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ACCIDENT ANALYSIS AND PREVENTION: COURSE NOTES 1987/88

by

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and

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PREFACE

This report consists of the notes from a series of lectures given by the authors for a course entitled Accident Analysis and Prevention. The course took place during the second term of a one year Masters degree course in Transport Planning and Engineering run by the Institute for Transport Studies and the Department of Civil Engineering at the University of Leeds. The course consisted of 18 lectures of which 16 are reported on in this document (the remaining two, on Human Factors, are not reported on in this document as no notes were provided). Each lecture represents one chapter of this document, except in two instances where two lectures are covered in one chapter (Chapters 10 and 14). The course first took place in 1988, and at the date of publication has been run for a second time. This report contains the notes for the initial version of the course. A number of changes were made in the content and emphasis of the course during its second run, mainly due to a change of personnel, with different ideas and experiences in the field of accident analysis and prevention. It is likely that each time the course is run, there will be significant changes, but that the notes provided in this document can be considered to contain a number of the core elements of any future version of the course.

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1. INTRODUCTION

1.1. BASIC DEFINITIONS

Accident - an event occurring on a public roadway or footway, and involving a vehicle and personal injury or property damage

- injury accidents and non-injury (property -damage-only) accidents
- generally, only injury accidents must be reported and often accident statistics relate to injury accidents only

Injury - fatal, if person dies within specified time of Severity event (30 days for Great Britain)

- serious, if person is either detained in hospital as "in-patient" or suffers fractures, concussion, internal injuries, crushings, severe cuts and lacerations, severe shock, or death after specified time limit
- minor (slight), if not fatal or serious (e.g. sprain, bruise, minor cuts, minor shock).

Accident Severity - based on severity of injury to most severely injured participant

Participants - generally classified according to whether driver, passenger, rider (of pedal cycle, motor cycle, or animal) or pedestrian

- "road user" incorporates all classes of participants

Vehicles - generally classified as cars, goods vehicles (heavy or light), two-wheel motor vehicles (motor scooters and motor cycles) and pedal cycles

Accident Location - generally classified according to whether in a

(i) "built-up" or urban area; on roads with permanent speed limit of 40 mph or less (say)

(ii) "non built-up" or rural area; on roads with permanent speed limit greater than 40 mph (say)

Accident time - generally classified according to whether in

(i) day-time (e.g. 30 min. before sunrise to 30 min. after sunset)
(ii) night-time (e.g. 30 min. after sunset to 30 min. before sunrise)

1.2. THE ACCIDENT SITUATION IN GREAT BRITAIN

Described in the documents (published annually by the Department of Transport)

(1) Road Accidents Great Britain
(2) Road Accident Statistics English Regions
(3) Road Accidents: Scotland
(4) Road Accidents: Wales

Items 2-4 supplement item 1, and concentrate on data of most use to traffic engineers, planners and administrators in local and regional government. All four documents are based on analysis of data in the accident report form (Stats 19).

The situation in Great Britain has been changing with time, with changes in factors such as population, the number of vehicles, and vehicle use (see Figure 1).

It should be noted that aggregate statistics (for all road users) masks the variability that exists between road users (see Figure 2). Further disaggregation of the data for each class of user, according to age (say), reveals that there is considerable variation between groups within the same user class (see Figure 3).

1.3. INTERNATIONAL COMPARISONS

Comparisons of accident situations in different countries is fraught with danger, due to

(1) variations in definitions in injury severity; for instance, the specified time limit for a fatal injury varies from 3 days (Greece, Austria) to 12 months (Canada), with 30 days being most common.

(2) variations in accident reporting requirements.

(3) variations in the reporting rate; the reporting rate may vary considerably according to the accident severity and the class of participant.

A study of the time interval between the accident and death, for fatal accidents in Great Britain in 1985, has revealed that

(1) death occurs more quickly for non built-up roads (68%, 86%, 95%, 99% and 100% within 1 hour, 12 hours, 5 days, 15 days and 23 days, respectively)

(2) death occurs less quickly for built-up roads (53%, 73%, 90%, 97% and 100% within 1 hour, 12 hours, 5 days, 15 days and 25 days, respectively)

Hence, a 30 day period seems appropriate, and using such information, the number of deaths for countries using a different period can be adjusted.

Comparisons between countries are generally in terms of deaths, injuries or accidents per head of population, vehicle or vehicle-kilometres (a measure of vehicle usage). Some such rates are not an ideal basis for comparison (see Andreassen, Traffic Engineering and Control, November 1985), but there are practical difficulties obtaining some data in some countries. Table 1 shows the results of a recent international comparison.

TABLE

1. International comparisons of road deaths: number, and rates for different road users: by selected countries: 1985

	Number of road deaths[1]	Motor vehicles per 1,000 population	Road deaths per 100,000 population	Road deaths per 10,000 motor vehicles	Car user deaths per 100 million car kilometres	Pedestrian deaths per 100,000 population
England	4,322	394	9.2	2.3	..	3.1
Wales	242	366	8.6	2.3	..	2.9
Scotland	601	295	11.7	4.0	..	4.6
Great Britain	5,165	384	9.4	2.4	0.9	3.2
Northern Ireland	177	301	11.4	3.8	..	3.8
United Kingdom	5,342	381	9.4	2.5	..	3.3
Belgium	1,801	415	18.3	4.4	2.7[2,7,d]	3.3
Denmark	772	381	15.1	4.0	1.2[3,7]	2.5
Federal Republic of Germany	8,400	493	13.8	2.8	1.3	2.9
France	11,387	510[b]	20.7	4.1[b]	3.1[3,7]	3.1
Greece	1,908[2]	206	19.3[2]	10.1[2]	..	4.9[2]
Irish Republic	410	235	11.5	4.9	..	3.9
Italy	7,687[2]	479[3]	13.5[2]	3.0[3]	1.8[2,7]	2.4[2]
Luxembourg	79	462[5]	21.6	4.7[5]	..	3.3
Netherlands	1,438	378	9.9	2.6	1.1	1.3
Portugal	3,021[3]	218[2b]	30.2[3d]	14.4[3b]	..	..
Spain	6,374	300[5]	16.5	5.5[5]	6.2[8]	3.4
Austria	1,524	493[2]	24.0[2]	4.5	2.7[7]	4.7[2]
Czechoslovakia	1,536	206[3,5,6]	10.4[3]	4.5[2,5,6]	..	4.2[3]
Finland	541	397	11.1	2.8	0.9[9]	2.6
German Democratic Republic	1,670	295[5]	10.0	3.4[5]	..	3.1
Hungary	1,756	188[5]	16.5	8.7[5]	..	6.2
Norway	402	462	9.7	2.1	1.1[7]	1.7
Poland	4,980[2]	159[2,5]	13.4[2]	8.4[2,5]	5.7[2,a]	5.9[2]
Sweden	808	507[5]	9.7	1.9[5]	1.1[7,a]	1.4
Switzerland	863	572	13.4	2.3	1.1	2.8
Yugoslavia	4,142	132[4]	22.5[4]	12.9	..	7.3[4]
Australia	2,942	..	18.7	3.2	..	3.4
Canada	3,914[2]	591[2d]	15.6[2d]	2.6[2]	..	2.2[2]
Japan	12,039	400	10.0	2.5	..	2.9
New Zealand	747	607	22.7	3.7	..	3.8
United States of America	43,795	727[2]	18.3	2.6[2]	1.1[c]	2.8

[1] In accordance with the commonly agreed international definition, most countries define a fatality as being due to a road accident if death occurs within 30 days of the accident. The official road accident statistics of some countries however, limit the fatalities to those occurring within shorter periods after the accident. Numbers of deaths and death rates in the above table have been adjusted according to the factors used by the Economic Commission for Europe and the European Conference of Ministers of Transport, to represent standardised 30-day deaths: France (6 days) + 9%; Italy (7 days) +7%; Greece, Austria (3 days) +12%; Spain, Japan (24 hours) +30%; Canada, Switzerland (1 year) - 5%; Portugal (at the scene) +35%
See article 15, which analyses the time to die after a road accident. This article estimates the percentage of deaths occurring within a specified number of days after a road accident. The results obtained from this study may at some stage influence the adjustment factors used in this table to standardise road accident deaths to the agreed international definition of death within 30 days

