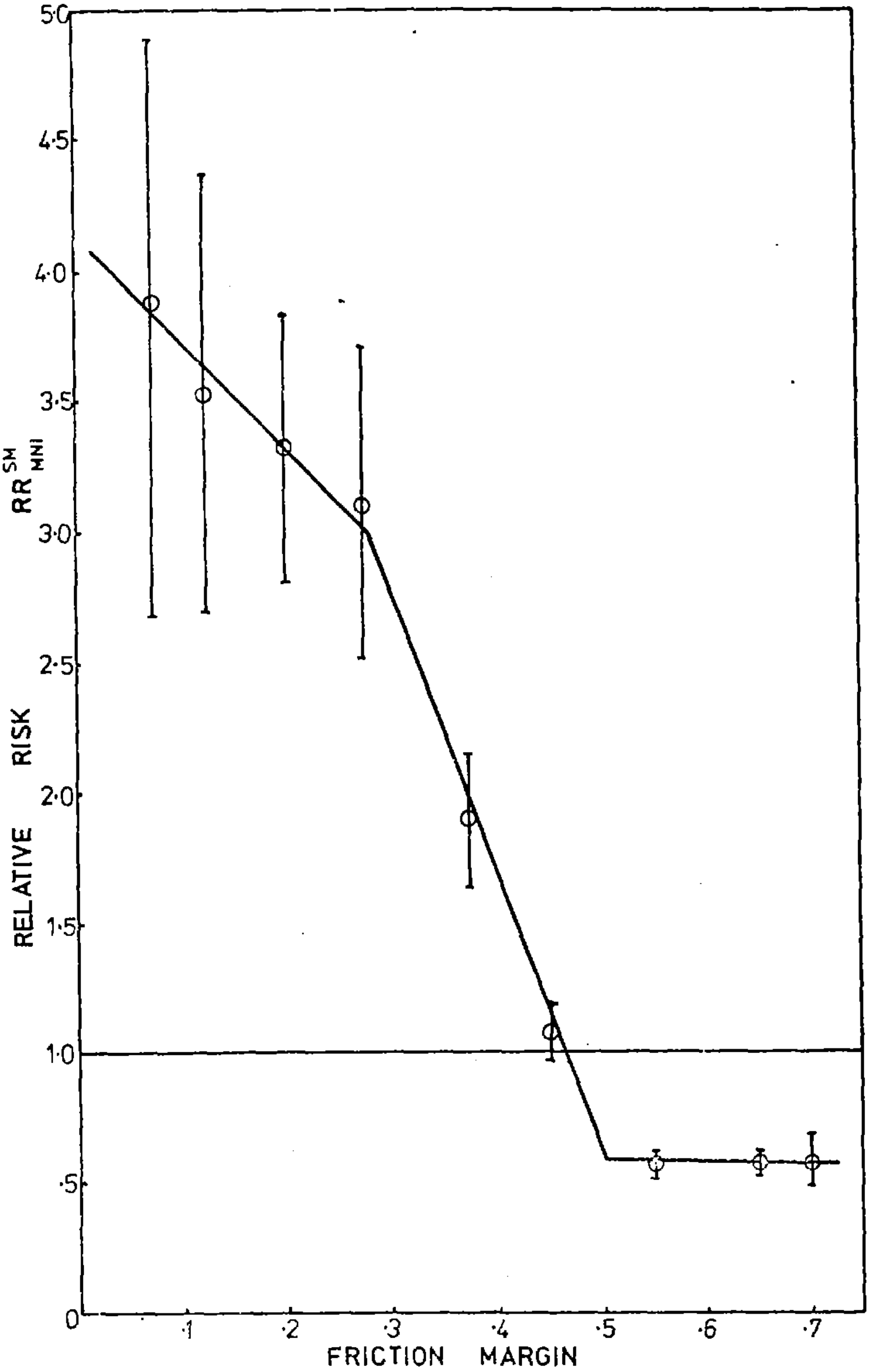


Figure 4.23. Relative risk versus side friction margin - MNI data group

(v) Distance between curbs - undivided roads
(vi) Distance from curve start
(vii) Pavement deficiencies
(viii) Superelevation at the curve
(ix) Friction margin.
(x) Pole on inside or outside of the curve

(q) Risk factor and total relative risk

The graphs and tables presented thus far have described the relationship between relative risk and each of the individual site variables within the MNI data group. An overall relative risk for poles in this data group, which takes account of the simultaneous presence of all relevant site attributes can now be calculated. Provided the individual relative risks are mutually independent, this 'risk factor' (RF), as it is termed, is equal to the product of the individual relative risks. That is,

$$RF_{MNI} = \prod_{i} RR_{MNI}^{V_i}$$

where V_i represents an individual predictor variable. In other words, the risk factor for a particular pole is the product of the individual relative risks associated with its particular site characteristics, these being obtained from the relevant graphs and tables already presented. To calculate the overall or total relative risk for a particular pole, its risk factor must be multiplied by the relative risk associated with the pole being a member of the MNI data group. The derivation of the 'between groups' relative risks, and the total relative risk, is presented in Section 4.3.

(r) Selection of the best model

The risk factor calculated for each pole is a composite representation of the characteristics of the site, and its value can be regarded as an attribute of the site, just as maximum curvature or skid resistance are attributes. The relative risk RR_{MNI}^{RF} associated with the attribute 'risk factor' can therefore be calculated from the accident and random samples, just as before, by assigning to each pole its RF value. This procedure formed the basis of the selection of the 'best' predictor model, as is described in the following paragraphs.

If the derived attribute RF - which purports to account for the relative risk of a pole - did so reliably, then it could be expected that the relative risk RR_{MNI}^{RF} calculated from the data for a given value of RF would be numerically equal to RF. That is, a plot of RR_{MNI}^{RF} against RF would ideally follow a 45° straight line through the origin. However, should two of the RRs contributing to RF be not independent (because of a correlation between the predictor variables, say), then the data would not 'support' the purported RF, and the plotted points would diverge from the ideal 45° line. Similarly it could be imagined that the simultaneous occurrence of many attributes which individually infer a high relative risk might not result in an actual relative risk which is simply the product of the component RRs : there may be a 'saturation' relative risk above which the addition of further hazardous characteristics does not materially affect an already high risk. At the other extreme, there could be a 'background' relative risk below which the presence of further low-risk characteristics would not decrease the probability of an accident.

To investigate these possibilities, and to aid the selection of a sensitive and reliable predictor model, relative risk plots were obtained for risk factors based on a number of alternative predictor variables. To illustrate, Figure 4.24 shows the relative risk associated with a risk factor based on the following variables.

(i) Maximum curvature
(ii) Annual average daily traffic
(iii) Pendulum skid test
(iv) Pole lateral offset
(v) Distance between curbs - undivided roads
(vi) Distance from curve start
(vii) Pavement deficiencies
(viii) Superelevation at curve
(ix) Pole on inside or outside of the curve

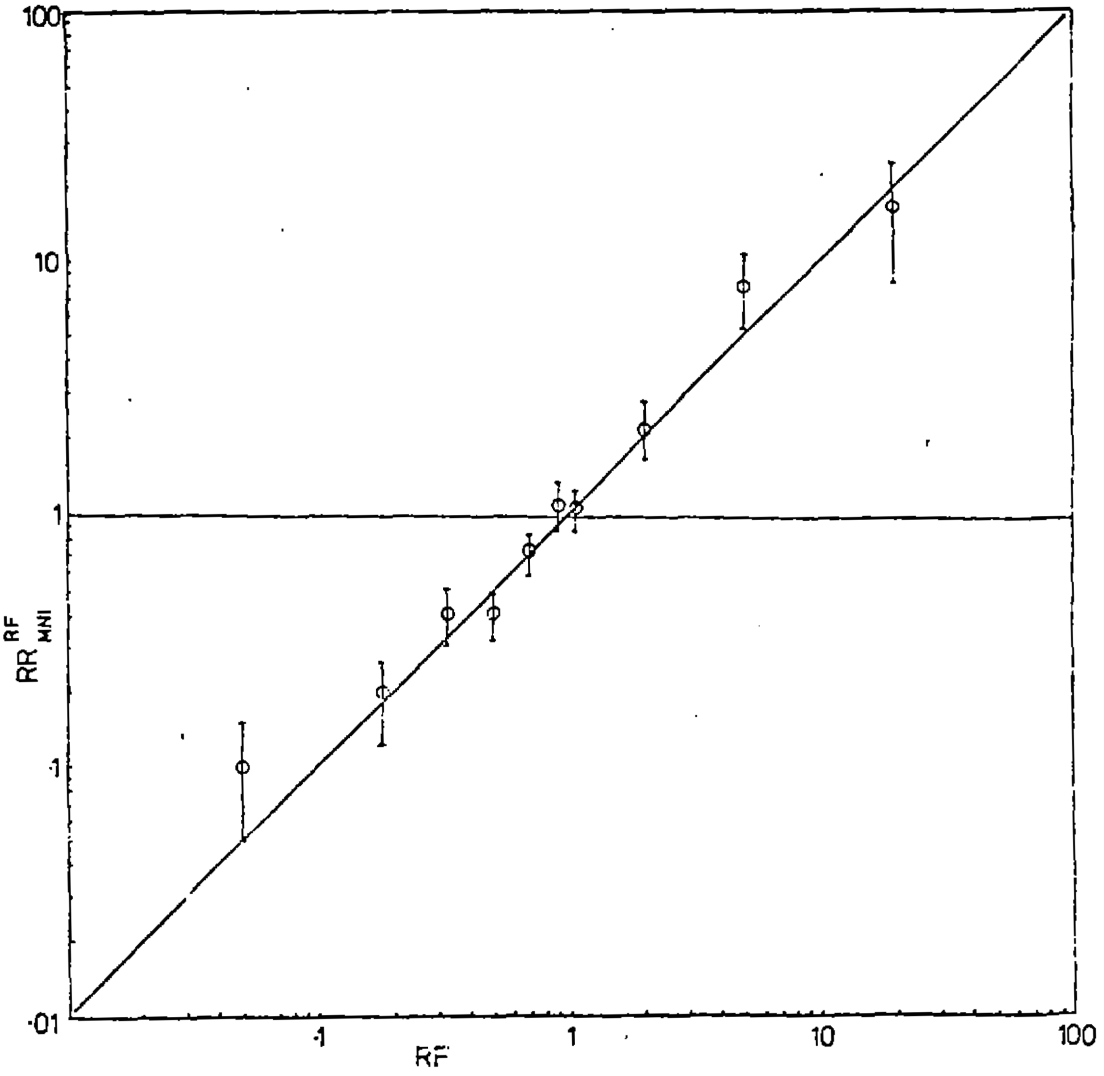


Figure 4.24.Relative risk versus risk factor calculated from apparently mutually independent RRs

To demonstrate the effect of the inclusion of individual relative risks that are not mutually independent in the model, Figure 4.25 shows the relative risks derived for a model which includes 'friction margin' in addition to the above variables. The calculation of friction margin makes use of curvature, superelevation and skid test, so that its addition provides a clear example of a model incorporating relative risks that are not independent of each other. As predicted, the RR^{RF}_{MNI} points diverge from the ideal 45° line, and follow a line with smaller slope. It can be seen that the largest RF is in excess of 100, but the maximum relative risk associated with this attribute is only 16.4. Thus, while this model produces a desirably wide range of risk factors, it clearly over-estimates the high relative risks, and is quite unsatisfactory.

The effect of each candidate predictor variable on the model was tested by successively removing the variables listed above from the model, one at a time, and plotting RR^{RF}_{MNI} as in Figure 4.24.

The criteria for selecting the 'best' model from these plots were :

(i) A wide range of relative risks associated with the risk factor is desirable, because this increases the discriminatory power of the model. This was quantified by the ratio of the maximum to minimum values of RR^{RF}_{MNI} obtained from the model.

(ii) The values of RR^{RF}_{MNI} should be numerically close to the corresponding RF value, because this means that the RFs accurately describe the relative risks of the poles. This was quantified by a measure analogous to the coefficient of determination (r^2) for a linear regression.

The calculation of r^2 differed from the conventional regression method in that the 'regression' line was fixed as $y = x$ (i.e., $RR^{RF}_{MNI} = RF$), and the contribution of each plotted point to the r^2 value was weighted according to the proportion of the data

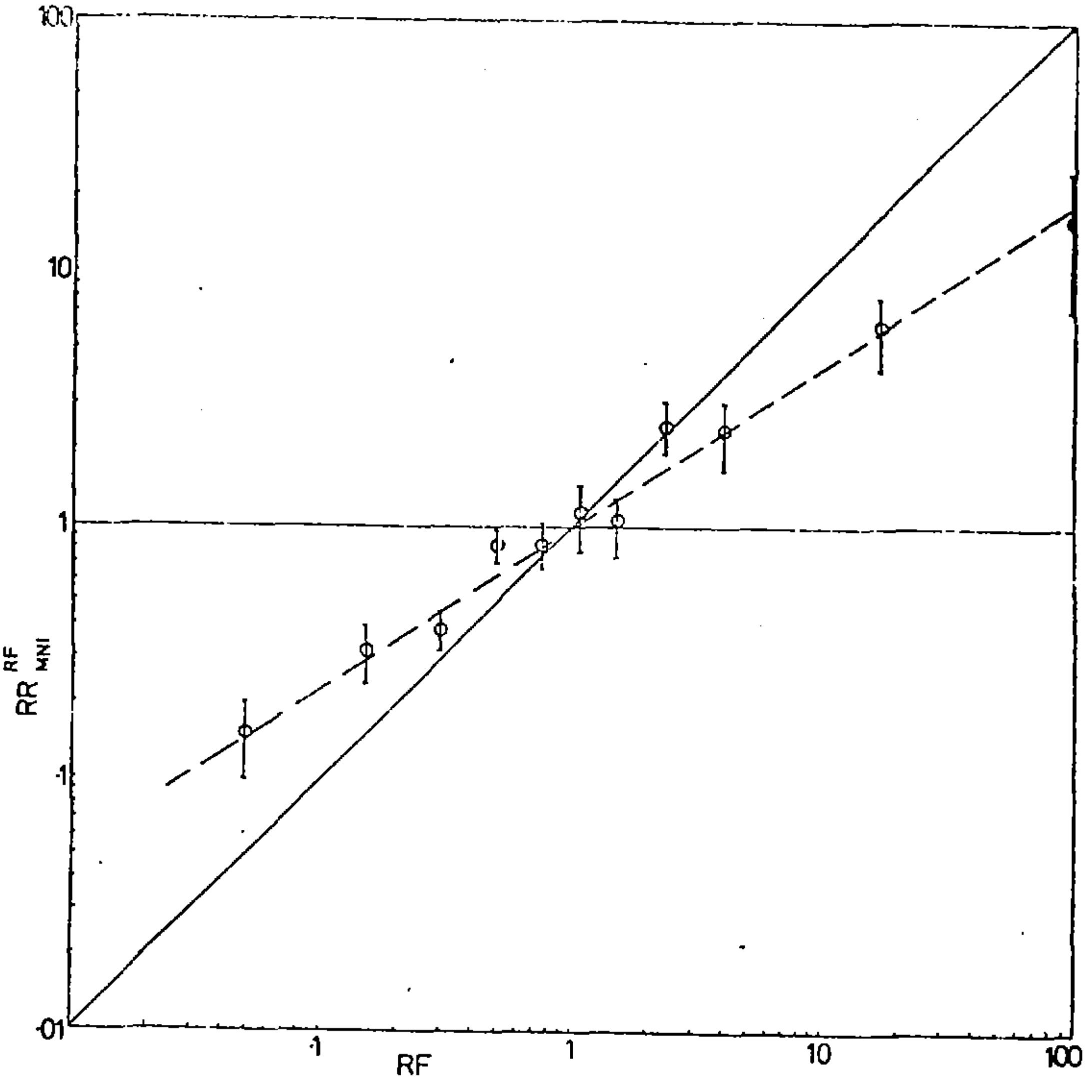


Figure 4.25. Relative risk versus risk factor calculated from non-mutually independent RRs

contributing to that estimate of relative risk.

The r^2 value for each graph was calculated as

$$r^2 = 1 - \frac{SS_{\text{about test line}}}{SS_{\text{about the mean}}}$$

where the sums of squares of deviations (denoted by 'SS') were defined as

$$SS_{\text{about test line}} = \sum_i p_i\ (y_i - \hat{y}_i)^2$$

and $$SS_{\text{about the mean}} = \sum_i p_i\ (y_i - \hat{y})^2$$

Thus, $$r^2 = 1 - \frac{\sum_i p_i\ (y_i - \hat{y}_i)^2}{\sum_i p_i\ y_i^2 - \bar{y}^2}$$

where p_i = proportion of data represented by the i th point

$\hat{y}_i$ = predicted value, from $RR^{RF}_{MNI} = RF_i$

y_i = observed value of RR^{RF}_{MNI} at RF_i

$\bar{y}$ = mean value of RR^{RF}_{MNI} .

An r^2 value of unity would mean that the model fitted the test line perfectly.

The addition of a variable to the model was considered favourable if it resulted in a greater relative risk range [RRR = max $(RR^{RF}_{MNI})/\min(RR^{RF}_{MNI})$], without decreasing r^2 'too much'. In order to incorporate these two criteria into one measure, an evaluation number (EN) was defined as the product of RRR and r^2 :

$$EN = r^2 \times RRR .$$

For example, from Figure 4.24 the following values were obtained :

$$r^2 = 0.96$$

$$RRR = 165.40$$

$$EN = 158.2 \quad .$$

On the other hand, Figure 4.25 gave the values :

$$r^2 = 0.60$$

$$RRR = 107.3$$

$$EN = 64.4 \quad .$$

The model represented by Figure 4.24 is clearly superior. Judgements concerning the retention or discarding of variables from the model were based on the value of EN for the relevant plot.

Figure 4.26 shows the test of the 'friction margin' model. In this model, the calculated friction margin is used as a predictor variable, replacing curvature, skid test, and superelevation. This model tracks the 45° line just as well as the 'curvature-skid test' model (Figure 4.24) but has a lower RRR . The two models are compared in Table 4.6 . It can be seen that the curvature-skid test model is more discriminating of relative risk than the friction margin model.

TABLE 4.6

COMPARISON OF THE 'CURVATURE-SKID TEST' MODEL AND THE 'FRICTION MARGIN' MODEL - MNI DATA GROUP

Model	RRR	r^2	EN
Curvature-skid test	165.4	0.96	158.2
Friction margin	93.6	0.95	88.9

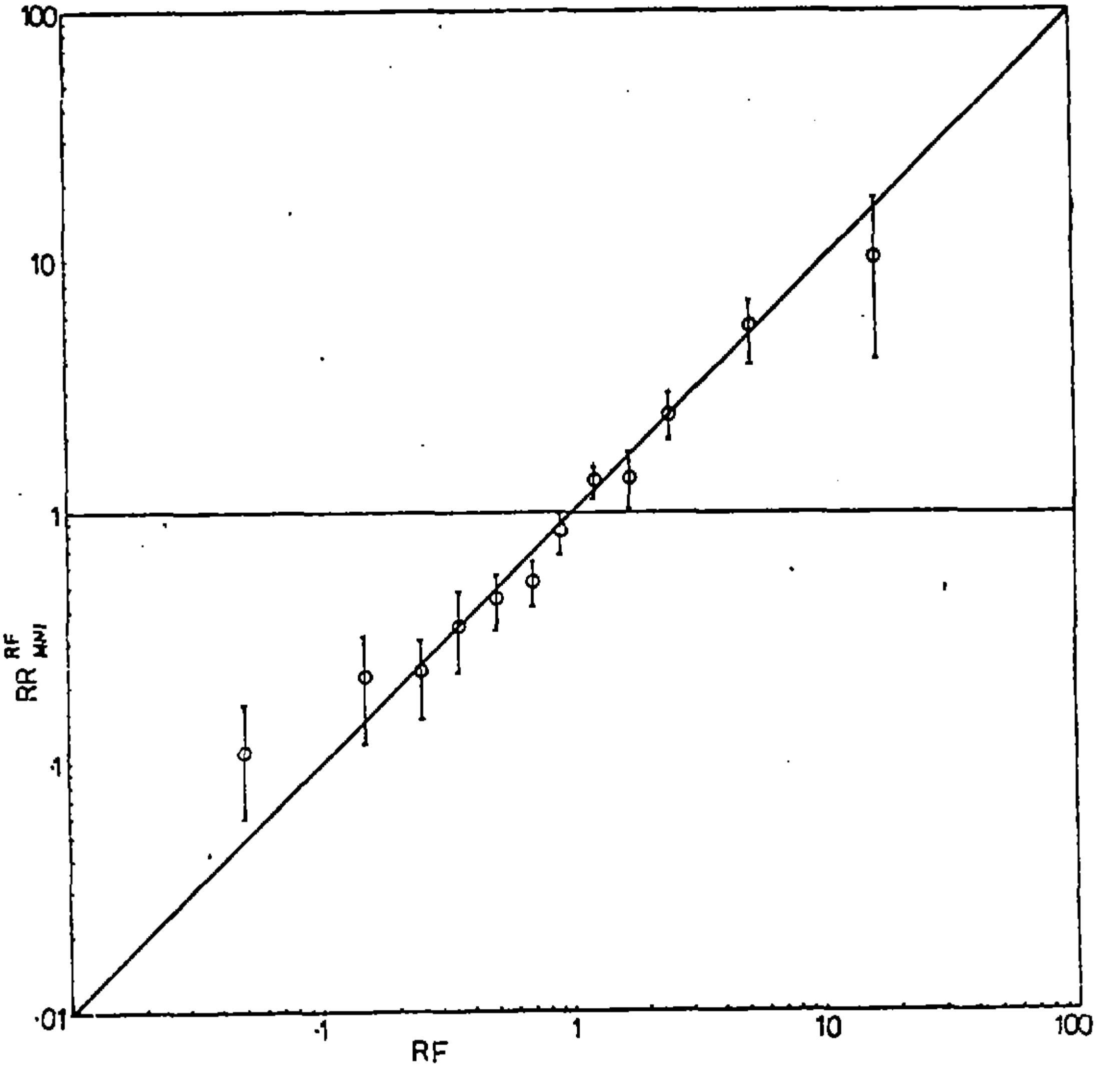


Figure 4.26.Relative risk versus risk factor calculated using the friction margin model

On the basis of the evaluation tests described, the recommended model for this data group includes the following predictor variables in the calculation of risk factor :

- (i) Maximum curvature
- (ii) Annual average daily traffic
- (iii) Pendulum skid test
- (iv) Pole lateral offset
- (v) Distance between curbs - undivided roads
- (vi) Location of pole with respect to the curve start
- (vii) Pavement deficiencies
- (viii) Superelevation at the curve.
- (ix) Pole on inside or outside of the curve.

(s) Cumulative distributions of risk factor

The cumulative distributions of risk factor for both the accident and random samples, within the MNI data group, are presented in Figure 4.27. There is a marked difference between the two distributions : for example, only ten percent of the random sites have a risk factor higher than 1.5, compared with fifty percent of the accident sites.

The fact that the accident distribution is biased towards the higher risk factors demonstrates that the model has been able to detect and describe a non-random accident process. Figure 4.27 also further demonstrates the short-comings created by the size of the random sample : the highest risk factor observed in the random sample was only 10, compared with 70 in the accident sample. Clearly, both distributions should cover the same range of risk factors, as the accident sample is drawn from the total population of poles, which is supposedly represented by the random sample. However, such a discrepancy is to be expected, given the existence of discernible risk differences between poles, when it is remembered that :

- (i) The number of poles with high risk factors in the total population is likely to be small, and therefore the chances of selecting even one of them in a random sample of 800 from a population of 600,000 poles are extremely slim.

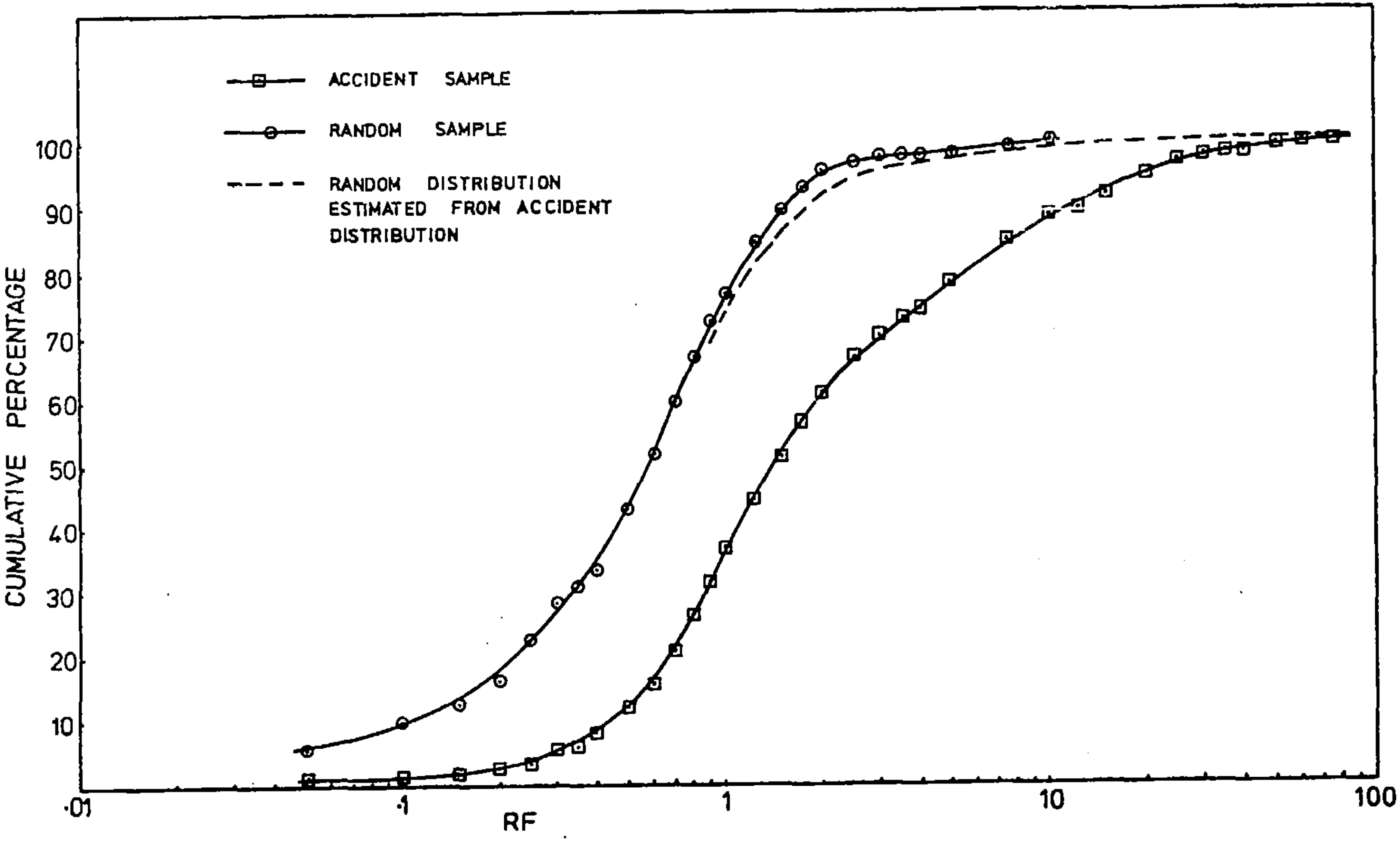


Figure 4.27. Cumulative percentage distributions of the accident and random samples - MNI data group

(ii) The high risk factor poles are the poles most likely to be represented in the accident sample, further adding to the difference in 'coverage' of high risk factors in the two samples.

Information is needed about the numbers of high risk factor poles in the population, however, if cost-benefit assessments are to be made of measures involving treatment of these poles. An estimate of the distribution of RF for the random sample can be derived from the distribution of RF for the accident sample. If the RFs for the accident sample are divided into cells, then the proportion of random poles expected in each cell is approximately equal to the proportion of accident poles divided by the value of RF at the midpoint of the cell. Thus, a predicted cumulative distribution for the random sample, which covers the same range of RF as the accident sample, can be generated.

Note that this process does not introduce new information, being simply a further test of the mutual independence of the individual relative risks, but it provides a better estimate of the proportion of poles with an RF higher than unity. The predicted random distribution for the RF values greater than unity is plotted on Figure 4.27. It predicts that approximately .6 percent of poles in the population of MNI poles have an RF of 10 or higher. This 'corrected' curve will be used in subsequent cost-benefit calculations, particularly when estimates of the number of poles requiring treatment to achieve a given level of accident reduction are required.

(t) Analysis of remaining data groups

The sections which follow present the derivation of the predictor models for the remaining data groups:

(i) Minor road non-intersection (MINI)
(ii) Intersection of major roads (MJMJ)
(iii) Intersection of major and minor roads (MJMI)

It can be seen that the MINI group (intersection of minor roads) is not included in the list of models to be derived. It was found that lack of data for this group made the derivation of a predictor model impossible. This omission is not too serious, however, as it will be found that poles in this group have the lowest relative risk of all the data groups, so that a cost-effective treatment method is an unlikely possibility.

As the remaining analyses follow the procedures already described in this section, only departures from the MNI group method and results will be discussed in detail.

4.2.5 Derivation of the Minor Road Non-Intersection (MINI) Data Group Model

(a) Predictor variables and their relative risks

As AADT data was not available for this road class, and as there were no correlations between the primary variables and pole density, the MINI model derivation was greatly simplified. The number of accidents that occurred on this road class was relatively small, so that the total data base for this group is correspondingly small. This fact will be reflected in the size of the 'confidence' intervals for the estimates of relative risk presented.

The predictor variables finally selected for the MINI model (by the same evaluation process described for the MNI data group) are :

(i) Absolute maximum curvature
(ii) Grade
(iii) Pendulum skid test
(iv) Lateral offset
(v) Road width
(vi) Location of the pole on the inside or the outside of the bend.

Figures 4.28 through 4.32 are the relative risk plots for curvature, grade, skid test, lateral offset and road width respectively. Table 4.7 presents the relative risks for poles on the inside and outside of curves.

TABLE 4.7

RELATIVE RISK VERSUS LOCATION OF POLE ON A CURVE -
MINI DATA GROUP

Position of Pole	RR	S.D.
Inside of curve	1.25	0.40
Outside of curve	0.70	0.25

(b) Discussion

The results for this group show the same trends as for the major road non-intersection group. Absolute maximum curvature remained a strong variable, although the range of relative risk was lower than for the major roads. The distribution of curvature on minor or residential roads is biased towards sharper curves compared with the distribution on major roads, thus reducing the relative risk (*within* this data group) for high curvature sites. The presence of more sharp curves on minor roads will be reflected in the relative risk associated with this data group (derived in Section 4.3).

In contrast to the major road result, grade proved to have a significant effect on accident occurrence for the minor roads, with downhill sites having the higher relative risk (Figure 4.29). The distinction between 'uphill' and 'downhill' depends, of course, on the direction of travel. For the accident sample there was no ambiguity about this; for sites in the random sample the direction was assigned randomly. When a pole is being investigated for its accident potential, however, it must be regarded as being exposed to both downhill and uphill traffic. Thus, the increase in hazard for downhill traffic is balanced by a reduction

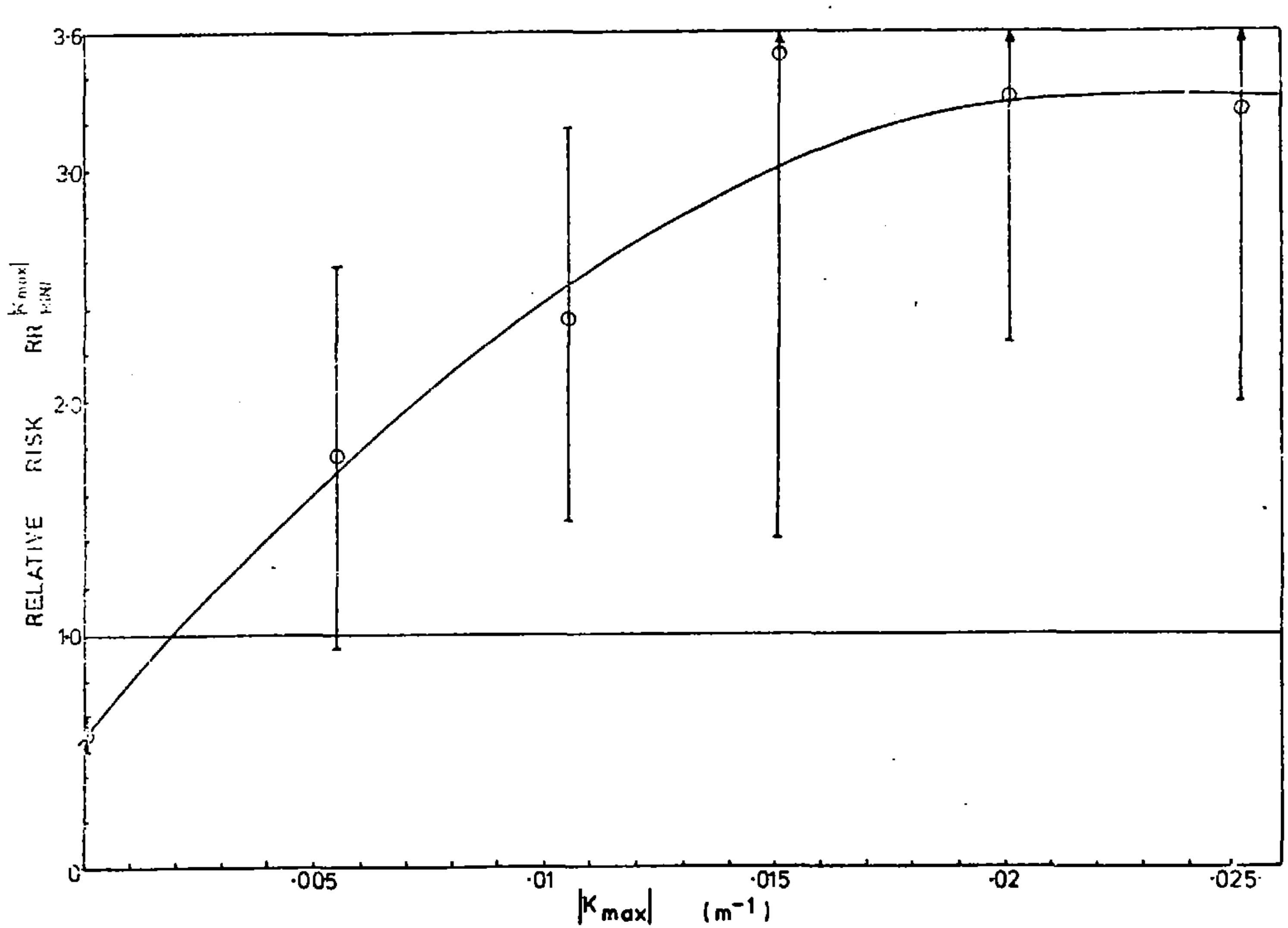


Figure 4.28. Relative risk versus absolute maximum curvature upstream of the pole - MINI data group

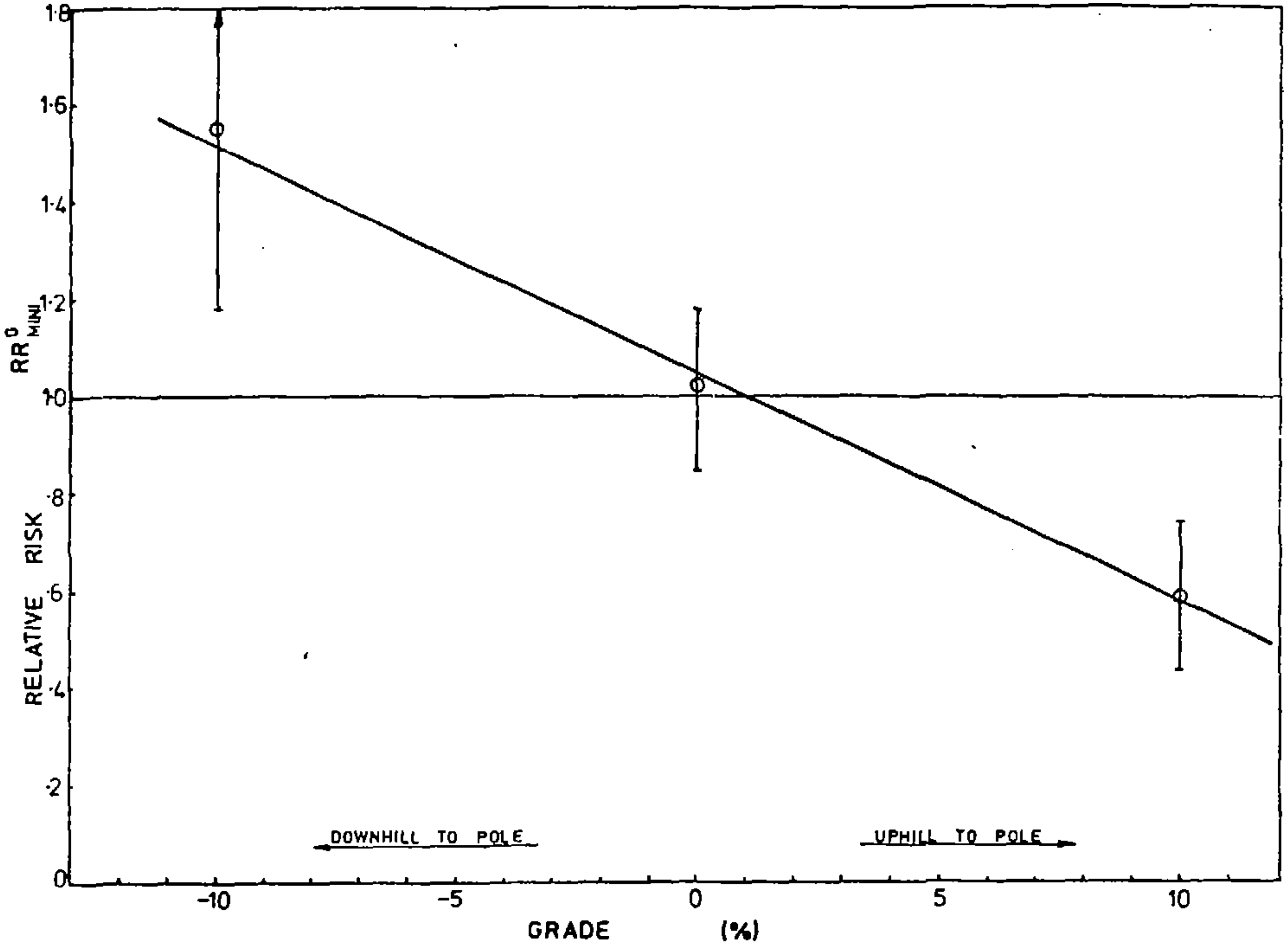


Figure 4.29. Relative risk versus grade 30m upstream of the pole - MINI data group