[2] 1984
[3] 1983
[4] 1981
[5] excluding mopeds
[6] excluding lorries
[7] nationals' vehicles only
[8] traffic on state roads only
[9] including traffic on private roads
[a] including nationals' cars abroad
[b] excluding all two wheel motor vehicles
[c] intercity transport
[d] revised

FIGURE

1: Population, vehicles licensed, accidents, traffic and casualities: 1926–1986

(Logarithmic Scale)

* See Note to Table 1

FIGURE 2: Fatal and serious casualties by type of road user: 1972–1986

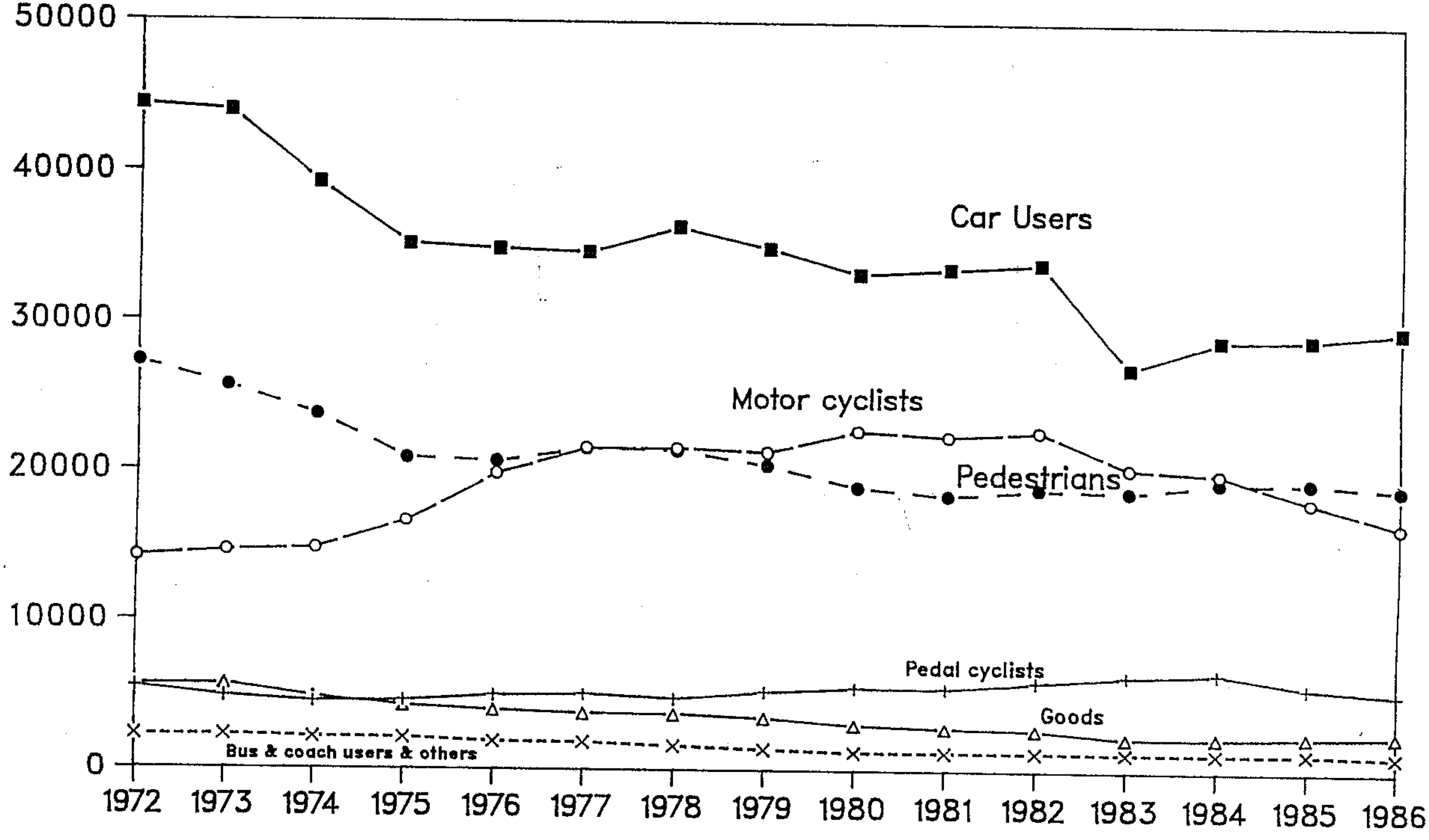
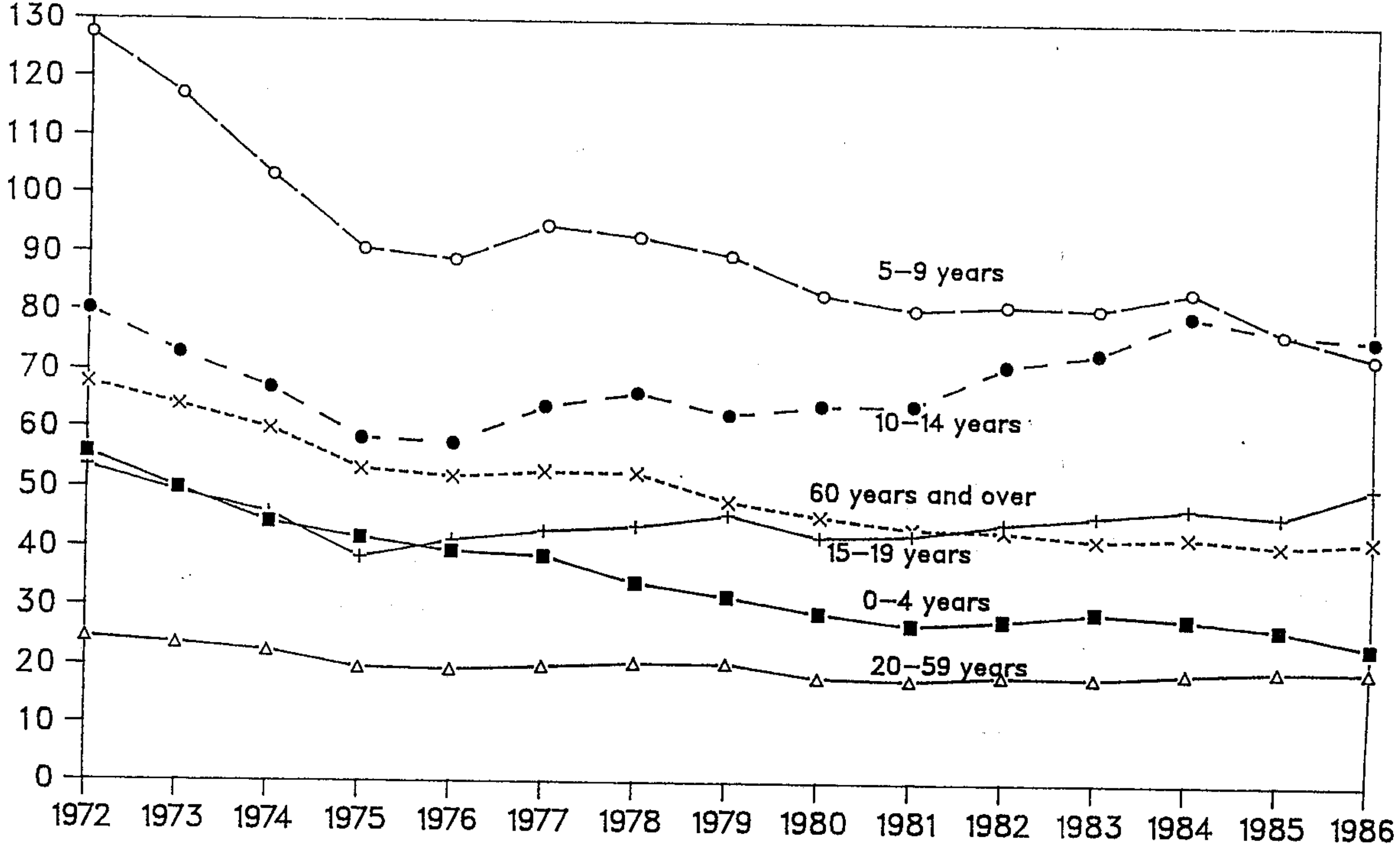


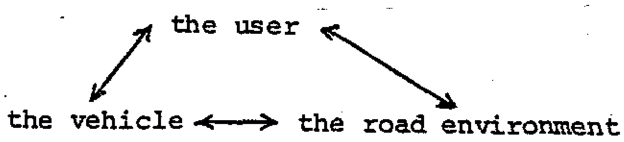
Figure 3 · Pedestrians killed or seriously injured per 100,000 population: 1972–1986



2. THE DRIVER, THE VEHICLE AND THE ROAD ENVIRONMENT

2.1. INTRODUCTION

The driver-vehicle-road environment system is rather complex. It is convenient to consider it as <u>3 interacting sub-systems</u>:



Accidents arise from the interaction of 2 or 3 of the sub-systems. Traffic engineers should have a clear understanding of

(1) the elements of each sub-system, and
(2) how each sub-system interacts with the other two.

2.2. THE USER

The elements of the user sub-system are either <u>physiological</u> or <u>psychological</u>, and include

Physiological	Psychological
the nervous system	motivation
vision	intelligence
hearing	learning/experience
stability sensations	emotion
other senses (eg touch, smell)	maturity
modifiers (eg fatigue, drugs)	conditioning/habits

<u>User behaviour</u> is derived from the interaction of the above <u>human factors</u> amongst themselves, subject to other factors, including those related to the vehicle and road environment sub-systems

<u>Nervous System</u>
The central part of the nervous system contains about 2000 million cells. Different parts of the brain are concerned primarily with different functions, there being <u>no single master central control</u> i.e. it is a system maintained by the effectiveness of intercommunicating parts.

The basic unit of the nervous system is the <u>neurone</u>, of which there are two types
(1) <u>motor</u> (for muscle control - messages from brain)
(2) <u>sensory</u> (sense external environment - message to brain)

Vision

The eye is the primary sensory organ for road users.
The visual field for normal sight is approximately
180° horizontally
145° vertically

There are various cones of vision
(1) cone of reading vision - 2½° horizontally and2½° vertically
(2) cone of acute vision - 6° horizontally and 4° vertically
(3) cone of sensitive vision - 20° horizontally and 13° vertically

The above cones constitute the central field of vision, and the eye can detect the details of objects within the central field.

As well, there is the remainder of the visual field, giving rise to peripheral vision. Objects within the peripheral limits (180° horizontally and 145° vertically) can be detected readily, if those objects are sufficiently stimulating.

For example, a child moving from the footpath may be initially detected by peripheral vision, and the driver can shift his gaze, in order to focus upon the point of activity.

Both central and peripheral vision are important to road uses, with peripheral vision being particularly important with regard to speed judgement and steering.

Visual acuity is the ability to discern details, and an adequate level of visual acuity is required before drivers are licensed. (Snellen visual acuity test)

Vision is affected by movement. As speed increases, drivers focus on objects further away. As the focal point distance increases, the visual field decreases (i.e. peripheral vision is reduced)

speed (km/h)	focal point distance (metres)	field of vision
40	180	100°
50	230	90°
75	365	60°
100	500	40°

Also, as speed increases, concentration increases and detailed scanning is reduced (i.e. the point of focus shifts less).

Linear streaming is the term applied to the linear 'expansion' of objects in the field of vision. The apparent rate of displacement of objects increases as the object moves away from the centre of the visual field, assuming that the driver is looking in the direction of travel. In the case of linear streaming, moving objects will appear as marked discontinuities, and will be readily detected.

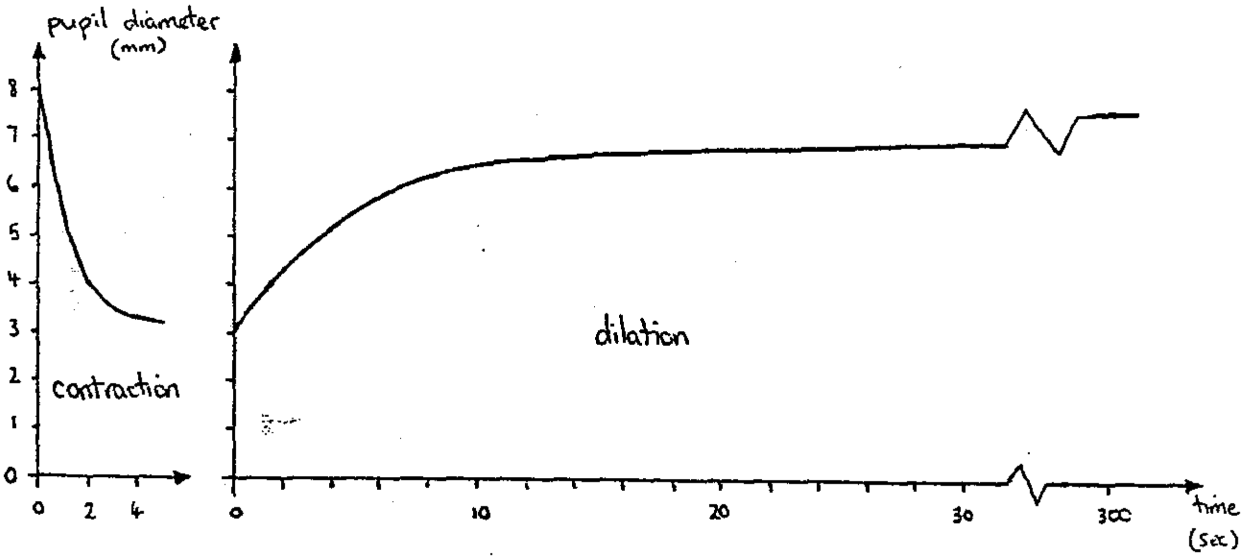
However, if the driver's eyes are directed away from the direction of movement, then the detection of moving objects is difficult, unless they are within the immediate vicinity of the point of focus. That is, 'vulnerability' increases whenever drivers' eyes are not directed in the direction of movement (e.g. higher accident rates at intersections, where drivers must look for cross-traffic).

During driving, the point of fixation will move regularly, and vision is poor during such shifts.

shift time 0.15 - 0.33 sec
fixation time $\geq$ 0.10 - 0.30 sec

The frequency of shifts will depend upon the driving situation. Also, blinking occurs about 5 times per minute (if lower, then fatigue results) and vision is lost for about 0.3 sec during each blink.

Driver vision can be reduced massively by glare, especially glare from approaching headlights - perhaps to only about 30% of the no-glare vision. Also, changes in the level of light cause the pupils to either contract or dilate. The contraction time is fairly short, but the dilation time can be considerable.



about 2½ sec for 90% contraction
about 200 sec for 90% dilation

Therefore, a change from light to dark (e.g. upon entering a tunnel) is a critical time for drivers.

Hearing

The sense of hearing is generally much less important to road users than is vision, with pedestrians probably relying more upon hearing than other road users.

However, the sound of tyres on pavements, wind, engine noise, horns and other traffic noise are useful to road users.

Stability sensations and other senses

The vestibular organs (located within the inner ear) are sensitive to acceleration/deceleration and orientation, and many of the vehicle control adjustments are based upon the information relating to balance and stability.

Also, drivers can detect fire or overheating engines/brakes via the olfactory senses (i.e. by smell). The sense of touch enables the detection of vibrations.

Fatigue, drugs, age - these affect the physiological state of drivers.

Psychological factors

A driver receives various stimuli (e.g. visual, auditory, vestibular) while driving. The response depends upon:

(1) the nature of the stimulus
(2) the strength of the stimulus
(3) the psychological state of the driver, as defined by the psychological factors listed above.

Some examples of how psychological factors affect driver behaviour are:

(1) the purpose of a trip might be such that the driver is strongly motivated to reach the destination as quickly as possible;
(2) a driver may be disturbed because of an event prior to driving and may be less attentive than usual;
(3) young/immature drivers tend to take greater risks while driving;
(4) a conditional response (or habit) when approaching particular intersections might be to assume the right-of-way and maintain speed.