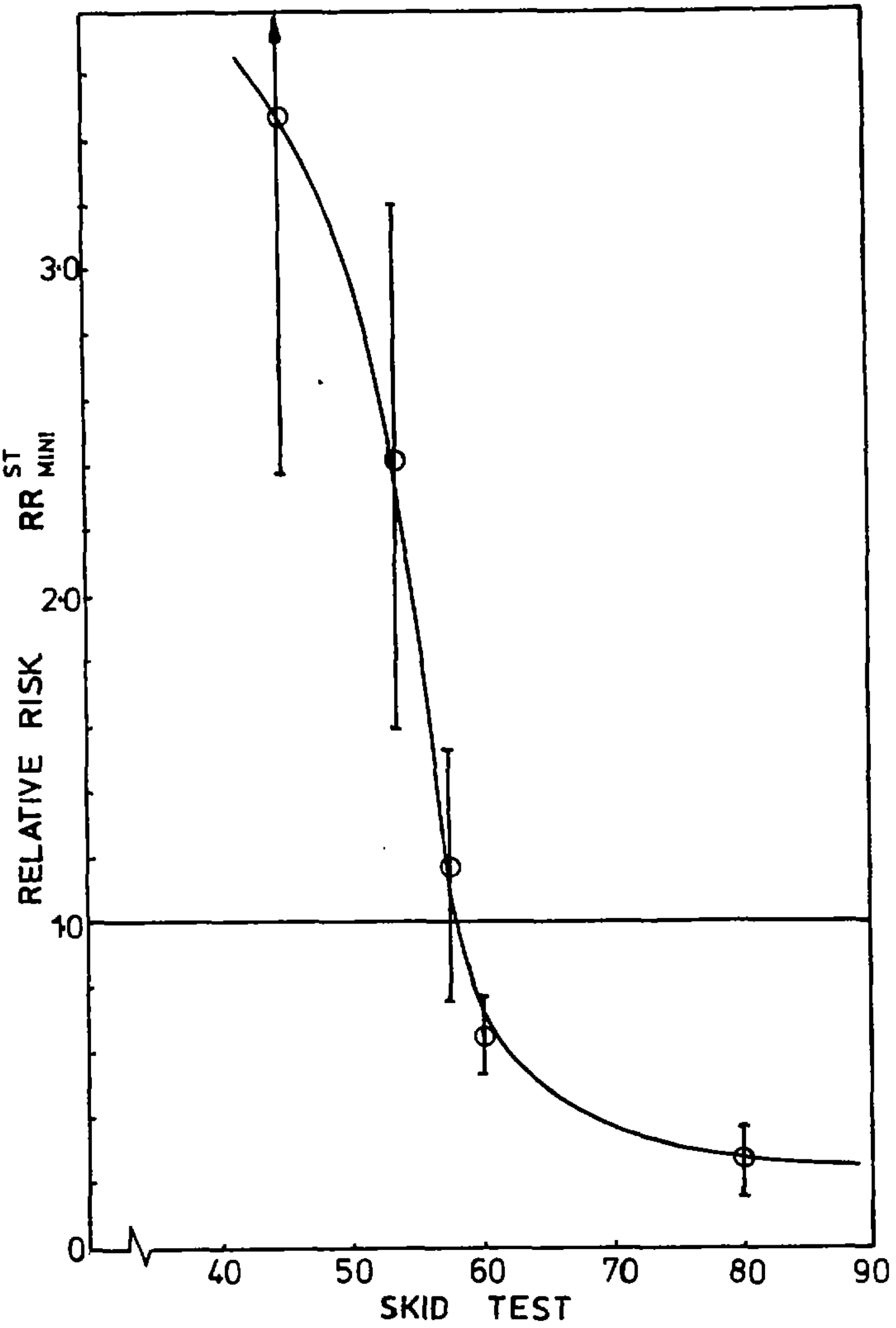


Figure 4.30.Relative risk versus skid test - MINI data group

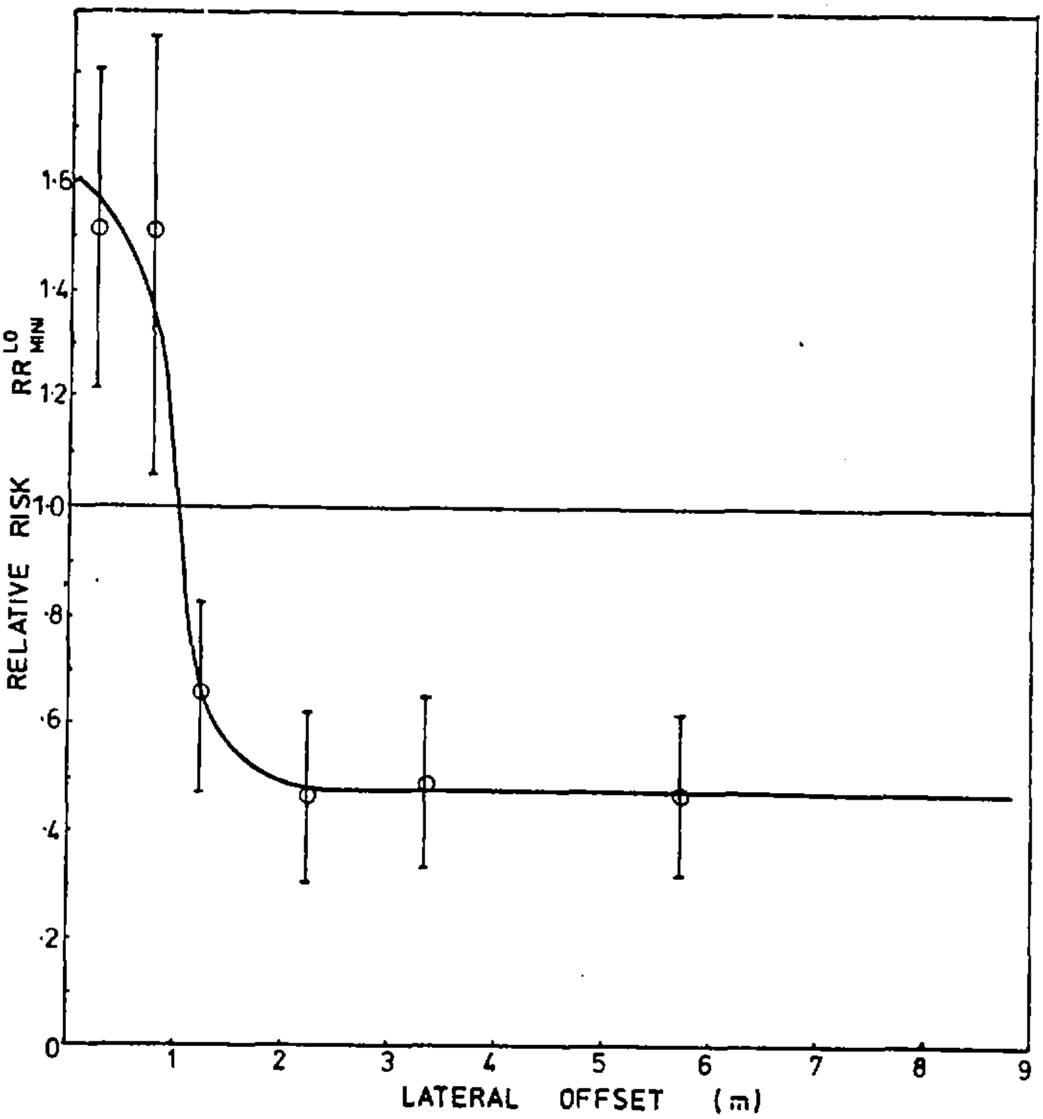


Figure 4.31. Relative risk versus pole lateral offset - MINI data group

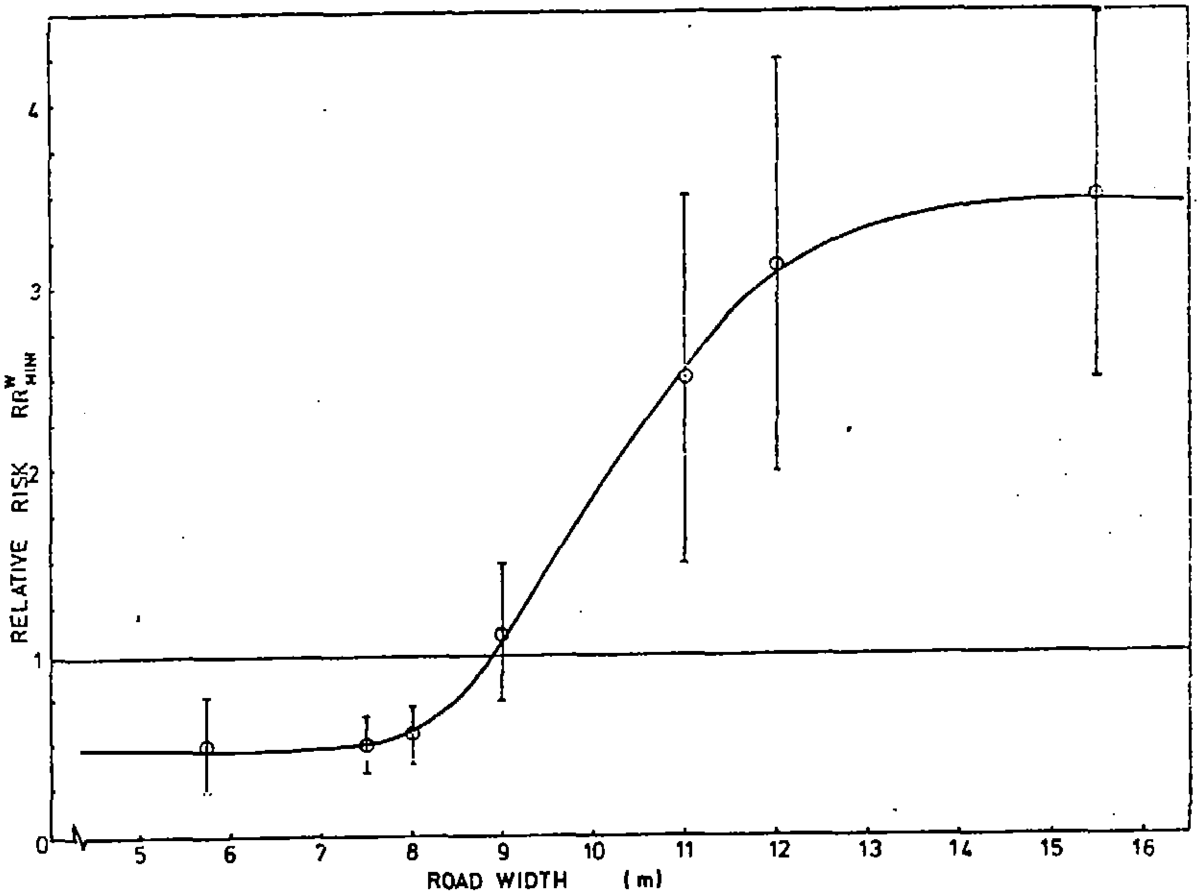


Figure 4.32. Relative risk versus road width - MINI data group

in risk for uphill traffic. Overall, therefore, the presence of grade does not contribute to an increase in accident numbers (unless, of course, the pole is at the top (bottom) of a hill and can only be approached in an uphill (downhill) direction!).

Skid test and lateral offset affect risk in the same way as on major roads, although the slope of the skid test relative risk plot is steeper for minor roads. The range of values of these two variables is lower for this road class, with the skid test results tending to be higher, and the poles closer to the edge of the road.

A further minor road result that was markedly different from that for major roads was the relative risk plot for road width (Figure 4.32). Road width was defined as the distance between curbs. As the great majority of roads in this data group were undivided, road width generally means total road width. The form of the curve is similar to the relative risk plot for AADT in the MNI data group (Figure 4.10), and is identical to the curve obtained for AADT in the intersection of major and minor roads data group (Figure 4.41). It is likely that minor road width and traffic volume are strongly correlated (as they are for major roads). Thus, in the absence of AADT data for this road class, road width seems to serve as a reasonable proxy for AADT.

Because of the similarity between the form of the relationships between relative risk and predictor variables in the major and minor non-intersection data groups, the possibility was considered that identical relationships might have been obtained if comparable levels of data had been obtained for the two groups. To check the sensitivity of the model to the particular relationships assumed, relative risks for MINI poles were found as a function of risk factors based on both the present MINI results and the MNI results of Section 4.2.4. Both model tests are plotted in Figure 4.33. The plot indicates that the better model is the one derived from the minor road data, and it is recommended that this model be used for such cases.

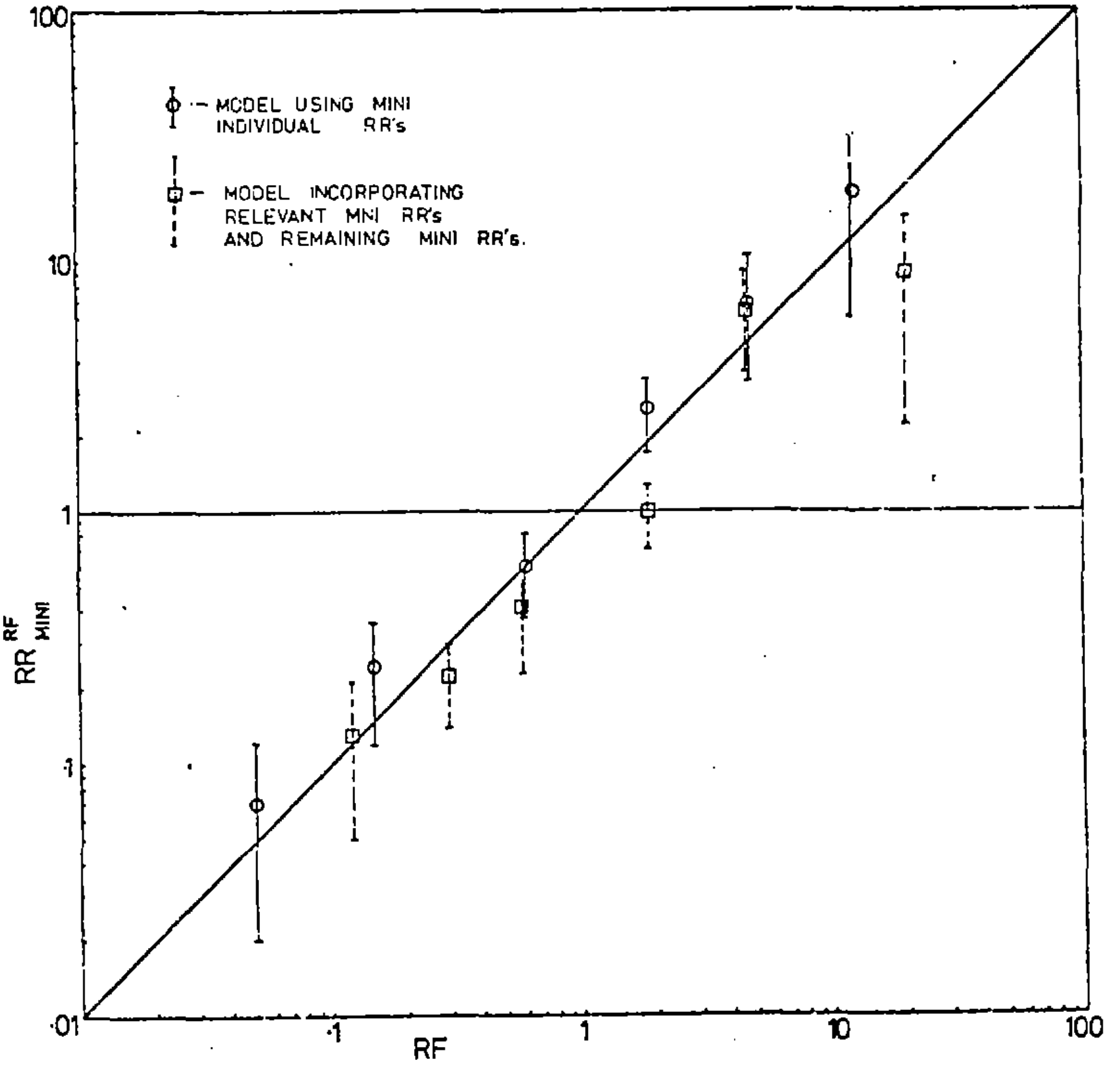


Figure 4.33.Relative risk versus risk factor - MINI data group

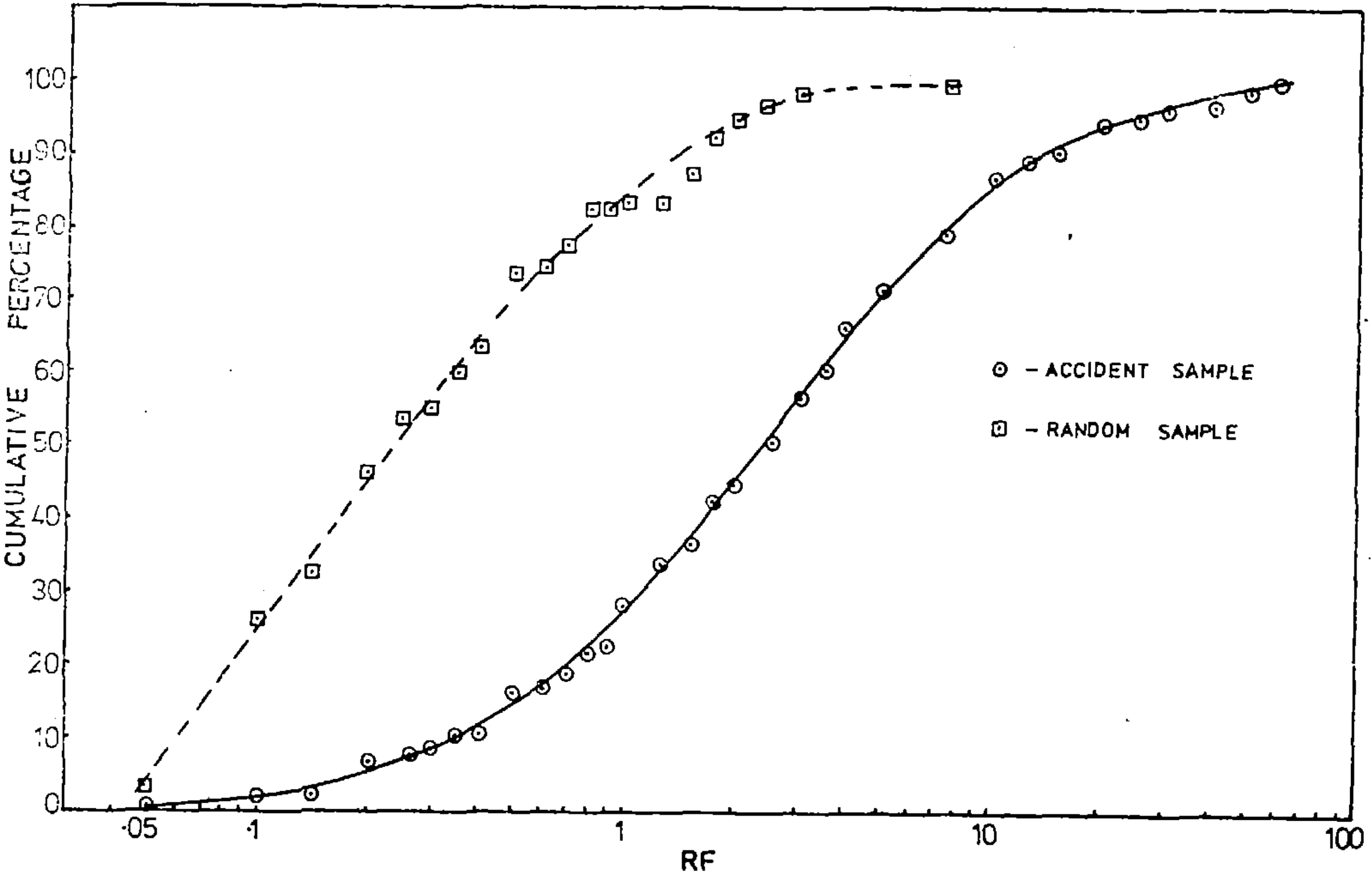


Figure 4.34. Cumulative percentage distribution of risk factor for the accident and random samples - MINI data group

The model for this group demonstrated an even greater level of discrimination between the accident and random samples, as shown in Figure 4.34 : ten percent of random sites have a risk factor of 1.4 or higher, compared with sixty-five percent of the accident sample.