It is widely believed that there is an optimum amount of driver anxiety - too little or too much is related to a deterioration in driving ability. Likewise, fits of depression or elation are not conducive to good driving, there being an 'optimal' medium emotional state. A driver's response to frustration (e.g. unnecessary delay at signalised intersections) depends upon the psychological state at that time.

2.3. THE VEHICLE

Fortunately, the vehicle has less variable characteristics than road users (there are fewer manufacturers of vehicles than road users). Also, there is a greater amount of legislative control over the features of vehicles than of road users, for instance:

(1) limits upon overall weight, size and performance;
(2) minimum requirements for brakes, lights etc.

The more important vehicle factors are:

(1) visibility
(2) lighting
(3) warning and instrument systems
(4) brakes
(5) stability
(6) size and weight
(7) power.

Visibility

Because of pillars, roof and bonnets, the driver's field of view is restricted somewhat. Typical fields of view are (for saloon cars)

(1) forward:

58° to left and 31.5° to right - horizontally
12.2° upwards and 9.3° downwards - vertically

(2) rear:

28.5° horizontally via mirror
38° horizontally directly
5.7° vertically

The pillars can be critical, obscuring the driver's view of pedestrians and cyclists - typically, the obstructions are

about 4° for right front pillar
and 2° for left front pillar

The presence of a passenger adjacent to driver can reduce the view to the side.

Clearly, the vehicle body restricts the driver's view, which is dependent upon the eye position of the driver relative to the body of the car.

Also, the height of the driver's eye relative to the ground is of significance when determining how far ahead the driver can see (especially on vertical curves). The driver's eye height has been decreasing in recent times.

Lighting

Vehicle lighting has two main purposes:

(1) to define the vehicle to external viewers;
(2) to provide an illuminated field of view for the driver.

The illuminated field of view can vary considerably, depending upon:

(1) vehicle and lamp type
(2) whether beams dipped or not
(3) climatic/weather conditions
(4) presence of opposing vehicle.

Vehicle Warning and Instrument Systems

The style and positioning of instruments varies between vehicles, with driver vision being lost for 1-3 seconds each time the instruments are monitored.

Brakes

With efficient modern braking systems, the onset of skidding generally limits the deceleration capability of vehicles. Typical rates of deceleration and thresholds are:

(1) initial slowing down: 1-3 m/s^2
(2) final braking to stop: up to 3.5 m/s^2
(3) emergency stops : between 6 and 10 m/s^2

The locking of wheels in a non-symmetric manner (with respect to the direction of travel) may induce vehicle swerving (i.e. a loss of control).

Stability

The suspension characteristics of vehicles vary, giving rise to varying degrees of understeer (desirable) and oversteer (undesirable).

Size, Weight and Power

The ability of a vehicle to accelerate depends upon its weight (and vehicle size) and the power (and engine size and performance). Typical acceleration rates in normal use are

(1)	medium cars	3-8 km/h/s (0.85 - 2.20 m/s^2)
(2)	sports cars	12-16 km/h/s (0.33 - 4.50 m/s^2)
(3)	commercial vehicles	0.75-2 km/h/s (0.21 - 0.56 m/s^2)

2.4. THE ROAD ENVIRONMENT

There are five major components of the road environment:

(1) the traffic stream - flow rate, flow composition, traffic speed;
(2) the road design - alignment, road surface, frequency and type of intersections;
(3) the land use adjacent to road - urban, rural, commercial etc.
(4) the legislation and enforcement measures;
(5) climatic/weather conditions, lighting.

The road environment places demands upon drivers and their vehicles. The demand upon a driver varies with time and space, because the road environment changes in time and space.

While driving, one does not maintain a constant level of alertness. Rather, there are periods of high alertness (or concentration) separated by periods of relative relaxation.

The ideal/perfect driver will ensure a matching of his level of alertness with the demands imposed by the road environment. Drivers are not perfect and there are instances where the demands upon a driver are not met, because:

(1) the driver responded too slowly to a changing demand;
(2) the demand exceeded the driver's capability, even when at a peak alertness.

In such situations, an accident may occur; the driver may manage to recover and avoid an accident.

As well as placing demands upon drivers, the road environment can affect the driver's ability to function. For instance:

> weather and lighting conditions affect the physiological functions, either directly (e.g. excessive heat can induce fatigue, with consequent deterioration of physiological functions) or indirectly (e.g. effects upon psychological state of a driver);
>
> also, bad weather can reduce the field of view from within a car (the wipers do not clear the whole windscreen area).

2.5. PERCEPTION-REACTION

At the heart of the user-vehicle-road environment interaction is the process of perception.

Recognising and responding to a stimulus is more complex than simply receiving sensory information (e.g. visual information). Once a stimulus has been detected (e.g. an object has been seen), the road user must interpret the information. The interpretation results from a complex association between the conscious physical and unconscious psychological world.

A stimulus will only be registered by the brain if it exceeds a certain threshold level. There are two major reasons why a stimulus is not registered:

(1) The activity level of the brain (known as the level of arousal) varies, from deep coma through relaxed wakefulness to extreme excitement. High levels of arousal (induced by strong stimuli or superposition of several stimuli) are normally followed by a period of low response (or recuperation). Regular stimuli of similar type and magnitude, may impose rhythmic sensations upon the brain, leading to a hypnotic state (e.g. regularly spaced service poles at side of road crossing expansive plain can induce hypnosis).

(2) There are stronger stimuli competing for attention.

Reaction time is defined as that time which elapses between the reception of an external stimulus and the taking of an appropriate action.

Reaction time necessarily includes perception time. Complex and new situations require more thought and association with past experience, in order to identify an appropriate action, than do simple or frequently encountered situations (e.g. a red traffic signal). This thinking process is known as intellection.

Intellection does not always follow perception - emotion sometimes intervenes, giving rise to irrational decisions/actions. Emotion is a strong, complex mental and physical response to external stimuli. Emotion can exert a powerful effect upon driver behaviour (e.g. irritation at other drivers).

Volition is the exercise of the will and the settlement of deliberation by making a decision, which is actioned.

Traffic engineers are interested in the total time taken, that is the perception-intellection-emotion-volition time (or PIEV time). It is also commonly called the perception-reaction time.

Consider the following simple sequence of events:

(1) at time t_0, an obstruction on intended vehicle path becomes visible;
(2) at time t_1, the driver registers the fact that his intended path is obstructed;
(3) the driver thinks about the situation and considers alternative actions, before deciding at time t_2 to stop;
(4) at time t_3 the driver commences depressing the brake pedal.

t_1 - t_0 - perception time

t_2 - t_1 - intellection time
t_3 - t_2 - volition time
t_3 - t_0 - PIEV time

In the above sequence, emotion appears to have not entered into the process. If the driver determines that the obstruction is a vehicle which should have given way, he may decide to 'teach the other driver a lesson' and ram into the obstruction (which may be relatively small).

Most studies of perception-reaction time have been confined to estimating driver brake reaction time (i.e., the time taken to perceive the situation, to decide upon applying the brakes, and to commence depressing the brake pedal).

It has been found that brake reaction time depends upon:

(1) whether the stimulus is expected or unexpected;
(2) the strength of the stimulus.

For example, in laboratory tests, the average b.r.t. is 0.4 to 0.5 sec, compared to normal road conditions, where the average b.r.t. is:

0.8 sec - if brake lights of preceding vehicle functioning

1.7 sec - if brake lights of preceding vehicle not functioning

Steering reaction time is shorter than brake reaction time. However, the perception-reaction time for more complex or new situations may be much greater - between 2 and 6 seconds.

Finally, it seems that brake reaction time is not correlated with accident frequency. Although brake reaction time has been found to increase with age, it seems that this is not the cause of a higher accident rate amongst aged persons. Rather, they display a greater tendency to allow their attention to drift and are more easily distracted from the prime task when driving.

3. A COMPREHENSIVE STRATEGY FOR ACCIDENT COST REDUCTION

3.1. ACCIDENT FACTORS

During the 1960s and 1970s, a number of in-depth investigations of road accidents were undertaken in several countries, with a view to obtaining a better understanding of the factors involved in accidents (the "causes") and the interrelationships between those factors. The results of three of the more notable studies are shown below, with factors having been grouped as "road environment" (E), "user" (U) or "vehicle" (V), or some combination.