4.2.6 Derivation of the Major Roads Intersection (MJMJ) Data Group Model

(a) Significant variables

Throughout the derivation of the intersection models the following convention is adopted to distinguish between the two intersecting roads :

(i) Roadway 1 is taken to be the road along which the vehicle which struck the pole was travelling.

(ii) Roadway 3 is the intersecting roadway.

The analysis of the MJMJ data group was somewhat complicated by correlation between traffic volume, type of intersection control, pole density, and intersection type, and by the small sample size. The initial single variable significance tests and distribution plots indicated very few statistically significant variables. Those which emerged were :

(i) Intersecting roadway traffic
(ii) Intersection type
(iii) Type of traffic control
(iv) Intersection area
(v) Roadways divided/undivided.

(b) *The effects of skid test, AADT and lateral offset*

As was pointed out earlier, the outcome of the χ^2 independence test is influenced by the number of cases tested. Therefore, given the size of the MJMJ data group (131 accident cases and 130 random) it might be expected that some effects that are not as clearly defined as others, although of practical significance, will fail the test of statistical significance.

For example, the relative risk plots in Figures 4.35 - 4.37 for roadway 1 skid test, AADT, and pole lateral offset, show the same characteristics as their MNI counterparts, although the strength of the affects is somewhat reduced. Consistent with the statistical tests, the majority of relative risk points in the three graphs have 'confidence' intervals that overlap unity. Despite the apparent lack of 'strength', the relative risk plots have distinct and consistent trends and so were retained for the final model testing.

(c) The effect of grade

The grade of roadway 1 was also not statistically significant at the five percent level, but the relative risk plot demonstrated enough of an effect to be retained for the final model (Figure 4.38). It can be seen that downhill grades into the intersection have a higher relative risk than uphill grades, which in turn have a higher risk than the no-grade intersection approaches. The relative risk curves have been arbitrarily assigned a constant value outside the range of the data, equal to the relative risk of the outer points. This is likely to be a conservative assumption, since the trends shown within the range of the data probably continue for more extreme grades.

(d) The effect of divided versus undivided roads

One of the significant variables describing roadway 1 was whether it was divided or undivided. The density of poles at an intersection is affected by whether or not traffic lights are installed. To allow for this, the raw relative risks for divided/undivided were obtained controlling for the type of intersection traffic control (Table 4.8).

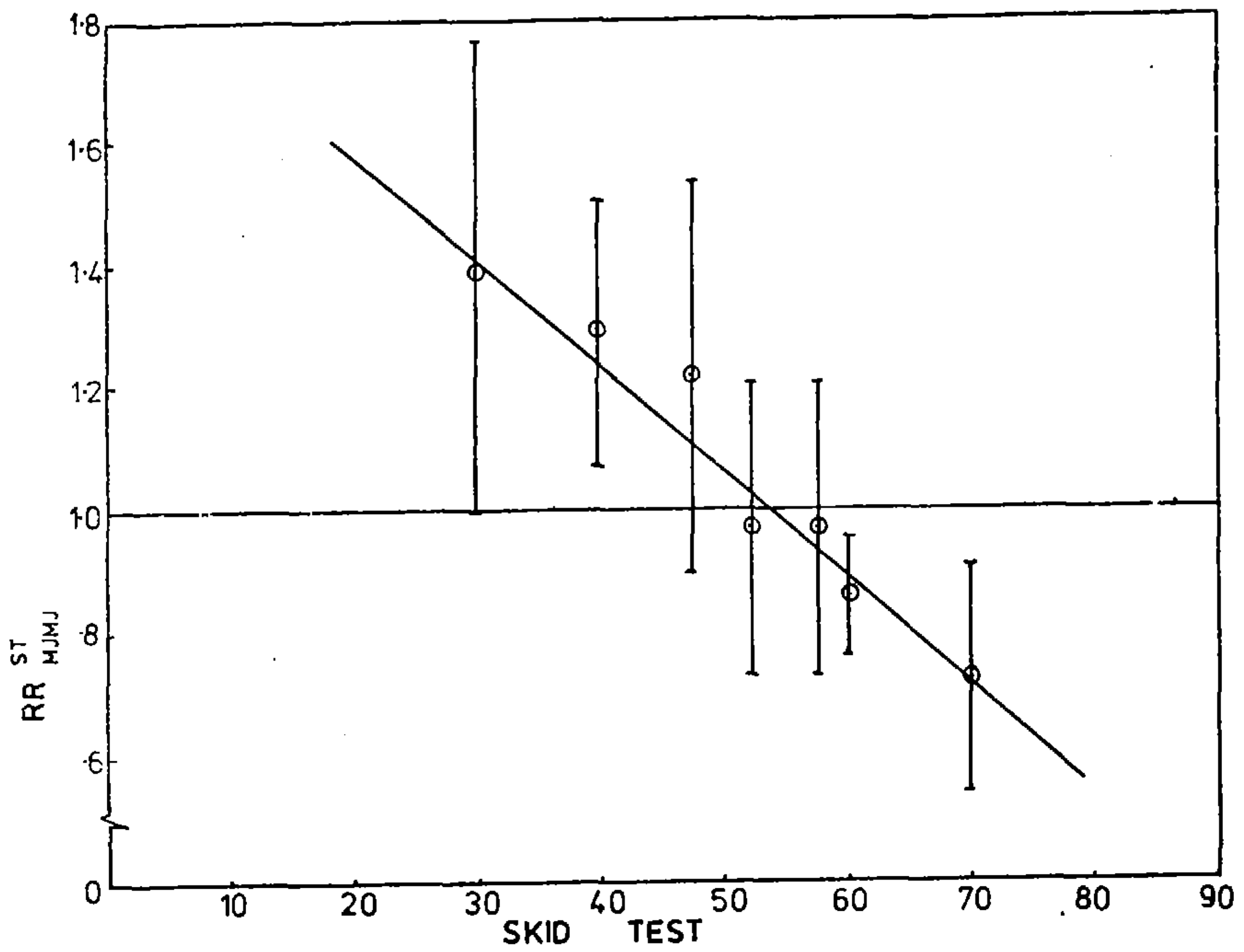


Figure 4.35. Relative risk versus skid test on roadway 1 - MJMJ (intersection) data group

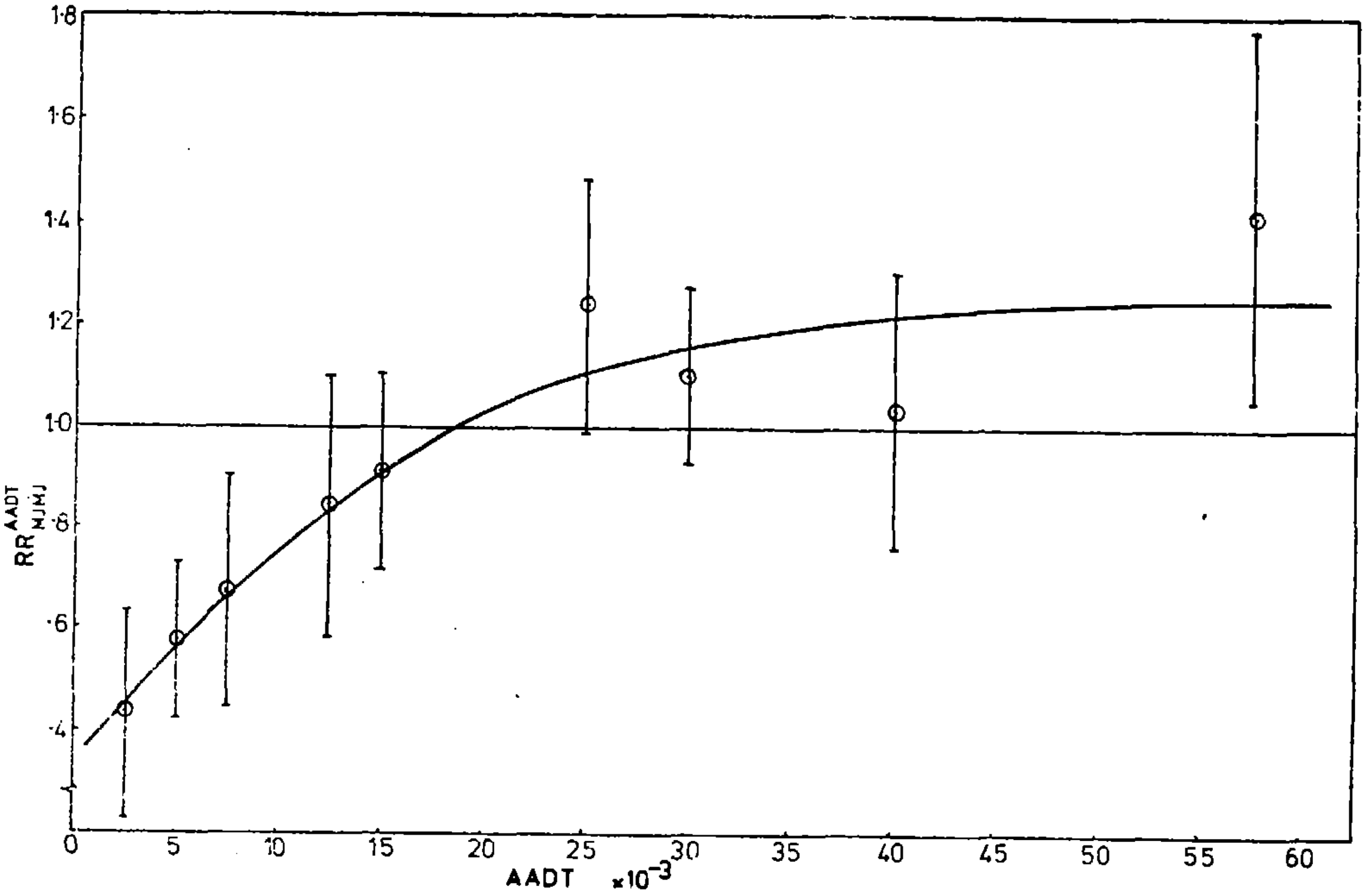


Figure 4.36. Relative risk versus AADT on roadway 1 - MJMJ data group

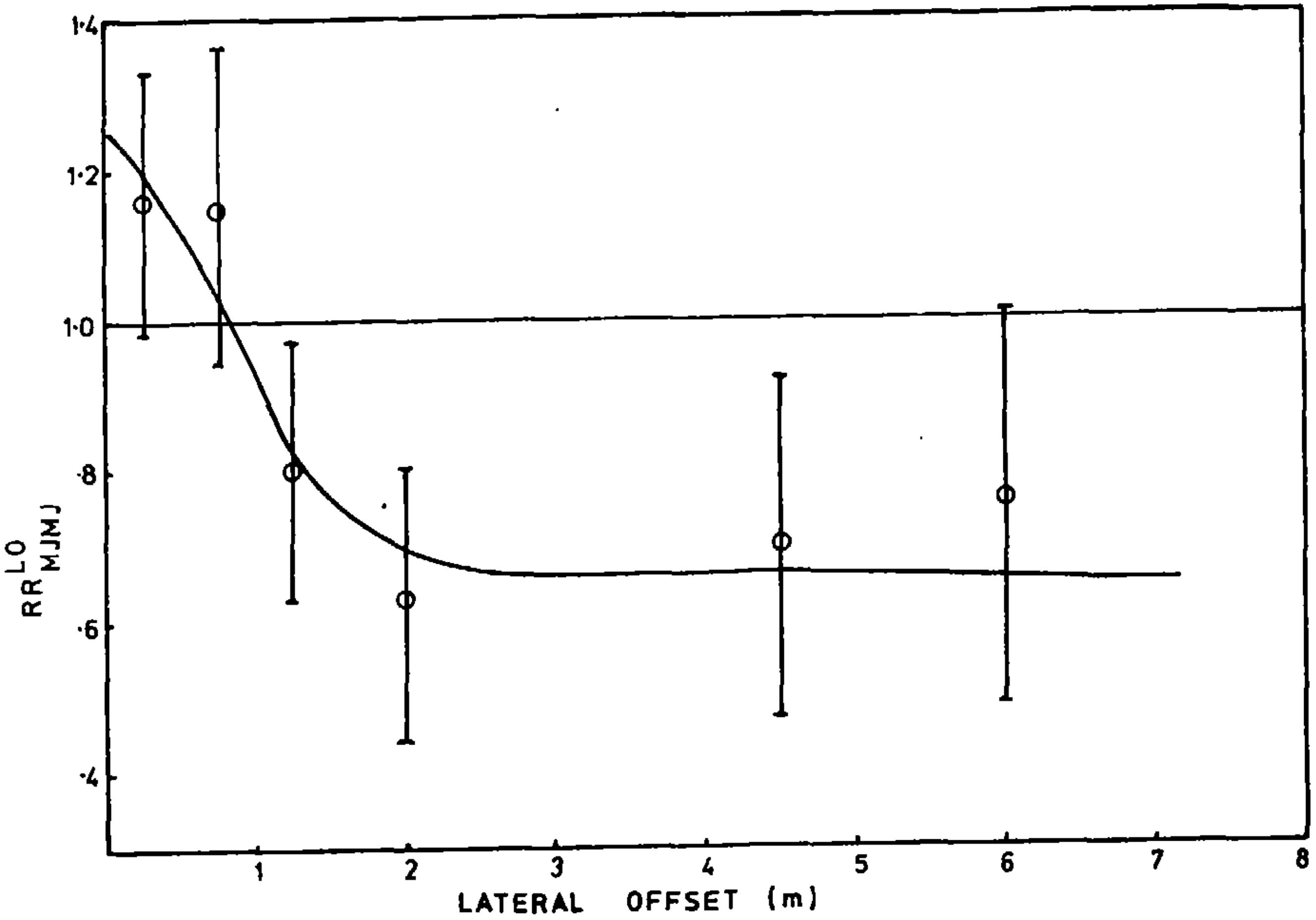


Figure 4.37. Relative risk versus pole lateral offset - MJMJ data group

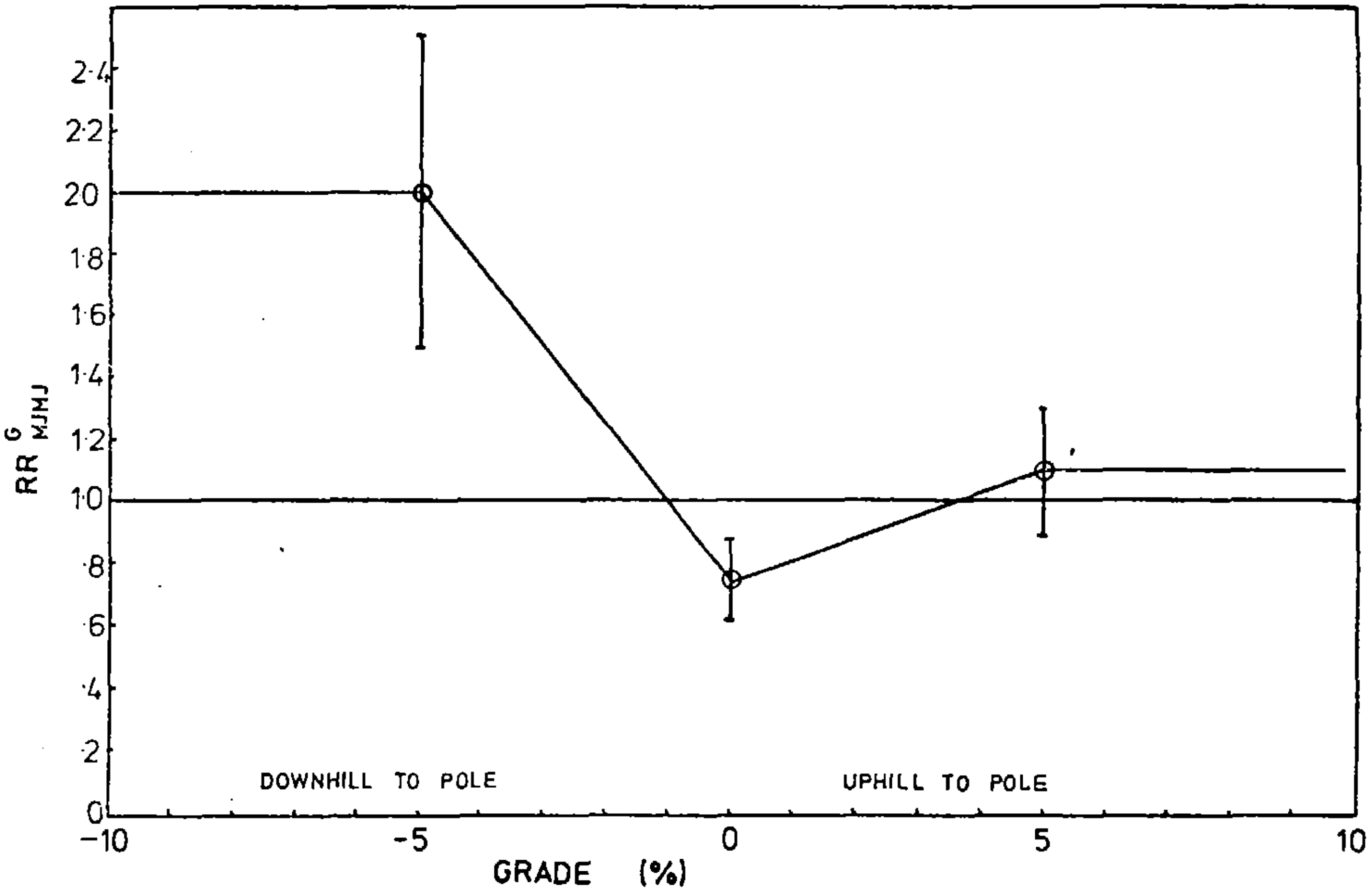


Figure 4.38. Relative risk versus grade of roadway 1, 30m before the intersection - MJMJ data group

TABLE 4.8

RAW RELATIVE RISK AGAINST ROADWAY 1 DIVIDED/UNDIVIDED, CONTROLLING FOR THE PRESENCE OF TRAFFIC LIGHTS

Roadway Divided/ Undivided	Control			
	Traffic Lights		Other	
	RR	SD	RR	SD
Divided	2.20	0.45	0.14	0.14
Undivided	0.51	0.08	1.43	0.15

As was discussed in the analysis of MNI data, divided roads are associated with a higher pole density and AADT than undivided roads. If the appropriate adjustments for these two factors are made, the final relative risks are as presented in Table 4.9.

TABLE 4.9

RELATIVE RISK (ADJUSTED FOR POLE DENSITY CORRELATIONS) AGAINST ROADWAY 1 DIVIDED/UNDIVIDED, CONTROLLING FOR THE PRESENCE OF TRAFFIC LIGHTS

Roadway Divided/ Undivided	Control			
	Traffic Lights		Other	
	RR	SD	RR	SD
Divided	1.45	0.30	0.11	0.11
Undivided	0.80	0.13	1.80	0.20

Because of the uncertainty associated with the correlations between pole density, traffic flow and roadway divided/undivided, and given the size of the RR standard deviations for the intersections controlled by traffic lights, it was decided that there was no real justification for adopting relative risks for intersections with traffic lights other than unity. The intersections not controlled by traffic lights, on the other hand, had more clearly defined relative risks which showed that undivided roads were associated with higher risk. The results for the intersecting roadway were almost identical, and were therefore set equal to those of roadway 1 (Table 4.10).

TABLE 4.10

VALUES ADOPTED FOR RELATIVE RISK (FOR BOTH INTERSECTING ROADWAYS) ASSOCIATED WITH DIVIDED/UNDIVIDED, CONTROLLING FOR THE PRESENCE OF TRAFFIC LIGHTS - MJMJ

	Control	
Roadway Divided/ Undivided	Traffic Lights	Other
Divided	1.00	0.11
Undivided	1.00	1.80

(e) The effect of traffic flows

The strongest predictor of risk in this data group was AADT on roadway 3 (the intersecting roadway) as shown in Figure 4.39. It is also interesting to note that this roadway was typically the lower traffic flow arm of the intersection. The finding that accident risk is more sensitive to the 'cross' flow than the 'through' flow, where the 'through' flow is defined as the higher AADT, is consistent with the results reported by Priest (1964) and Box and Associates (1970). A number of combinations of the traffic flows for the two arms of the intersection were investigated as candidate variables for the predictor model, but it was found that AADT for roadway 3 by itself was the strongest predictor (Table 4.11).

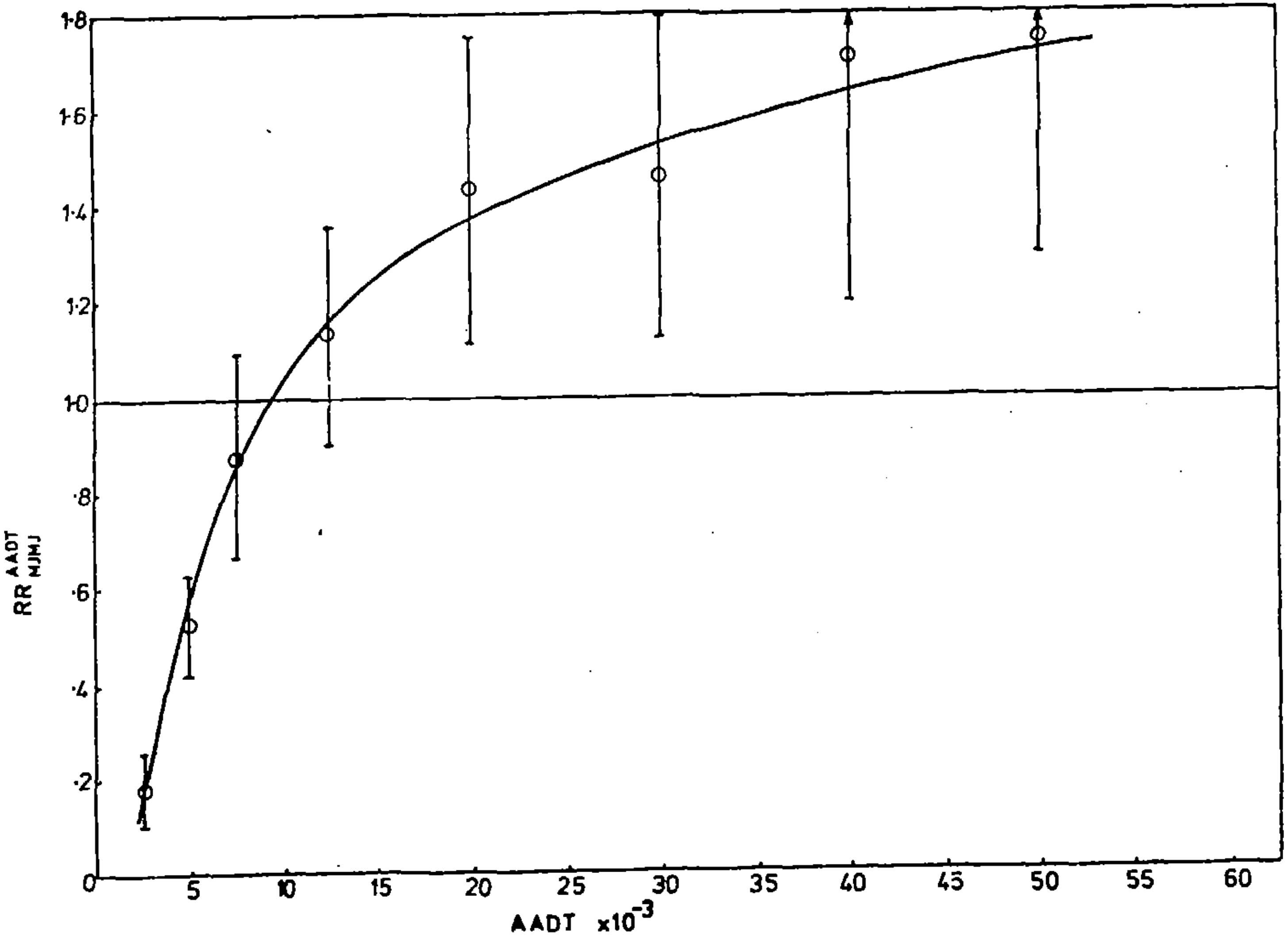


Figure 4.39. Relative risk versus AADT on the intersecting roadway - MJMJ data group

TABLE 4.11

χ^2 SIGNIFICANCE TESTS FOR VARIOUS COMBINATIONS OF INTERSECTING TRAFFIC FLOW VARIABLES - MJMJ

Variable Combination[1]	Probability that observed effect is due to chance variations
AADT 1	$P < 0.277$
AADT 3	$P < 0.008$**
AADT 1 + AADT 3	$P < 0.336$
$\sqrt{\text{AADT 1} \times \text{AADT 3}}$	$P < 0.014$
$\frac{\text{AADT 3}}{\text{AADT 1}}$	$P < 0.275$
$\frac{\text{AADT 1}}{\text{AADT 1} + \text{AADT 3}}$	$P < 0.203$

(1) AADT 1 - traffic volume roadway 1
AADT 3 - traffic volume roadway 3.

AADT and roadway divided/undivided, were the only two significant variables associated with roadway 3. Road width appeared initially as significant, but was correlated strongly with AADT , and so was discarded.

(f) The effects of intersection type, control and size

Variables describing the overall characteristics of the intersection that were statistically significant were

(i) Intersection type (+ or T)
(ii) Intersection traffic control
(iii) Intersection area.

Intersection type was divided into two broad categories for the analysis, namely 'cross' or 'tee'. Oblique 'crosses' and oblique 'tees' were included in the cross and tee categories respectively. There were very few cases which did not fall easily within this broad classification system.

It was found that cross intersections were more likely to have traffic light controls than tee intersections as has been pointed out already, the presence of traffic lights at an intersection is associated with both higher AADT and pole density, so the analysis of intersection type was carried out controlling for the presence of traffic lights as shown in Table 4.12.

Taking account of the 'confidence' intervals for the estimates of relative risk, it appears that when the intersection is controlled by traffic lights, there is no difference in risk between the cross and tee types. With less formal traffic controls, however, cross intersections appear more hazardous for pole accidents than tee intersections. The relative risks adopted for the MJMJ model are also shown in Table 4.12.

TABLE 4.12

RELATIVE RISKS FOR CROSS AND TEE INTERSECTIONS, CONTROLLING FOR PRESENCE OF TRAFFIC LIGHTS - MJMJ

Intersection Type	Type of Control			
	Traffic lights		No traffic lights	
	RR	SD	RR	SD
Cross	1.12 (1.0 adopted)	0.09	1.90 (1.9 adopted)	0.55
Tee	0.72 (1.0 adopted)	0.29	0.67 (0.7 adopted)	0.16

The type of intersection control (overhead traffic light, corner mounted traffic lights, METCON* and uncontrolled) was found to be correlated with traffic volume on both roadways, as well as affecting pole density. The 'raw' relative risks shown in Table 4.13 therefore need to be modified to take account of these two effects.

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*METCON - the name given to a system of assigning priorities at intersections in Melbourne by way of STOP and GIVE WAY signs and associated pavement markings.

TABLE 4.13

RAW RELATIVE RISKS ASSOCIATED WITH TYPE OF INTERSECTION CONTROL (MJMJ)

Type of Control	RR	SD
Traffic lights - overhead	2.09	0.44
Traffic lights - corner mounted	1.35	0.23
METCON	0.40	0.09
Give Way to right	0.98	0.48
Uncontrolled	0.20	0.11

The raw relative risks indicate that overhead traffic lights are the most 'dangerous' form of intersection control in terms of pole accidents. However this type of intersection control occurs typically at the intersection of divided roads, and is therefore also associated with high traffic flows. Conversely, intersections controlled by the 'give way to the right' rule and those that are uncontrolled are associated with lower pole densities and traffic volumes. Table 4.14 lists the pole density corrections used to modify the raw relative risks presented in Table 4.13.

TABLE 4.14

POLE DENSITY CORRECTION FACTOR BY TYPE OF INTERSECTION CONTROL

Type of Control	Correction Factor
Traffic lights - overhead	1.8
Traffic lights - corner mounted	1.2
METCON	0.7
Give way to right	0.6
Uncontrolled	0.5

The pole density correction factors were derived from the random survey, and are based on a mean pole density of 14.68 poles per intersection for this intersection class. The mean pole density was determined for each traffic control type and was divided by the overall pole density mean to give the correction factor. It should be noted that the data relating to both uncontrolled and 'give way to the right' intersections are scant; the correction factors associated with these two types are correspondingly less certain. To obtain relative risks adjusted for pole density, the data of Table 4.13 is divided by the appropriate correction factor. The results are displayed in Table 4.15.

TABLE 4.15

RELATIVE RISK ADJUSTED FOR POLE DENSITY BY TYPE OF INTERSECTION CONTROL (MJMJ DATA GROUP)

Type of Control	RR
Traffic lights - overhead	1.16
Traffic lights - corner mounted	1.13
METCON	0.57
Give way to the right	1.63
Uncontrolled	0.40

Apart from intersections controlled by the 'give way to the right' rule (for which few data are available) the ranking of the relative risks in Table 4.15 corresponds with the ranking of mean traffic volume associated with each control type. It appears that the relative risks associated with type of traffic control directly reflect the relative risk associated with AADT. It was therefore decided that, given this relationship, and the uncertainty associated with the pole density corrections, the relative risk for intersection control would be set to unity. It is emphasized that these results relate to pole accidents only. While it is generally accepted that the presence of traffic lights is associated with a reduced overall accident rate at intersections, this does not seem to be the case for pole accidents.

Intersection area was strongly correlated with the two traffic flows and was discarded as a predictor variable when the relative risks associated with it (controlling for traffic) were little different from unity.

In an attempt to quantify the 'zone of influence' of the intersection, the radial distance of the pole from the centre of the intersection was measured. It was thought that it might be possible to define a 'zone of higher risk' around the intersection, perhaps in the form of an annulus. The pole radii for the accident sample ranged from 5 m out to 70 m, the mean radius being 20 m. Unfortunately the selection of random poles was limited to a maximum radius of 40 m , thus limiting the range of the relative risk tests. However, for poles within this range, no significant effect of radial distance could be detected. Taking account of the intersection size did not alter this conclusion.

(g) Evaluation of MJMJ model

The final list of variables included in the model for this data group is as follows :

(i) Roadway 3 AADT
(ii) Roadway 1 AADT
(iii) Skid test, roadway 1
(iv) Grade, roadway 1
(v) Roadway 1 divided/undivided
(vi) Roadway 3 divided/undivided
(vii) Pole lateral offset
(viii) Intersection type.

Because the relative risks for so many of the variables have been adjusted for AADT and pole density effects, testing the complete model by means of a plot of RR^{RF}_{MJMJ} against 'risk factor' RF , and plots of the cumulative distributions of RF , is of little value.

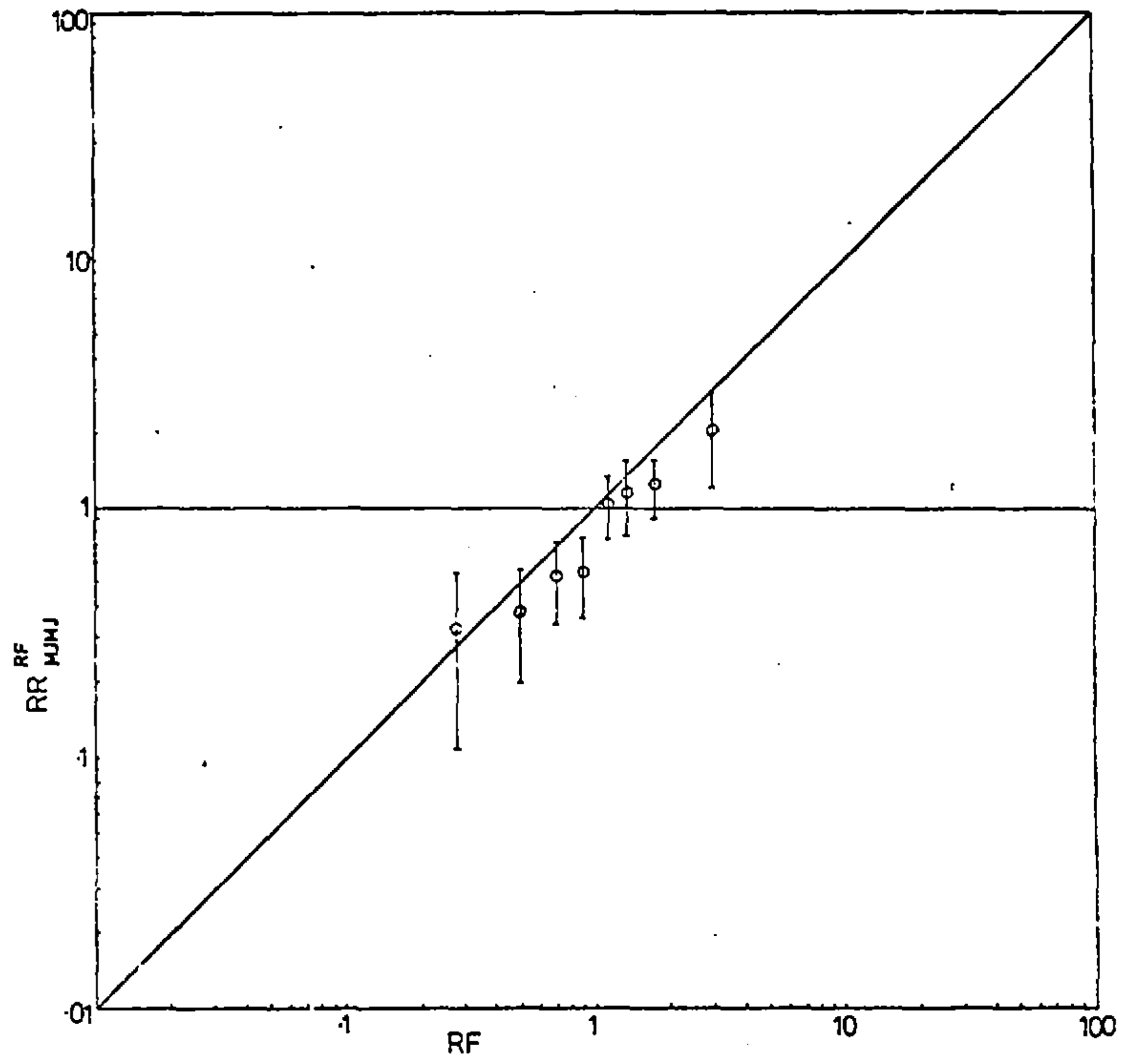

Figure 4.40. Relative risk versus risk factor for the simplified MJMJ data group model