E	U	V	EU	EV	UV	EUV
2.0	76.5	3.0	16.0	0.1	2.0	0.3
	UK, 1978-81 (Sabey, 1983)					
2.5	65.0	2.5	24.0	0.3	4.5	1.4
	UK, 1970-74 (Sabey & Staughton, 1975)					
3.3	57.1	2.4	26.4	1.2	6.2	2.9
	USA, 1972-77 (Treat et al, 1977)					

Single	(U + E + V)	81.5	70.0	62.8
Double	(EU + EV + UV)	18.1	28.8	33.8
Triple	(EUV)	0.3	1.4	2.9
		UK, 1978-81	UK, 1970-74	USA, 1972-77

Note: (1) Substantial difference in study results in the extent of user/environment interaction

(2) Bias towards blaming user?

Sub-System	% of accidents in which involved		
E	18.4	28.2	33.8
U	94.8	94.9	92.6
V	5.4	8.7	12.7
	UK, 1978-81	UK, 1970-74	USA, 1972-77

Results of studies of accident factors seem to suggest the greatest potential for reducing accidents lies in changing user behaviour.

When a user fails to cope with the road environment, the "cause" may be ascribed to user error. However, changes to the environment so that more users can cope may well be more cost-effective and practicable.

Accident costs can be reduced by:

(1) reducing accident frequency
(2) reducing injury severity

Primary safety measures reduce accident frequency
(e.g. improved geometry, relocation of poles)

Secondary safety measures reduce injury severity
(e.g. seat belts, energy-absorption systems)

3.2. POTENTIAL SAVINGS

Sabey and Taylor (TRRL, 1980) estimated the potential savings of proven remedial actions, for which there is strong evidence of potential benefits.

They estimated, for each remedy individually,

(1) the % reduction in accidents or injuries (x%, say)
(2) the % of accidents or injuries susceptible to reduction by the remedy (y%, say)

The potential accident cost saving is simply (xy).

The individual remedies were grouped, as follows:

		POTENTIAL SAVING (%)
Environment - Overall		20
Geometrical design, especially junction design and control		10.5
Road surface texture		5.5
Road lighting		3.0
Land use, road design and traffic management in urban areas		5.0 to 10.0
User - Overall		33.3
Drinking and driving restrictions		10.0
More appropriate speed limits		5.0
Propaganda and information		up to 5.0
Enforcement		up to 5.0
Education and training		up to 5.0
Other (e.g. parking restrictions)		up to 5.0
Vehicle - Overall		25
Vehicle maintenance	)	2.0
Anti-lock brakes and safety tyres	) primary	7.0
Improved motorcycle conspicuity	)	3.5
Seat Belts	)	7.0
Other occupant protection measures	) secondary	5.0 to 10.0
All Measures		60

Sabey and Taylor conclude that it is possible to obtain

(1) a 60% reduction in the cost of injury accidents
(2) a 50% reduction in the cost of non-injury accidents (must exclude effects of secondary measures)

A recent review of road safety policy in the UK (Department of Transport, 1987) concluded that a reduction

(1) of 30% in injuries per annum by the year 2000 is reasonable (i.e. 320,000 to 220,000 per annum).

(2) the bulk of the reduction (80% of the 100,000) will be achieved by the "indirect approach" and only 20% by the "direct approach".

Indirect approach: involves creating an environment in which the scope for the road user to behave in an unsafe manner is reduced.

Direct approach: involves inculcating in each road user an understanding of the standards of skill and behaviour conducive to road safety and persuading each user to comply with those standards.

Note that here, "environment" refers to what surrounds the user and thus includes both the vehicle and the road environment.

	Expected Injury Saving
Direct measures	20,000
Indirect measures:	
(i) vehicle	43,500
(ii) safety benefits of highway improvement schemes	15,000
(iii) safety engineering (especially accident investigation and prevention in urban areas)	21,500

3.3. ACCIDENT INVESTIGATION AND PREVENTION

In the UK, each local authority has a statutory obligation (Road Traffic Act, 1984, s.8) to:

> "prepare and carry out a programme of measures designed to promote road safety, and shall have power to make contributions to the cost of measures for promoting road safety taken by other authorities or bodies".

To assist local authorities to discharge their statutory obligation, the Institution of Highways and Transportation have produced "Highway Safety: Guidelines for Accident Reduction and Prevention" (second edition, 1986).

In the guidelines, it is stated that:

> "The whole area of accident reduction and prevention endeavour calls for a systematic approach to achieve:
>
> (1) the greatest benefits from minimum cost
> (2) to enable past work to be evaluated."

This is tantamount to saying that a "comprehensive strategy" is required for improving road safety.

Development of a comprehensive strategy will entail the following:

(1) Defining overall objectives and setting quantified targets.

(2) Determining what financial and staff resources are required and ensuring those requirements are met.

(3) Identifying what data is required and ensuring they are available.

(4) Establish appropriate procedures for the analysis and interpretation of the data, and the development of effective remedies and a programme of works.

(5) Implementing that programme and monitoring the effects, checking that the overall objectives and specific targets are being achieved.

Non-achievement of targets should result in an analysis of the reasons and either

(i) allocating more resources or revising the data collection, data analysis and/or solution synthesis stages;

(ii) revising objectives and/or targets.

3.4. OBJECTIVES AND TARGETS

The IHT guidelines propose the following objectives:

> "To reduce the overall number and severity of accidents by road engineering and traffic management through
>
> (i) the application of cost effective measures on existing roads as a basis for accident reduction, and
>
> (ii) the application of safety principles in the provision, improvement and maintenance of roads as a means of accident prevention."

A survey of highway authorities in the UK has revealed that virtually all accept the IHT statement of objectives (Silcock and Smyth, 1985).

The IHT guidelines endorse a 20% saving as a feasible target for accident reduction by low cost engineering measures, as proposed by Sabey and Taylor (1980) and confirmed by the Department of Transport (1987).

3.5. FINANCIAL AND STAFF RESOURCES

Experience in the UK, NZ and elsewhere has revealed that "low cost engineering measures" aimed at accident reduction are very cost-effective, in general. A typical first-year-rate-of-return is 200% - 300%.

It is now common that a specific financial allocation of funds is made for such work, which is generally the most cost-beneficial of the works undertaken by highway/roading authorities.

The need for the application of safety principles in roading improvement schemes to reduce delay, etc. must not be forgotten. The budget allocation for the planning, design and implementation of such schemes must allow for "safety checking".

> "Low cost engineering measures": the cost of the implementation is low, but the cost of preparatory work is high relative to the implementation cost. Preparatory work is typically 20% - 50% of the total cost (c.f. 2% - 5% for other roading improvement schemes).

The preparatory work is time-consuming and requires specialist skills:

> "The technique of accident investigation and the design of remedial measures requires specialist engineering expertise of a high order."
>
> IHT guidelines.

The IHT recommends the establishment of a separate, specialist accident unit, giving

(i) economies of scale
(ii) improved effectiveness through the pooling of expertise

The recommended staffing level is 1 engineer (or highly skilled technician) for every 400 - 1000 injury accidents in the authority's area each year.

The accident unit would be responsible for:

(i) accident investigation and prevention via low cost works
(ii) safety checking of other roading improvement works

The latter task can readily take 20% - 25% of staff time.

Appropriate training for new road safety engineers and technicians is essential. In addition, it is a relatively new field of work, and new techniques are being developed. Hence, up-dating via continuing education is important.

3.6. DATA-BASE REQUIREMENT

The IHT state that a basic data system is needed, for

(i) investigation and assessment of sites and situations amenable to accident reduction by cost effective measures
(ii) assessment of safety implications of new highway and traffic management schemes
(iii) monitoring results

The basic data will need to be supplemented by data specially collected for detailed investigations of specific locations or problem areas.