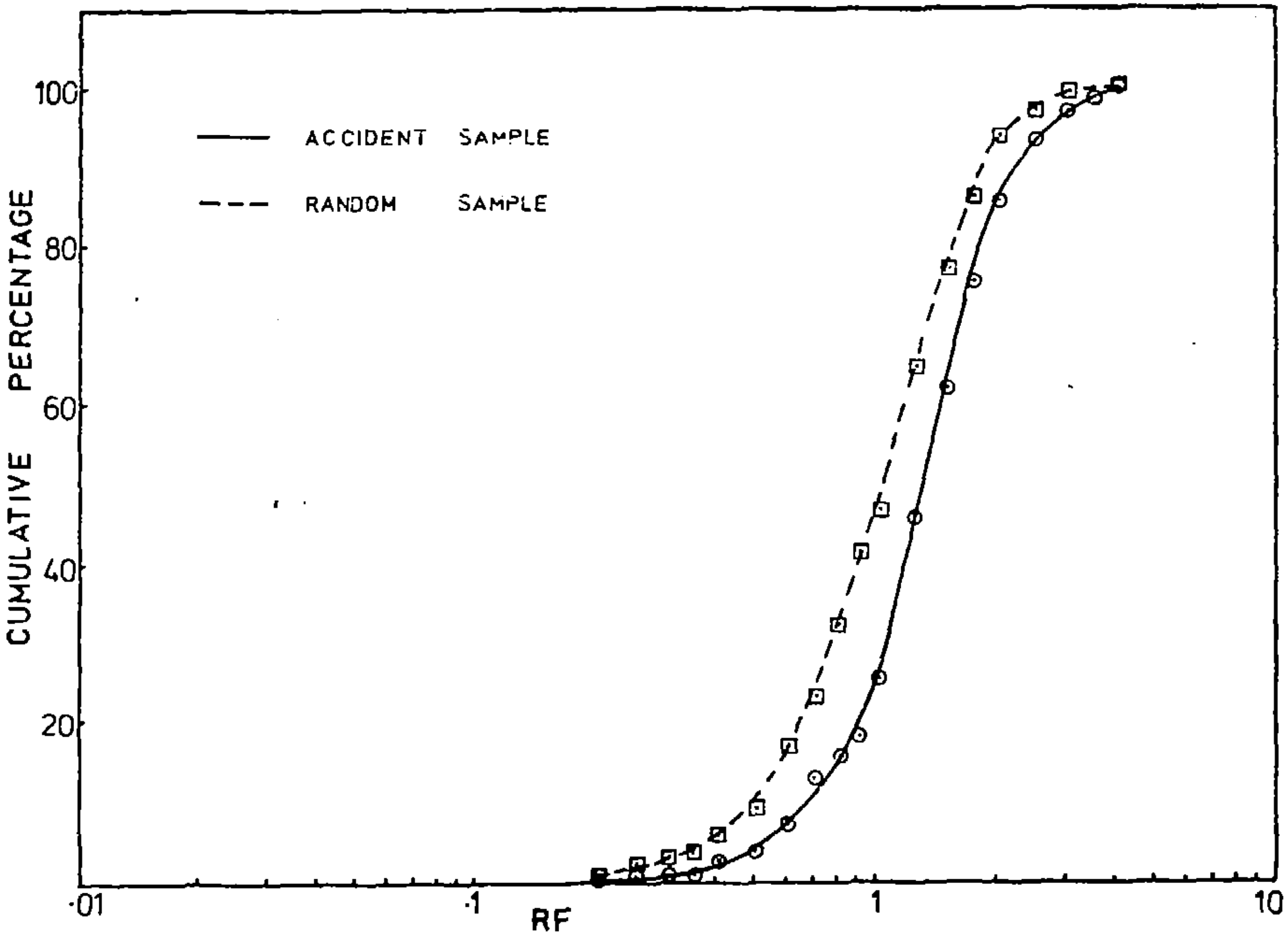

Figure 4.41. Cumulative distributions of RF for the random and accident samples - MJMJ data group

Whereas for the previously discussed data groups, the deficiency of the random sample in relation to pole density proved to be unimportant, for the MJMJ group it is fairly critical. Thus a test of a predictor model based on 'corrected' relative risks, using an 'uncorrected' random sample, would be meaningless. However, as a guide to the characteristics of the complete model, the tests were applied to a restricted model made up of only those variables not correlated with pole density, viz :

(i) Roadway 3 AADT
(ii) Roadway 1 AADT
(iii) Skid test, roadway 1
(iv) Grade, roadway 1
(v) Pole lateral offset.

The test results are presented in Figures 4.40 and 4.41. As expected the model produces a low risk factor range, and there is very little separation between the random and accident cumulative distributions of risk factor. No doubt this is due in part to the omission of the variables correlated with pole density. However, the initial statistical tests indicated that only one 'strong' predictor, roadway 3 AADT, existed for this data group.

Taken overall, the results indicate that, given that a pole is adjacent to an intersection of major roads, there is not a great deal that can be done to distinguish its accident risk from that of neighbouring poles. Certainly, more extensive investigations, using a larger and better structured random sample, would be required if variations in risk are to be discriminated more finely than with the present model.

4.2.7 Derivation of the Model for the Intersection of a Major and Minor Road. (MJMI Data Group)

(a) Introduction

As the majority of this class of intersection was not controlled by traffic lights, many of the analysis problems encountered with the MJMJ data group were not present for this model. It is noteworthy also that, although this data group is of comparable size to the MJMJ data group, it produced a greater number of significant predictors of risk, and therefore a model which is better able to identify poles which are at risk relative to other poles.

The variables included in the final model are as follows :

(i) AADT - roadway 1
(ii) Skid test - roadway 1
(iii) Lateral offset
(iv) Road width - roadway 3
(v) Roadway 1 divided/undivided
(vi) Grade - roadway 1
(vii) Radius of pole from intersection centre
(viii) Intersection type.

The random sample in this group was set up in a slightly different manner to the MJMJ random sample, in that the choice of which road to assign as roadway 1 or 3 was not made randomly. For the majority of accident cases in this group (90%), the vehicle which struck the pole entered the intersection on the major road. AADT data was not available for the minor road system. Thus, in order to have an equivalent level of random site data to investigate the effect of traffic flow in the major road, it was decided to always regard the major road as roadway 1 in the random sample.

(b) The effect of traffic flows

The form of the relative risk curve for AADT roadway 1 is similar to the previous results, with the (unweighted) risk levelling off at high levels of AADT (Figure 4.42). The curve is almost identical in form with the plot of relative risk associated with the width of the intersecting minor road, in Figure 4.45. As was conjectured in relation to the road width relative risk plot for minor non-intersection cases (Figure 4.32), it is probable that road width serves as a proxy for traffic flow, because of the strong correlation between these variables. Given the lack of

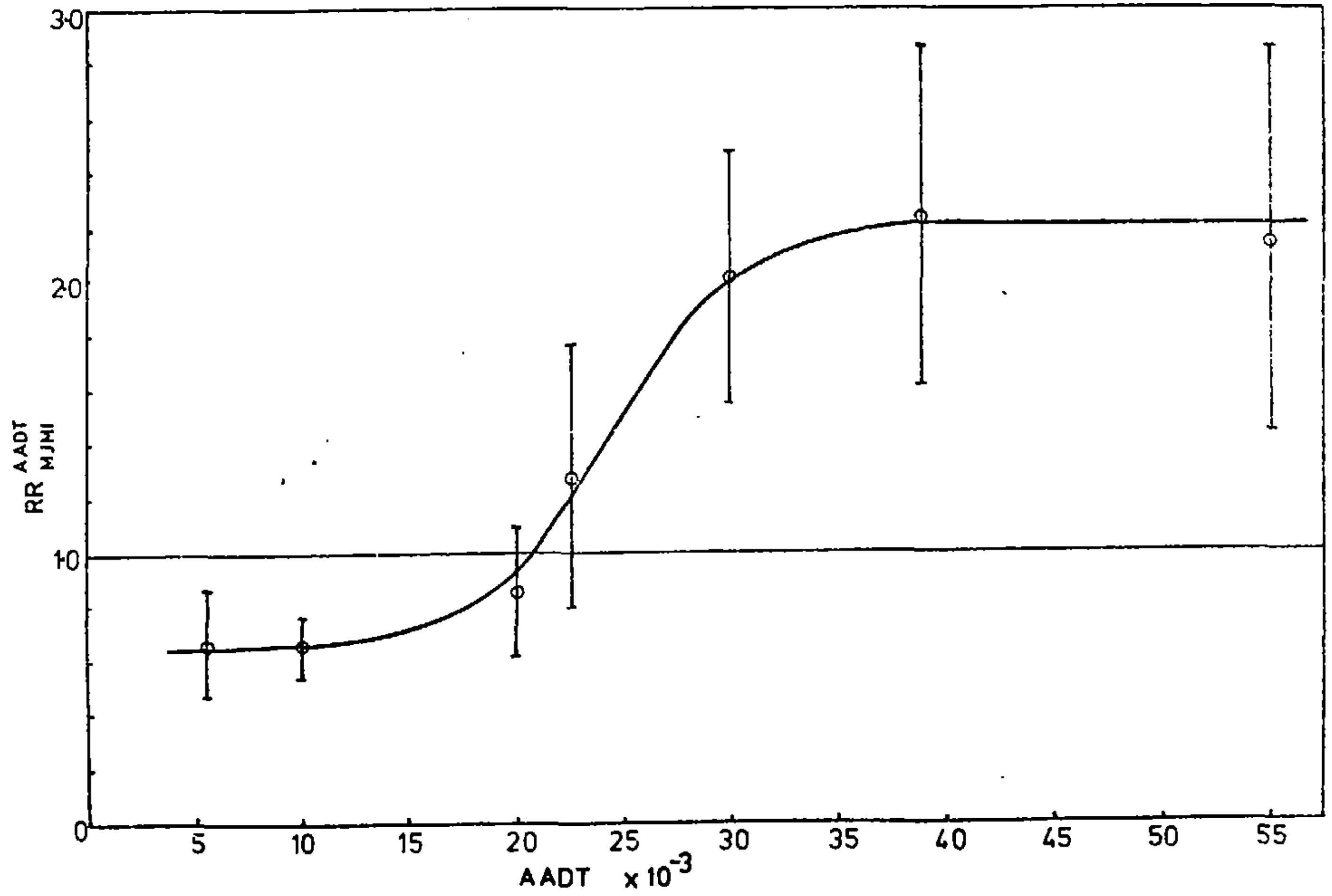

Figure 4.42. Relative risk versus AADT on the major road - MJMI data group

AADT data for minor roads, road width will be retained as a predictor variable in this proxy role.

(c) The effects of skid resistance, lateral offset and radial position

Figures 4.43 and 4.44 show relative risk plotted against skid test for roadway 1, and pole lateral offset, respectively. They are of similar form to the corresponding results obtained for the previous data group models : both graphs demonstrate a region of high return in terms of risk reduction, followed by a levelling off of risk. The only new significant variable which emerged for this data group was the radius of the pole from the centre of the intersection (Figure 4.45). The curve suggests that poles 20 m from the centre of the intersection have the highest relative risk. Poles either closer in or further out than 20 m have a progressively lower relative risk. This result seems reasonable, in that vehicles leaving the road as a result of evasive manoeuvres, secondary collisions or turning manoeuvres, are likely to do so just beyond the bounds of the intersection area.

(d) The effect of grade

Grade on the major road proved to be important, although the minor road grade was not. The results are similar to the MJMJ intersection results, with downhill grades into the intersection causing the greatest risk, followed by uphill grades and, least of all, no grade. (Figure 4.47)

(e) The effect of divided/undivided major roads

Divided major roads were found to be 'safer' for this intersection class, compared with undivided roads. Little effect was found for the minor roads, the great majority of which were undivided. Table 4.16 presents the appropriate relative risks which have been corrected to allow for correlation with pole density and AADT.

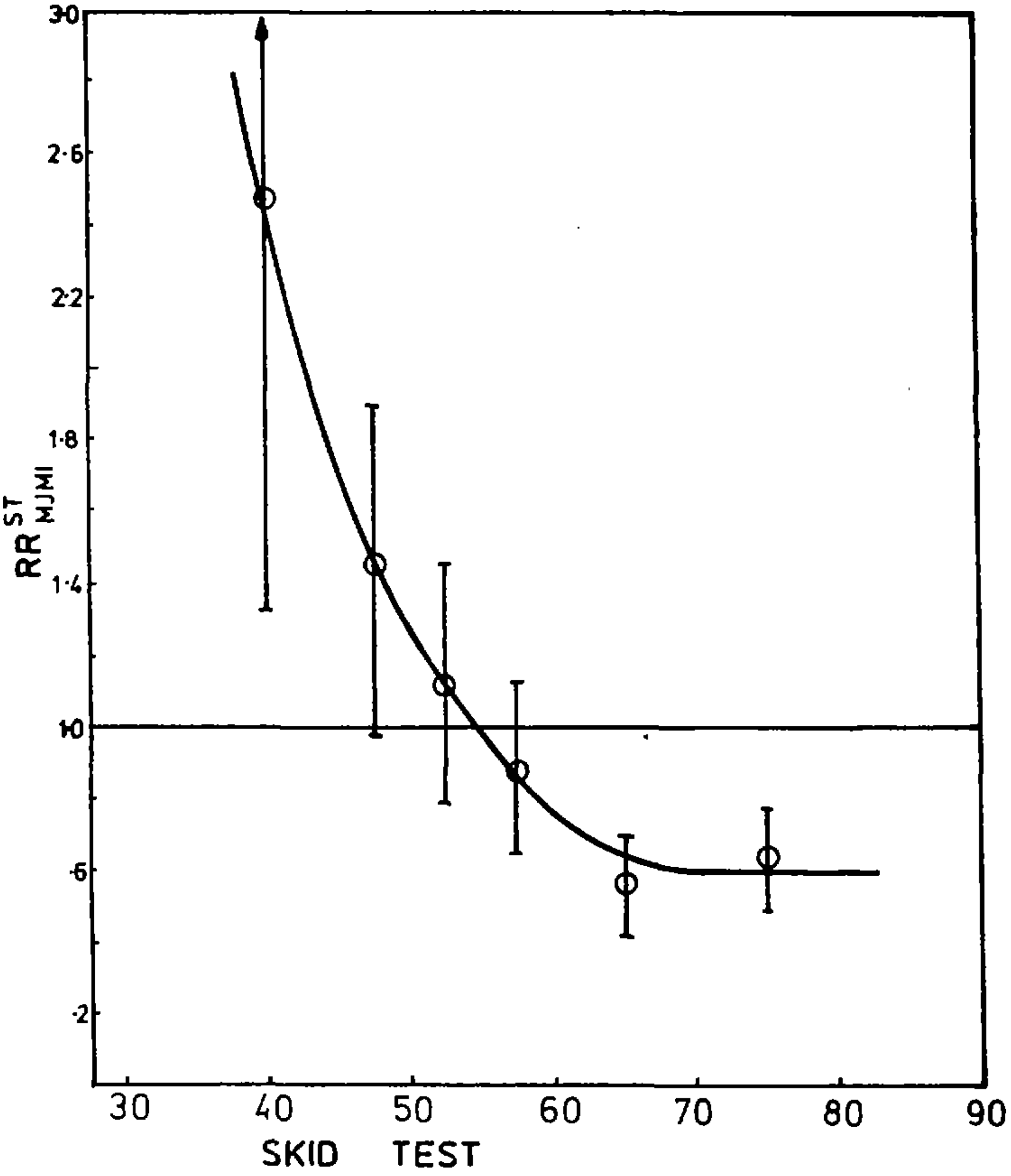

Figure 4.43. Relative risk versus British pendulum skid test on the major road - MJMI data group

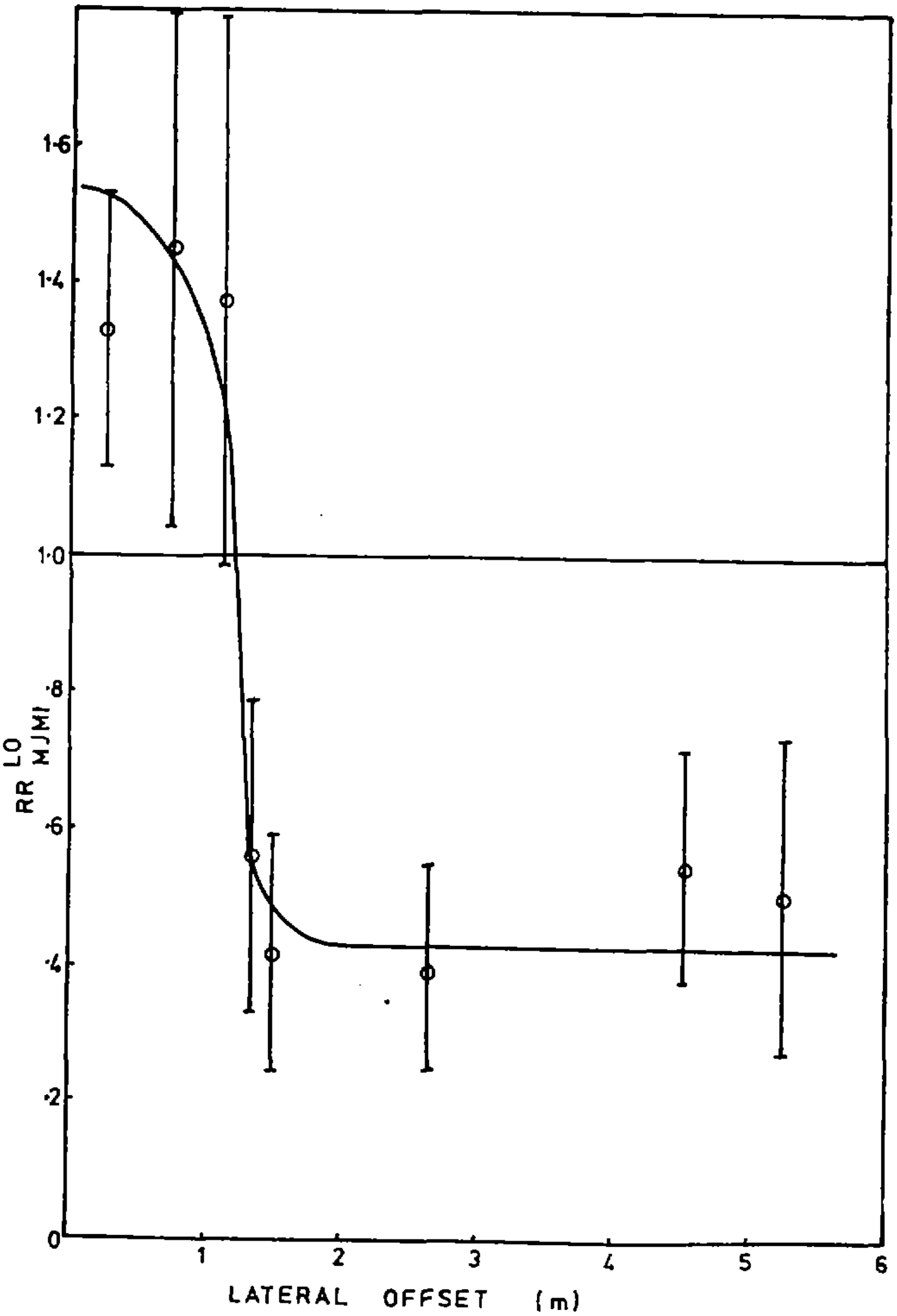

Figure 4.44.Relative risk versus pole lateral offset - MJMI data group

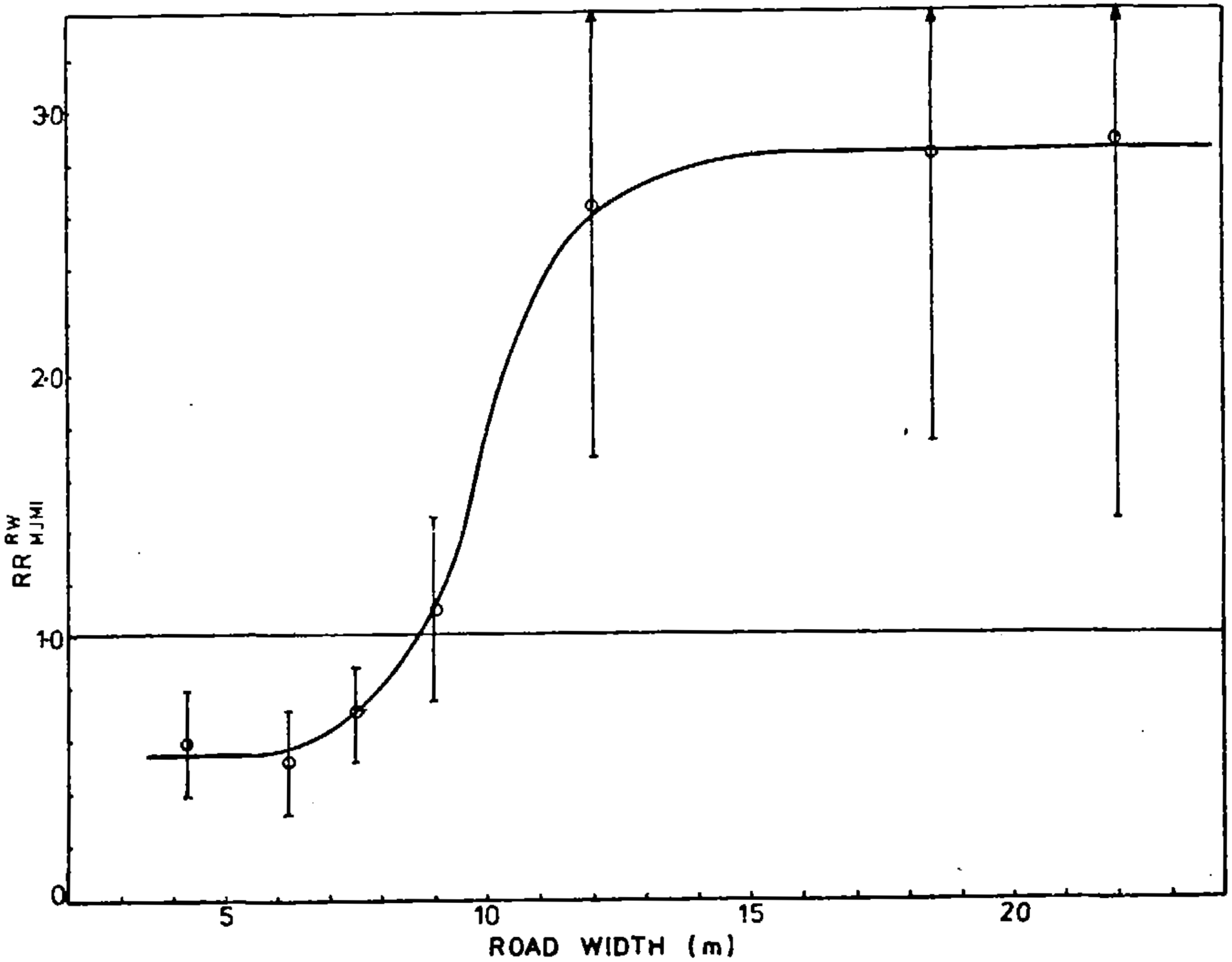

Figure 4.45. Relative risk versus width of intersecting minor roadway - MJMI data group

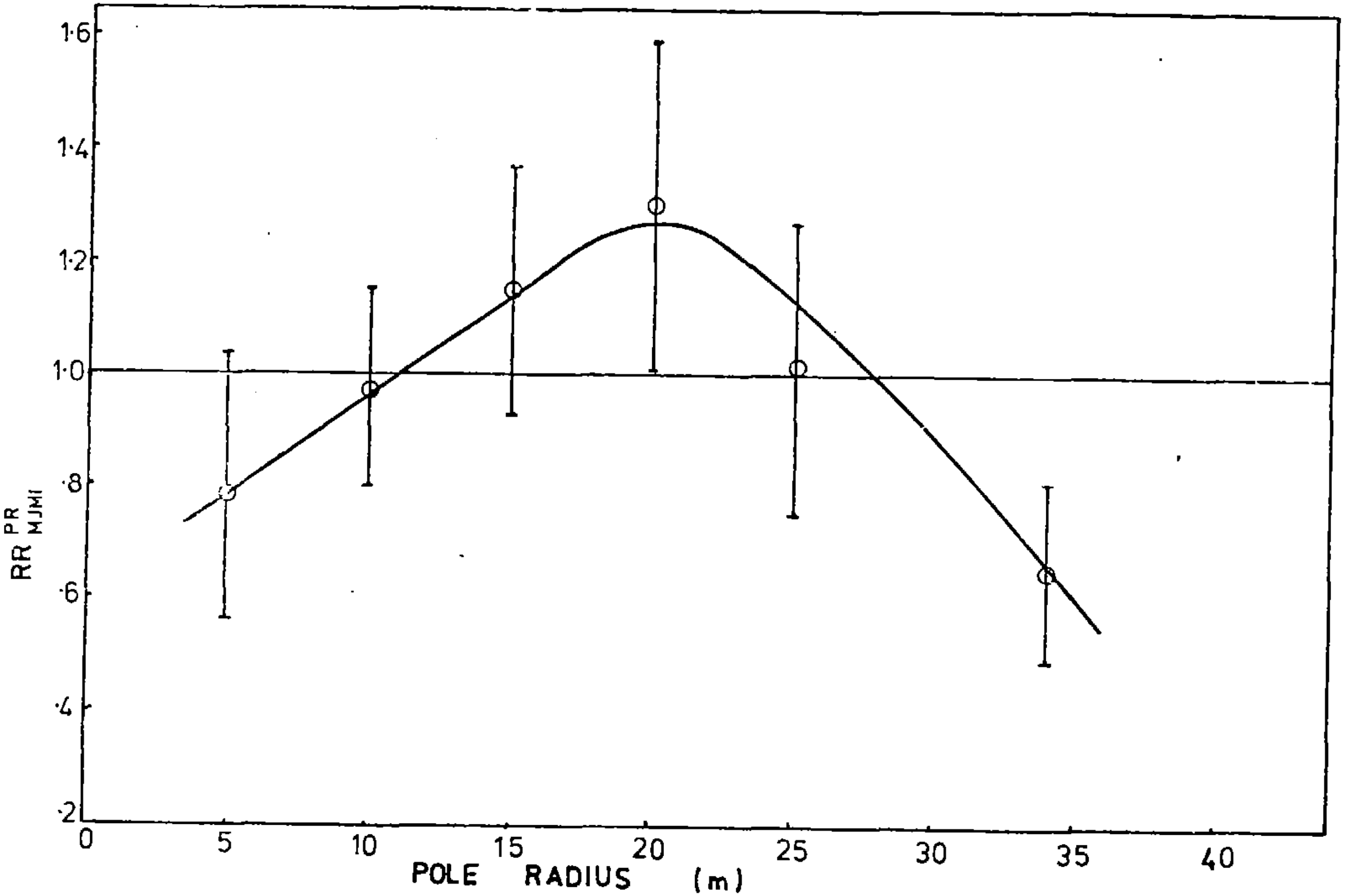

Figure 4.46. Relative risk versus radial distance of the pole from the centre of the intersection - MJMI data group

TABLE 4.16

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

The result obtained is possible due in part to the fact that the presence of a median strip allows vehicles entering the intersection from the minor road to cross one stream of traffic at a time, pausing between the two flows, thereby eliminating impatient manoeuvres caused by having to wait for a gap in both streams. It may also be that minor road drivers are more prepared to assign priority to the major road when it is divided, and clearly of a different category.

(f) The effect of intersection type

'Cross road' type intersections were found to be more hazardous than the 'tee' type, as was the case with MJMJ intersections. The relative risks are shown in Table 4.17.

TABLE 4.17

RELATIVE RISK BY INTERSECTION TYPE (+ OR T) - MJMI DATA GROUP

Intersection Type	RR	SD
+	2.50	0.53
T	0.70	0.13

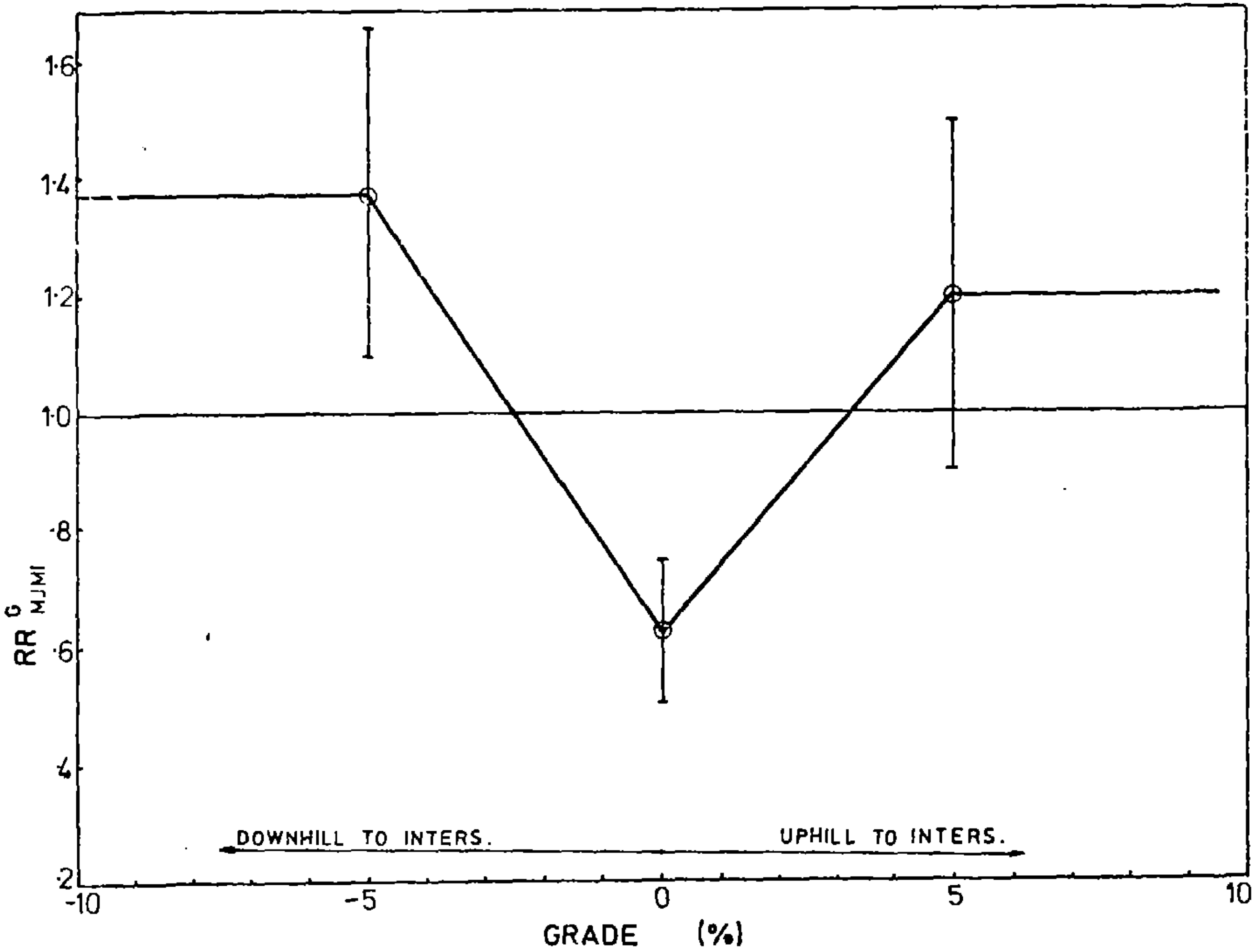

Figure 4.47. Relative risk versus grade of the major road 30m before the intersection - MJMI data group

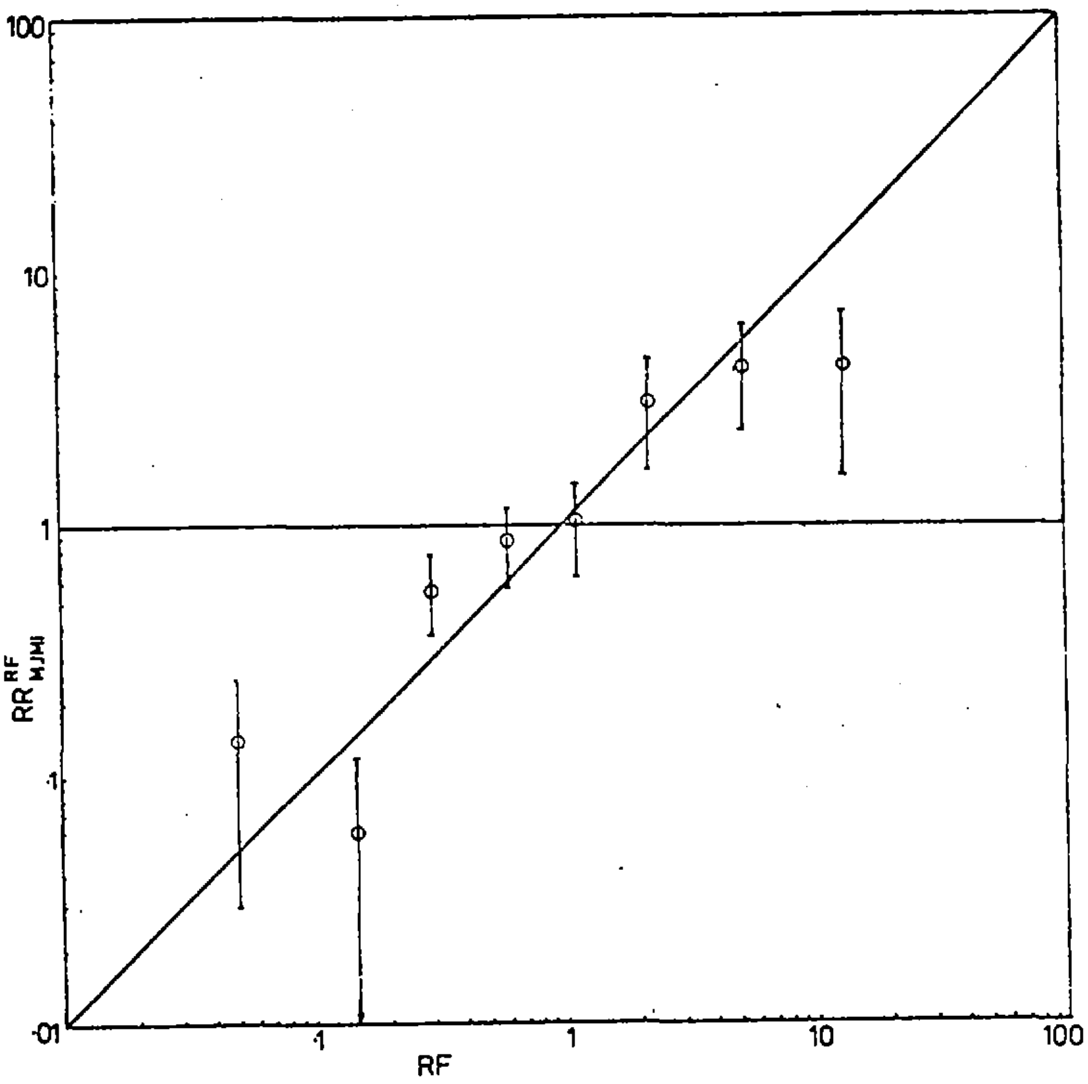

Figure 4.48. Relative risk versus risk factor for the MJMI data group

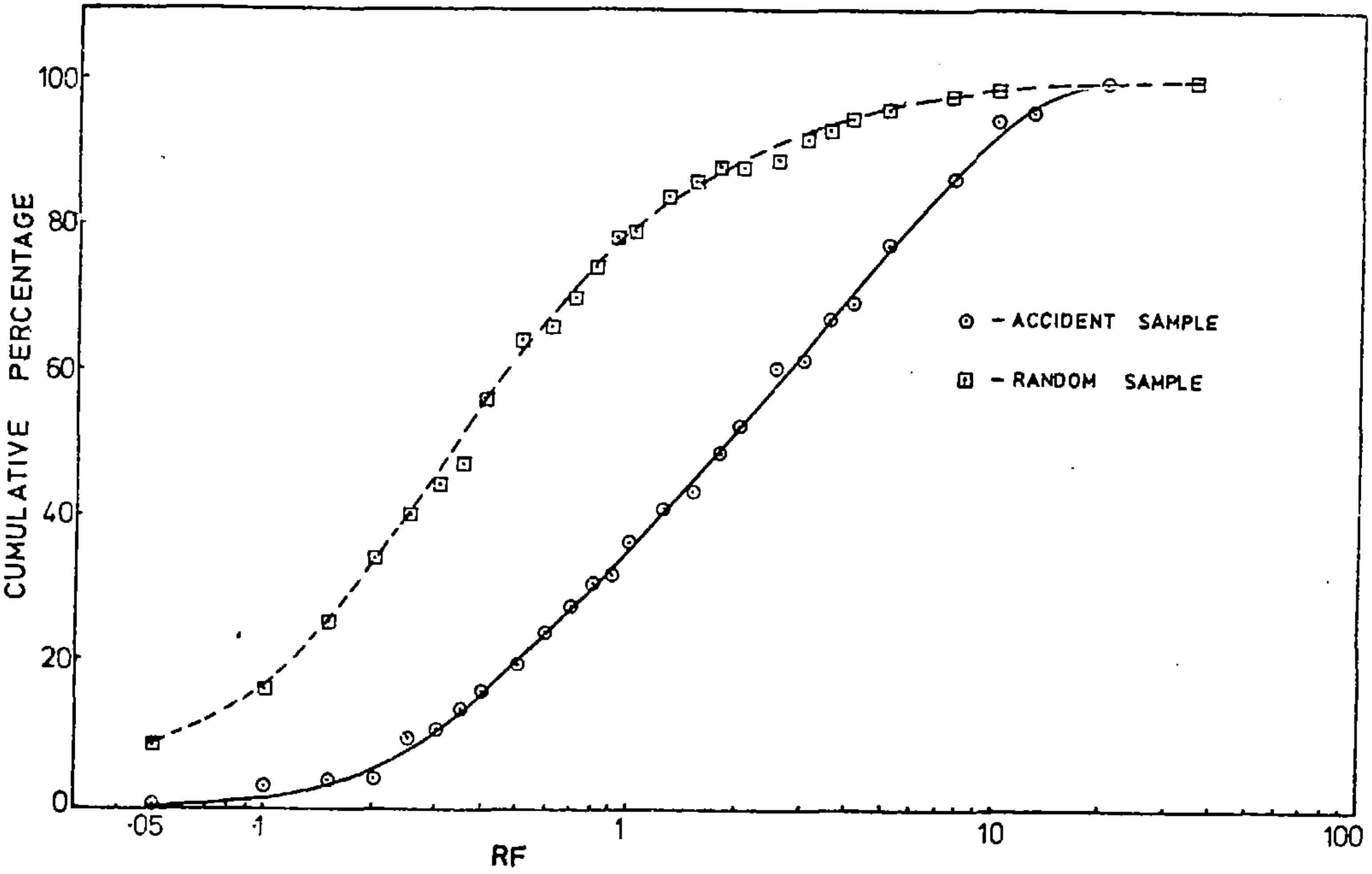

Figure 4.49. Cumulative percentage distributions of risk factor for the random and accident samples - MJMI data group

(g) Evaluation of the MJMI model

The model tests involving RR^{RF}_{MJMI} and the cumulative distributions of RF were feasible for this data group because none of the model variables were strongly correlated with pole density. These tests, shown in Figures 4.48 and 4.49, show that the MJMI model is not quite as discriminating as the non-intersection models. Nevertheless it is still able to discriminate well between the accident and random pole distributions and is a superior model to that obtained for the MJMJ intersections : only ten percent of the random poles had risk factors higher than 2.2, compared with forty-five percent of the accident poles. Tests were also carried out with relevant MJMI relative risks being replaced by those derived from the larger data base of the major road non-intersection group, to test the sensitivity of the models to the particular risk relationships adopted. These tests showed, however, that a far more satisfactory result is obtained using the MJMI relative risks.