Three types of data are required, relating to

(i) accidents
(ii) road
(iii) traffic

3.6.1. Accident Data. The accident data required are as follows:

(i) Basic accident description: (accident reference number, severity, no. vehicles, no. injuries, date, day, time, location, contributory factors)

(ii) Road features: (class and identification no. of road(s), carriageway type/markings, speed limit, junction type and form of control)

(iii) Environmental features: (pedestrian crossing facilities, light conditions, weather, road surface condition, special conditions and hazards)

(iv) Vehicle features: (type, manoeuvres and directions of movements, vehicle locations with respect to road or junction, whether skidding and/or overturning, whether left carriageway, location and nature of objects struck)

(v) Driver features: (sex, age, whether breath/blood tested, whether fled from scene)

(vi) Casualty (Injury) details: (user class, sex, age, severity)

(vii) Pedestrians: (location, movement, direction, whether going to/from school if attending school)

Note: If treat cycles as vehicles, include cycle/cyclist details above, but may treat separately (as for pedestrians).

3.6.2. Road Data. The road data required are as follows:

(i) Geometric details (curvature, grade, lane numbers and widths, shoulder type and width, median width)

(ii) Road surface details (type, macrotexture, microtexture)

(iii) Physical aids (lighting, signs and markings)

(iv) Permanent extraneous features (noticeboards, posts, guard rails, street furniture)

(v) Speed limits, adjacent land use

3.6.3. Traffic Data. The traffic data required are as follows:

Traffic flow and composition, and pedestrian flow (with hourly, daily and seasonal variations)

Traffic speeds

3.6.4. Data-base Management. This is required for:

(i) avoiding the omission or duplication of records
(ii) manipulation of data to produce tables, plots and statistical significance reports

Integration with mapping graphics software enables different types of accidents to be selectively plotted over maps of areas, showing the road network. Such pictorial presentations can assist considerably with the analysis and interpretation of accident data. Accident diagrams showing movements and locations of accidents are very useful.

3.7. ANALYSIS AND SYNTHESIS

Accident reduction programmes can take several forms:

(i)	single site plans -	treat sites of accident clusters (blackspots)
(ii)	route action plans -	treat routes (black routes)
(iii)	area action plans -	treat areas with many dispersed accidents
(iv)	mass action plans -	have well-known remedy (e.g. anti-skid surfacing for wet-road accidents) and apply to locations with sufficient number of accidents susceptible to that remedy

The choice of plan depends upon the pattern of accident occurrence.

The plans differ with respect to:

(i) the expected accident reduction
(ii) the economic return

Type of Plan	Expected Accident Reduction	Expected Economic Return (*)
single sites	33%	> 50%
routes	15%	> 40%
areas	10%	10%, to 25%
mass	15%	> 40%

* first year rate of return

(i) Should start with single site (blackspot) plans.

(ii) If these are effective, will have to aggregate sites (routes) to have blackroutes, which can treat with route action plans.

(iii) If these are effective, will have accidents well dispersed, and can treat areas with many accidents, by managing the traffic in the area as a whole (i.e. identifying and enforcing a roading hierarchy in the area).

That is, have a natural progression or evolution process.

There are essentially three stages in the development of an accident reduction program:

(i) identification (of blackspots, blackroutes, blackareas, or sites with sufficient susceptible accidents)
(ii) diagnosis - not required for mass action plans
(iii) selection - ditto

3.7.1. Identification. This stage involves selecting sites, routes and areas which have above-average accident occurrence or an identifiable pattern of accidents.

It might be ideal to examine in detail all sites, routes and areas, but this is impractical.

The identification stage acts as a screen, to reduce drastically the sites/routes/areas for detailed examination.

Hopefully, the truly worse-than-average sites, etc. will be caught by the screen (i.e. identified).

Whether this is achieved depends heavily upon the quality of the techniques and criteria used for the identification process.

The techniques used include:

(i) analysis of accident, road and traffic statistics

(ii) preparation of maps showing location of selected accident types on the road network

(iii) grouping of data for sites of similar physical and/or accident features, as basis of mass action plans

(iv) monitoring surveys of physical characteristics of the road network (e.g. skidding resistance, road roughness)

The analysis of statistics involves the use of criteria, such as:

(i) critical number of accidents and/or
(ii) critical accident rate (per exposure).

3.7.2. Diagnosis. This is the procedure of analysing the symptoms of the accident problem at each individual site, etc., to identify

(i) the cause(s) of the accidents
(ii) appropriate remedial treatment(s).

This stage involves some or all of the following techniques:

(i) analysis of accident details

(ii) analysis of diagram showing locations and movements of participants for all accidents

(iii) study of road (network) and traffic characteristics

(iv) on-site observation of environment, user and vehicle characteristics

(v) on-site observation of traffic behaviour (traffic conflicts technique) and analysis of results

3.7.3. Selection. This is the final stage, involving:

(i) deciding on best treatment at each individual site, etc., taking account of the cost and benefit of each alternative treatment

(ii) deciding on the best programme of work, taking account of the costs and benefits of the best-treatments and the budget constraint.

3.8. IMPLEMENTATION AND MONITORING

Must implement plan as designed.

Must monitor effects of plan and reduce uncertainty with regard to estimating benefits during design.

Must monitor progress towards goals/targets and make changes to them and/or resource allocation if necessary.

4. ACCIDENTS, VEHICLES, POPULATION, SMEED TYPE ANALYSIS

4.1. PROBLEMS

a) Inaccuracy - The extent of inaccuracy varies from country to country, and between areas within countries. Types of inaccuracy include reporting errors and transcription errors. One can never hope to be completely accurate, though the nature of the recording system (complexity, user friendliness etc.) can have a big effect upon the accuracy obtained, as can the enthusiasm of the police officers who collect the data for filling in forms!

b) Underreporting - An OECD committee in 1983 accepted that accident reporting is far from complete. The problem is more severe the less serious the accidents. Studies have also shown that underreporting is more prevalent among the so-called 'unprotected' road-users (pedestrians, cyclists, and users of powered two-wheeled vehicles). Most international comparisons of road safety use fatalities rather than injuries on the basis that underreporting is less likely to be a problem.

c) Definition problems - OECD say "methods for data collection differ significantly from country to country and the definitions used for certain accident terms are often at variance". This problem is also apparent when examining trends in accidents as systems of recording change with time. Common types of definition problems include the definition of a fatality, definition of severity, type of vehicle etc.

4.2. METHODS OF MAKING INTERNATIONAL COMPARISONS

A number of commonly used methods exist:

1) Comparison of accident numbers - Easy to do, especially for gross figures, as data is available for most countries in annual series e.g. Road Accidents Great Britain, World Road Statistics etc. The conclusions which can be drawn from these figures alone are limited, and should be treated with care and a certain degree of scepticism. Comparisons of accident numbers alone fail to take account of differences between countries, in particular size, population, length of road system, number of vehicles and so on. These figures take no account of differences in exposure between countries.

2) Accident rates - Typically these take account of one other factor on the number of accidents in a country, so that it is possible to control for size, population etc. The most common rates used are: Fatalities per 10,000 motor vehicles
Fatalities per 100,000 population
Fatalities per 1000 million vehicle kilometres

The first two are more limited in use than the third as they take no account of the amount of use that is made of the road by road users. International comparisons based on rates per 100,000 population have to be interpreted with care as the ratios do not take account of the degree of exposure, which will vary according to factors such as the number of motor vehicles in use, the distribution of the victims amongst different categories of road user, and the relative rates in built up and urban areas

It is generally acknowledged that the number of accidents per vehicle kilometre travelled is the most useful of the three measures, as it more clearly relates to exposure. However, there are numerous problems in the collection of this data, and the accuracy and consistency which can be achieved in different countries. There is also the problem that if accidents rise at the same time as increasing motorisation, there is the possibility of this rate dropping, creating a false impression of safety.

Some other rates which have been used to make international comparisons, often as surrogates where data for one of the above does not exist, are:

a) number of accidents per 1000 million US dollars GNP
b) number of fatalities per 100 million tonnes of road transport fuels
c) the average number of deaths per accident
d) number of fatalities as a proportion of mortality from all causes

The table below shows the types of data which were collected in a study which attempted to compare road safety between the US and Western Europe.

Table 5.1.2-1: Vital statistics for Western Europe and the United States (1980).

Statistics	Western Europe	United States
Population (millions)	283.6	227.2
Population density (Inh./square km)	120.5	23.9
Motor vehicles registered (millions):		
Total	118.4	161.5
Passenger cars	91.2	121.7
Trucks and buses	11.1	34.1
Motorcycles and mopeds	16.1	5.7
Vehicle kilometres of travel (1000 millions)	1459.3	2433.4
Injuries (1000's)	1673.2	2000.0
Fatalities:		
Total	51451	51091
Per 1000 million veh km	34.8*	21.0
Per 100,000 inhabitants	18.1	22.5
0-14 years	3894	3747
15-24 years	15136	18459
25-64 years	21578	23215
Over 64 years	10303	5341
Pedestrians	11278	8070
Bicyclists	3846	965
Motorcyclists and moped riders	9105	5144
Passenger car occupants	24746	27449
Truck and bus occupants	2006	7899

* Without Denmark

Source: Lamm et al,1985

4.3. THE SMEED EQUATION

A further method of comparing fatality rates between countries was put forward by Smeed (1949). He showed empirically by using data from 20 developed countries for the year 1938, that the number of road accident fatalities in these countries was related to the population and the number of motor vehicles, and that this relationship could be described generally by the formula:

$$D/N = a\,(N/P)^{-b}$$

where D = annual number of fatalities;
N = motor vehicle registrations;
P = population;
a,b = constants.

By means of a regression analysis, using data from these 20 countries, the constants a and b were shown to be 0.0003 and 2/3 respectively.

In a later study Smeed examined data for 1930 and 1950 from 18 of the original 20 countries. Then in 1970 he examined data from 68 countries for the years 1960-67. In both studies it was shown that the above equation still produced good results using the same coefficients. Other authors have also studied the consistency of the Smeed equation. Adams (1985) has shown that the Smeed equation is a reasonably good fit using data from 1980 for 62 countries. A separate study used as near as possible Smeed's original countries and repeated the analysis for the years 1950, 1960 and 1970. The relationships they derived were very similar to those found by Smeed. In 1950 the values of the coefficients were a = 0.00034 and b = 0.58, in 1960 the values were found to be a = 0.00034 and b = 0.60, and finally in 1970 a = 0.00039 and b = 0.56. In a subsequent analysis of the situation in developing countries, it was shown that in 1968, a = 0.00077 and b = 0.40, and in 1971 a = 0.000914 and b = 0.43. It has been suggested that the variation in the value of 'a' is related to the level of safety in a country. Those countries which consistently have values lower than the 0.0003 suggested by Smeed (such as GB) can be said to have higher levels of safety, while countries which have values consistently higher (such as the Federal Republic of Germany) can be said to have lower levels of safety.

It was shown in the original 1949 paper, using data from 1938, that 10 of the 20 derived values of the number of deaths were within 15% of the actual values, 19 were within 40%, and 1 was in error by 67%. Thirty years later, in only 5 out of 70 countries, using 1968 data, is the ratio of the recorded to the predicted number of deaths outside the range 0.5-2.0. 33% of the actual numbers of fatalities are within 15%, and 67 are within 40% of the expected.

Various reasons have been put forward as to why fatality data from such differing circumstances should always apparently follow this general pattern. Smeed himself says "as the population accident rate becomes higher the urge to do something about it becomes greater, and that something is in fact done. In addition, as the number of motor vehicles increases, which is in practice as time goes on, people are growing up and becoming more used to dealing with the situations which motor traffic causes". He suggests "that the number of road fatalities in any country is the number that the country is prepared to tolerate. When the number of road accidents is greater than the tolerance level, new road safety measures are adopted".

Smeed predicted that there would be an almost universal tendency for fatalities per vehicle to fall with increasing motorisation. Some of the reasons suggested for this reduction include the trend in technically developed countries for a reduction to occur in the exposure of pedestrians, pedal cyclists, and (until recently) motorcyclists, all of whom have high risk of involvement in road accidents, and of receiving fatal injuries when so involved. For motor vehicles to become safer as technology improves, for the number of kilometres driven per vehicle to decrease as motorisation increases and for a shift to always higher proportions of cars, which are a relatively safe type of vehicle, compared to pedal cycles and motorcycles.

Criticisms of the Smeed equation

Most such criticisms seem to concern its accuracy. Numerous studies have found different values of a and b which fit a particular data set better than the original equation. However, Smeed's equation has been found to apply over such a wide range of circumstances, and while it is obviously possible to define a new equation which fits a particular data set more accurately, it is unlikely that this new equation will be as widely applicable. The fact that Smeed's equation does not exactly fit all data sets does not detract from its general usefulness. It provides a simple tool in international comparisons, which accounts for the relative size of a country (population) and level of motorisation (number of motor vehicles). It is neither a causal model, giving reasons why this relationship should be so, nor does the equation account for a wide variety of possible influencing factors. It also accommodates within the limits of variation around the basic equation a wide range of values. There is, however, scope for recalibrating Smeed's equation for the post-1973 years in view of the widespread reduction of fatalities experienced since then.

More specific criticisms have been cited in the literature concerning the mathematical techniques used by Smeed and subsequent users of his equation (see Andreassen, 1985). It is questioned whether the original regression equation can be manipulated algebraically to produce some of the derivative forms of the equation. He also considers the inaccuracy of the equation and concludes that Smeed's original analysis of 20 countries for one year of data was just that, and "cannot be extended to predict the number of deaths in any year in any country". This statement is true as it stands, although the Smeed equation can give a very good idea of the likely number of accidents in a country, but, the real aim of the equation is to identify countries which have large differences between the actual and expected numbers of deaths, and in so doing point towards areas where further more detailed research may be rewarding.

The Smeed equation has recently been the subject of considerable debate in road safety circles. The principle protagonists are probably John Adams from Britain and David Andreassen from Australia. The debate has taken up sizable chunks of the journal Traffic Engineering and Control recently in terms of articles and letters to the editor. Some of the content of this discussion has been mentioned above, though a much more detailed idea of the arguments should be gained by looking through back issues of the journal Traffic Engineering and Control for the years 1987 and 1988.

4.4. OTHER TECHNIQUES

As has already been mentioned, the Smeed equation was a regression equation which considered the effect of two factors upon the number of fatalities caused by motor vehicles (i.e the population and number of motor vehicles). It was shown that a large degree of variation between countries and over a wide variety of time periods can be explained by these two factors.. However, despite this, there is sufficient variation between the actual number of deaths and those predicted by the equation in many countries, to suggest that other factors also have substantial effects upon the number of accidents. Several studies have attempted to assess how much more accuracy can be gained by using a model with more than 2 factors. These studies use multiple regression techniques.

One particular study carried out in 1975 examined the effect of 6 factors thought to influence mortality rates from motor vehicle accidents. These factors were:

a) the numbers of vehicles per person in the total population;
b) the length of roads per unit area of country;
c) the proportion of the population in large urban areas;
d) the proportion of the population under 19 years;
e) the proportion of the population over 65 years;
f) the proportion of taxis and private cars in the total number of motor vehicles.

The study used data from 17 european countries for 1970, and concluded that for only three of the variables is there evidence in these data of a significant relationship with the levels of mortality due to motor vehicle accidents (at the 0.05 level of confidence). These were factors a, b and e.

Two other models are worth mentioning briefly here:

1) Sivak's 'Societal violence, young drivers and accident propensity model': This was a model created by applying multiple regression to 1977 data from each of the individual states in the USA. Traffic fatalities per registered vehicle was the dependent variable. The independent variables were the states' homicide rate, suicide rate, fatality rate from non-traffic accidents, unemployment rate, personal income, density of physicians, alcohol consumption, motor vehicles per capita, road mileage per vehicle, sex and age distribution of drivers, and attained education. From among these independent variables, only three proved to be significant predictors of traffic fatalities: homicides per capita, proportion of drivers under 25 years of age, and fatality rate from non-traffic accidents. These three variables accounted for 68% of the variance of states' traffic fatality rates. These results suggest the possibility that (a) " society's level of violence and aggression affects the extent of aggressive driving, and, consequently, the frequency of traffic accidents"; and (b) " young drivers are a significant factor in the traffic accident problem, probably because of their lack of experience".

2) Partyka's economic model: This is a model that was based on employment and population data using data from 1960 to 1982. The model was of the following form:

$$D = -101,605 - 0.0018569U + 0.0004971E + 0.0009616N$$

where D = traffic fatalities;
U = unemployed workers;
E = employed workers;
N = non-labour force (population - (U + E)).