4.3 CALCULATION OF TOTAL RELATIVE RISK AND THE ASSOCIATED ACCIDENT PROBABILITY

4.3.1 The Tree of Relative Risks

The models for each data group derived in the last section describe the relative risk associated with various site characteristics within that group, and take the relative risk between groups as given. In other words the models, as they stand, calculate the accident risk of a pole relative to the others *in that group*, but do not account for the risk associated with being in that group of poles. This concept of a 'tree' of relative risk is shown in Figure 4.50. The 'tree' consists of four layers of relative risk :

(a) The baseline relative risk of 1.0 for all pole accidents.
(b) The classification of the sites into the intersection or non-intersection group.
(c) The subdivision into data groups of the intersection and non-intersection groups by road class.
(d) The relative risk models within each of the data groups.

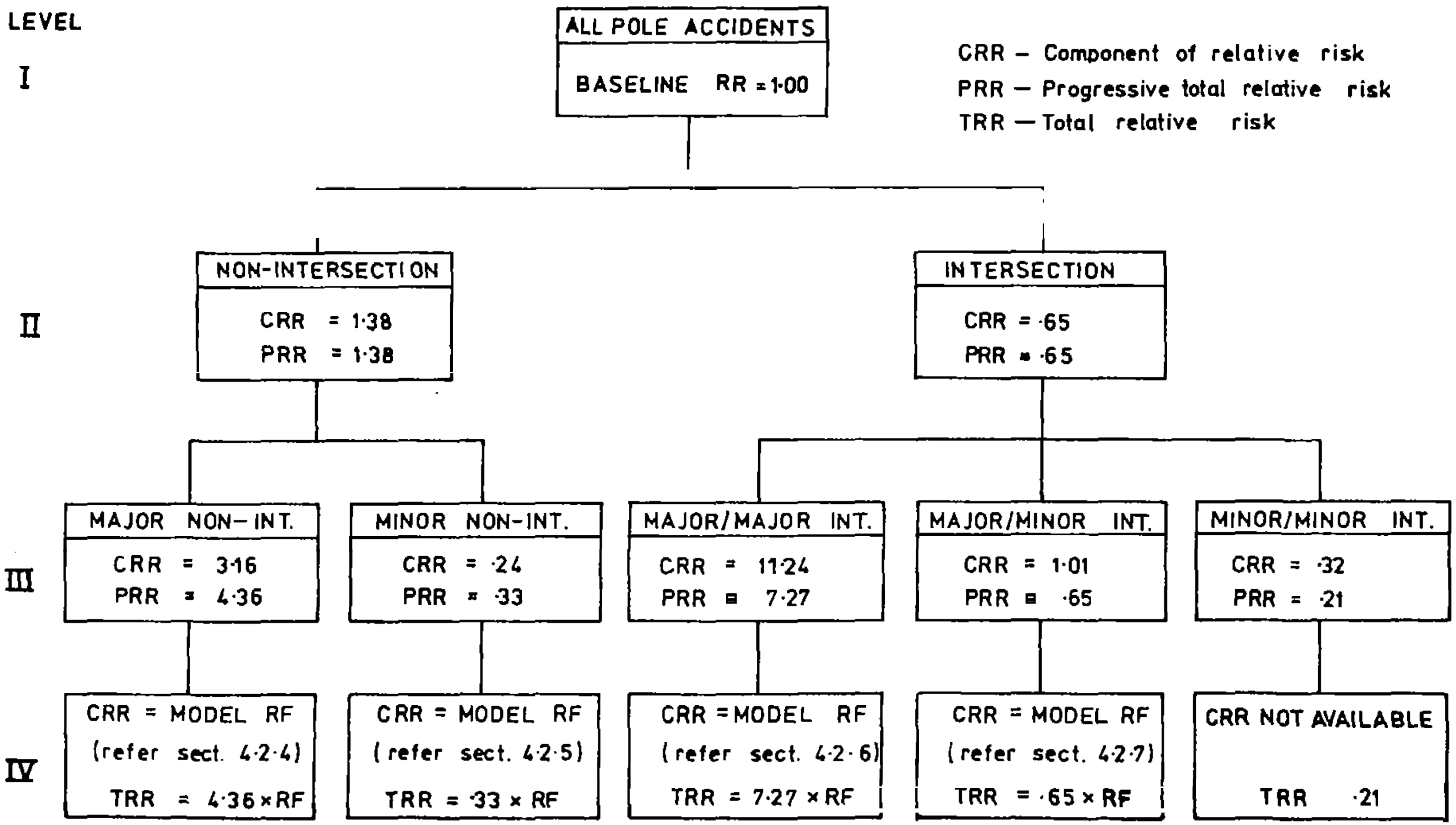

Figure 4.50. Relative risk 'tree'

Each of the cells in Figure 4.50 contains the Component of Relative Risk (CRR) associated with that cell, given its level in the tree of risk. For instance, the 'major non-int' cell has a CRR of 3.16, meaning that for poles within that data group the probability of an accident is 3.16 times higher than the average for all non-intersection poles. Going down the tree, the Progressive Relative Risk (PRR) represents the current total risk (relative to the baseline) for a cell. The PRR takes account of both the risk associated with the current level in the tree and the contribution of the cells to risk at that level. Again, for the 'major non-int' cell the PRR is calculated as :

$$\begin{aligned} PRR^{MNI} &= RR^{pole} \times RR^{NON\text{-}INT}_{pole} \times RR^{MNI}_{NON\text{-}INT} \\ &= 1.0 \quad \times \quad 1.38 \quad \times \quad 3.16 \\ &= 4.36 \end{aligned}$$

That is, the probability of an accident for a 'major non-intersection' pole is 4.36 times higher than the average probability for all poles.

The progressive relative risk for a given cell is obtained as the chain product of the CRR for that cell with the CRRs for all of the cells in a direct path to the baseline cell. The total relative risk for a pole is the PRR for the fourth, or model, level of the 'tree'. For example, the total relative risk for a particular pole on a major non-intersection road for which the MNI model indicates a risk factor of 20 (see Section 4.2.4) is :

$$\begin{aligned} TRR &= 1.0 \times 1.38 \times 3.16 \times 20 \\ &= 87.2 \ . \end{aligned}$$

Poles from various data groups can now be compared on the basis of their relative risk. The probability, P , that a trial (pole-second) will result in an accident is calculated as the product of the total relative risk and the mean probability of an accident for all poles. The expected number of accidents in a year is then the probability P , multiplied by the number of trials in a year.

4.3.2 Estimation of Pole Numbers

The calculation of both the mean accident probability ($\bar{P}$) and the CRRs for levels II and III in Figure 4.50 requires a knowledge of the number and type of poles in the population. It is in this area that the data is weakest. No inventory of poles is available, so that estimates of pole numbers had to be made, based on the random sample of poles.

The first step in calculating the 'tree' relative risks was to estimate the number of poles in the population associated with each of the cells in the tree. The number of poles on minor roads was calculated from the length of minor roads in the road system, multiplied by the mean number of poles per unit length. The pole density was estimated from the random sample by obtaining the mean pole spacing and the mean 'placement density'. A placement density of one indicates that, for the given road system, poles are put on one side of the road only. A placement density of two indicates that poles are on both sides of the road for the given road system. Lengths of road in the major and minor road systems were obtained from the Country Roads Board, Victoria.

For the minor road system (non-intersection) the following values were obtained :

Length of road system = 8782 km
Mean pole spacing = 46.1 m
Placement density = 1.14
∴ Number of poles = 2.171×10^5

For the major road system (non-intersection) :

Length of road system = 1913 km
Mean pole spacing = 43.3 m
Placement density = 1.73
∴ Number of poles = 7.644×10^4

Total number of non-intersection poles $N_{\text{NON-INT}} = 2.935 \times 10^5$

From the random sample of intersections, the mean number of poles per intersection was obtained for the three classes of intersection :

(a) Intersection of major roads (MJMJ) : 14.68
(b) Intersection of a major and a minor road (MJMI) : 8.28
(c) Intersection of minor roads (MIMI) : 5.66

A count of intersections in the street directory provided the intersection numbers in each of the three classes :

(a) MJMJ : 813
(b) MJMI : 11,658
(c) MIMI : 31,821

The number of poles for each intersection group is therefore :

(a) $n_{MJMJ} = 1.193 \times 10^4$
(b) $n_{MJMI} = 9.653 \times 10^4$
(c) $n_{MIMI} = 1.801 \times 10^5$

The total number of intersection poles is then :

$$N_{INT} = 2.886 \times 10^5$$

There are undoubtedly poles which are included in both groups. While this has no effect on the calculation of 'tree' relative risks, it will have to be accounted for in the calculation of $\bar{P}$.

4.3.3 Calculation of Component Relative Risks

The component relative risks for each level of the tree are calculated as the ratio of the proportion of relevant accidents to the proportion of corresponding poles. For example, the calculation of RR^{MJMJ}_{INT} proceeds as follows.

The total number of intersection accidents in the sample is :

$$A_{INT} = 282$$

The number of major/major intersection accidents in the sample is :

$$a_{MJMJ} = 131$$

$$RR_{INT}^{MJMJ} = \frac{a_{MJMJ}/A_{INT}}{n_{MJMJ}/N_{INT}}$$

$$= \frac{131/282}{1.193\text{x}10^4/2.886\text{x}10^5}$$

$$= 11.24 \; .$$

The other component relative risks in Figure 4.50 were calculated in a similar manner.

4.3.4 Estimation of Mean Accident Probability

The calculation of the absolute probability of an accident is, unfortunately, sensitive to the value of $\bar{P}$, which must be estimated from the (somewhat uncertain) total number of poles in the system. The overall relative risk model clearly has no difficulty in ranking poles according to relative risk. The model in fact discriminates a range of accident probabilities of 1000. When cost-benefit analyses are undertaken, however, it is necessary to know *absolute* probabilities, so that the expected number of accidents in a given time can be predicted for a particular pole.

The first step in calculating the mean absolute probability $\bar{P}$ is to estimate the total number of pole accidents in the study area for (say) one year. The present accident survey ran for eight months, rather than a year, and did not achieve a complete coverage of pole accidents during that eight months : certain zones in the survey area were under-reported because of lack of support from the particular towing companies in their zones; even in those areas well covered, accidents were 'lost' during periods when companies were too busy to ring (although most did follow-up when the workload eased). It is estimated that seventy percent of the random survey area was covered by the accident survey, and that within the well-covered areas, the notification rate was of the order of ninety percent. So an estimate of the total number of pole accidents for a year is the number observed multiplied by 1.5 (survey was 8 months long), by 1.43 to account for area coverage, and by 1.11 to account for the notification rate. The predicted annual number of pole accidents is then the observed number on the survey period 879, multiplied by 2.88, which is equal to 2093*.

The next step is to estimate the total number of poles in the population. The total number of poles classifiable as non-intersection poles and intersection poles has already been crudely estimated. It was pointed out that a number of poles could find their way into both groups, given the method of calculation. It was estimated that there would be an overlap of five percent between the two groups. The sum of the numbers in the two classes of poles was therefore reduced by that amount.

The estimated total number of poles in the population is then:

$$N = 5.530 \times 10^5$$

This figure appears to be of the right order of magnitude, based on information supplied by the various supply authorities, Telecom Australia, Road Safety and Traffic Authority, Victoria and the Melbourne and Metropolitan Tramways Board.

The mean probability, $\overline{P}$, of a 'pole-second' trial resulting in an accident is estimated as the number of accidents for a twelve-month period, divided by the number of poles in the population, and by the number of trials per pole (T = 31 536 000 seconds) that occur over twelve months:

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* It was subsequently realised that the number of fatal accidents observed should be scaled up by only 1.5, because it is thought that the sample coverage of such accidents was complete (see Section 3.2.2). However, this makes a difference of only 1 percent in the predicted number of accidents which discrepancy is insignificant compared with the uncertaintity in the estimate of pole numbers.

$$\bar{P} = \frac{2093}{5.53 \times 10^5 \times T}$$

That is, $$\bar{P} = \frac{3.785 \times 10^{-3}}{T}$$

4.3.5 Expected Accident Rates - Tests of the Model

The expected number of accidents per year for a pole with a total relative risk TRR is the expected number per trial, by the number of trials in a year :

$$E[a] = TRR \times \bar{P} \times T$$

Hence, $$E[a] = TRR \times 3.785 \times 10^{-3} \ .$$

If the expected accident rate E[a] is denoted by ν , and it is assumed that the accidents are Poisson distributed, then the probability that n accidents will occur in a year can be calculated as follows :

$$P_r(N = n) = \frac{e^{-\nu} \mu^n}{n!}$$

To illustrate, the highest total relative risk predicted by the model for a pole in the accident sample was 305. The probability of an accident occuring at this pole in a year is obtained as follows :

The expected number of accidents/year is given by

$$\begin{aligned} \nu &= 305 \times 3.785 \times 10^{-3} \\ &= 1.154 \ . \end{aligned}$$

The probability of at least one accident occuring in a year is then

$$\begin{aligned} Pr(N \geqslant 1) &= 1 - Pr(N=0) \\ &= 1 - \frac{e^{-1.154} \times (1.154)^0}{0!} \\ &= 1 - 0.316 \\ \text{i.e. } Pr(N \geqslant 1) &= 0.684 \ . \end{aligned}$$

Thus in roughly seven years out of ten it could be expected that there would be at least one accident at this pole - a reasonably high probability.

To further test the model, a number of specific accident sites were investigated, including the pole which was struck six times during the survey period. The total relative risk for this particular pole was 220 . The following probability table can be constructed for this pole :

$Pr(N = 0) = 0.435$
$Pr(N = 1) = 0.362$
$Pr(N = 2) = 0.151$
$Pr(N = 3) = 0.096$
$Pr(N = 4) = 0.009$
$Pr(N = 5) = 0.001$
$Pr(N = 6) = 0.0002$.

According to the model the probability of this pole being involved in six collisions is almost zero. Although the model has identified this as a very high risk, 'black spot' pole, it has not been sensitive to all the special circumstances of this pole.

The next check was made for accident sample poles which were struck at least twice during the survey period. All of these were in the MNI group. The total relative risks for this selection of poles ranged from 40 through 220, the average being in the vicinity of 60. A total relative risk of 60 leads to the following expected accident rate, and probability of two or more accidents per annum :

$$\nu = 0.227$$

$$Pr(N \geqslant 2) = 0.022$$

At first glance, the expected accident rate appears an order of magnitude too low for these 'multiple hit' poles. However, given the probability of two or more accidents, and the observed number of 10 poles with multiple collisions, it requires only 450 poles in the MNI population to have a risk factor RF of 13.7 (60 ÷ 4.36) to confirm the model. 450 poles corresponds to 0.6% of the MNI population, which is not inconsistent with the 'corrected' random distribution of RF in Figure 4.27. The figure of 450 poles is an upper bound estimate, as its calculation assumed that the total relative risk of all the multiple hit poles was equal to 60, whereas in fact a number of them have a total relative risk in excess of 150.

This rather rough test does demonstrate, however, that the model predicts accident probabilities that are, at the very least, of the correct order of magnitude.

The derivation of the models as a whole has revealed that the most likely areas of return for money invested in safety improvements are the major non-intersection poles, followed by poles at the intersection of major roads.

4.3.6 Case Studies

Three examples demonstrating the method of application of the model, as well as a complete set of relative risk graphs and tables, are presented as a 'User's Manual' in Appendix B. The examples chosen cover the range of situations likely to be encountered, and each case study is worked through step-by-step.

4.4 POLE ACCIDENT SEVERITY AS A FUNCTION OF THE SITE CHARACTERISTICS

Final decisions concerning possible pole accident remedial programs will be based on cost-benefit analyses. Accident severity, measured in 'community-cost' dollars, forms part of the input data required for such analyses. As a first step in investigating the relationship between accident costs and site characteristics, a brief analysis of occupant injury level, vehicle damage and pole damage as a function of the major site descriptors was undertaken.

4.4.1 Injury Severity

Two measures of occupant injury severity were used :

(i) Abbreviated injury scale (AIS)
(ii) Modified injury severity score (ISS)

The ISS concept proposed by Baker, O'Neill, Haddon and Long (1974) was modified in the manner suggested by Nelson (1974). The original Baker et al. ISS was calculated as : *the sum of the squares of the highest AIS grade in each of the three most severely injured areas.* Nelson proposed that an injury severity score be based on all injuries recorded, because of the somewhat arbitrary choice of body zones by Baker et al., and because he felt that intuitively a greater number of injuries implied a higher overall injury severity. As with Nelson and Baker et al., no AIS grade higher than 5 was used in the present score, even for the case of a fatality.

For the results presented in Figure 4.51, the highest AIS grade per accident was used as the severity measure. In this Figure, the distributions for the three accident types listed below are shown.

(i) Curved road accidents
(ii) Straight road accidents
(iii) Intersection accidents

It can be seen that intersection accidents generally result in less severe occupant injuries than the non-intersection cases. Although there is little difference between the curved and straight road accident groups, the curved road accidents tend to have slightly higher proportions of the more severe injuries. One possible explanation of this is contained in Figure 4.52, which shows the distribution of impact direction for the three accident groups. Curved road accidents tend to involve a greater proportion of oblique and side impacts, particularly on the driver's side, than do the straight road or intersection groups. The relationship between the likelihood of severe injuries and