As an interesting test of these models, Sivak in a more recent piece of work compared the results which would be obtained by fitting 1985 data (for the US) into the models, with what actually happened in 1985 (i.e a retrospective test of their predictive power). The following were the results obtained:

Model	Fatalities
Smeed's degree of motorisation model	64,816
Sivak's societal violence model	40,590
Partyka's economic model	54,730
Actual no. of fatalities in 1985	43,795

It can be seen that the different models met with differing degrees of success, with Sivak's societal violence model being the closest with an underestimation of the true figures by only 7%. It should be remembered that the Smeed equation, while providing the worst estimate, is calibrated on the basis of 1938 data. In conclusion, by careful examination of factors, these more complex multiple regression models can be made so that they explain more of the variation in the accident patterns at one point in time, than more simple models such as Smeed's. However, it is unlikely that they will be as consistent as Smeed's model over a long period of time, or over such a wide range of countries. This is because the extra variables taken into account (and the relationships between them) will vary from place to place and over time.

5. ACCIDENTS, EXPOSURE, RISK AND TRAFFIC FLOWS

5.1. INTRODUCTION

The number of accidents at a site, along a route or within an area, during a time period can be considered to depend upon:

(1) the number of potential accident situations that arise (N);

(2) the probability of an accident occurring, given a potential accident situation has arisen (p).

The interaction between the exposure N and the risk p gives rise to A accidents, where:

$$A = Np$$

Although sites (or routes or areas) may have the same accident exposure during a time period, the number of accidents may differ, because of variations in accident risk, which depends upon local conditions.

The number of accidents can be reduced by:

(1) reducing the exposure N,
(2) reducing the risk p.

The accident exposure can be reduced by:

(1) reducing the amount of travel,
(2) traffic management measures (e.g. banning turns across an opposing straight-through movement).

While the accident risk can be reduced by traffic management/engineering (e.g. changing intersection layout so that drivers of turning vehicles have a better view of opposing straight-through vehicles and can judge better when the turn can be made safely).

Reducing the amount of travel is outside the scope of this course.

5.2. MODEL ESTIMATION

The number of accidents in a period is observable, but exposure and risk are theoretical concepts and are not observable.

If it is assumed that both risk and exposure are functions of traffic flows alone, then it follows that the number of accidents is also a function of traffic flows alone. This assumption is often made, despite the fact that it is obviously an oversimplification; the number of accidents depends on several factors, of which traffic flow is but one. This assumption is justifiable when it is not feasible to take account of thew other factors (e.g. when devising a new traffic plan using a traffic management model, such as SATURN).

If:

$$A = A(q)$$
$$N = N(q)$$
$$p = p(q)$$

where:

$$q = \text{traffic flow (or flows)}$$

then there are essentially two approaches available for model estimation:

(1) a purely empirical approach, involving finding a relationship directly between the number of accident and traffic flows (risk and exposure are not estimated separately).

(2) a theoretical-empirical approach, involving:
  (a) defining N(q) on the basis of theoretical considerations
  (b) observing A(q)
  (c) obtaining $p(q) = A(q)/N(q)$

5.3. LINK EXPOSURE FUNCTION

The form of the accident exposure function depends upon the type of accident:

(1) single-vehicle accidents
(2) rear-end accidents
(3) head-on accidents

5.3.1. Single-vehicle accident exposure. The exposure may be:

(1) time-based (each instant of time a vehicle is on the road amounts to an exposure)

(2) distance-based (each small distance travelled amounts to an exposure)

A vehicle travelling for time T gives rise to ($T/\Delta t$) exposures, while a vehicle travelling a distance S gives rise to ($S/\Delta s$) exposures, where:

Δt = instant of time
Δs = small distance

In order that the two estimates of exposure are equal, it is necessary that:

$$(\Delta s/\Delta t) = V$$

where

v = vehicle speed

Consider a section of road (length S) with vehicles travelling in one direction at a mean speed v and flow rate q, for a period T. At the start of the period, the expected number of vehicles in the section will be:

$$S\ (q/v)$$

and those vehicles will travel, on average, only S/2 within the section. There will be an equal expected amount of travel within the section by vehicles in it at the end of the period.

The number of vehicles expected to enter and leave during the period T, travelling a distance S within the section, is :

$$qT - S\ (q/v)$$

Hence, the total amount of travel is:

$$[qT - S(q/v)]\ S + 2\ [S(q/v)]\ (S/2) = qTS$$

Now the choice of Δs (or Δt) is arbitrary, the only constraint being that once a value is selected for one, then the other must be such that $(\Delta s/\Delta t)$ equals the mean speed. Hence, the number of exposures for the road section is:

$$qT\ S/\Delta s$$

and if Δs is 1 km, the number of exposures is:

$$N = qTS \text{ veh-km/km}$$

The arbitrariness of the choice for Δs (or Δt) is not a problem, if one is estimating the number of exposures for comparison purposes; if the number of exposures for two roads are N_1 and N_2, then the ratio of the exposures is unaffected by changes in Δs (or Δt), so long as one uses the same Δs (or Δt) for all roads to be compared.

5.3.2. Rear-end accident exposure. Consider a single lane of vehicles travelling in the same direction, with flow rate q. Consider now the case of two consecutive vehicles, the leader 1 and the follower 2, travelling at speeds v_1 and v_2 respectively. Let h be the headway between them.

Now, if

$$\begin{aligned} v_1 &> v_2 \quad , \quad h \text{ is increasing} \\ v_1 &< v_2 \quad , \quad h \text{ is decreasing} \\ v_1 &= v_2 \quad , \quad h \text{ is constant} \end{aligned}$$

The interaction between consecutive vehicles can be analysed using car-following models. It is generally believed that the driver of the following vehicle will endeavour, by varying speed, to maintain a spacing or headway that the driver considers appropriate. Hence, it is unnecessary to consider both speeds and headways; it is sufficient to consider headways alone.

Let $\psi(h)$ = headway probability density function. Now, in general, the traffic flow comprises:

(1) free-flowing vehicles

(2) vehicles travelling in platoons

and the overall headway pdf can be consider the sum of two pdf's:

$$\psi(h) = m\phi(h) + (l\text{-}m)\ \theta(h)$$

where:

$\phi(h)$ = headway pdf for vehicles in platoons
$\theta(h)$ = headway pdf for free-flowing vehicles

m = proportion of vehicles travelling in platoons

There will be an upper limit to h in $\phi(h)$, beyond which headways would belong to $\theta(h)$. Let that upper limit be H_2, such that where the headway is greater than H_2, there is negligible potential for a rear-end accident to occur.

There will be a lower limit to h in $\phi(h)$. Clearly, the minimum possible headway, without an accident having already occurred or being in the process of occurring, is

$$H_1 = L/v^*$$

where:

L = length of the leading vehicle
$v^* = v_1 = v_2$

At a point in time, the number of vehicles exposed to a rear-end collision is simply the number of vehicles travelling with headways between H_1 and H_2. The proportion of headways between H_1 and H_2 is:

$$\int_{H_1}^{H_2} \psi(h)\ dh$$

For a section of road (length S) with vehicles travelling in one direction at a mean speed v and flow rate q, the expected number of vehicles in the section at any time is

$$S\ (q/v)$$

whence it follows that the expected number of headways between H_1 and H_2 is

$$S\ (q/v) \int_{H_1}^{H_2} \psi(h)\ dh$$

The number of exposures during a period T can be obtained by integration over time.

The exposure for rear-end accidents is rather difficult to estimate (much more so than for single-vehicle accidents).

5.3.3. Head-on accident exposure. There is a potential head-on accident whenever two vehicles travelling in opposite directions pass one another, and the head-on accident exposure is simply the number of such events.

Consider a section of road (length S), carrying opposing flows q_a and q_b, with mean speeds v_a and v_b respectively.

Consider now a vehicle i in flow q_a, travelling at speed v_i. It will meet during its passage through the section, the sum of:

(1) the number of b-flow vehicles in the section at the time it enters
(2) the number of b-flow vehicles entering the section during its time of transit.

That is, it will meet:

$$S\,(q_b/v_b) \;+\; q_b\,(S/v_i)$$

vehicles.

During a period T, the number of a-flow vehicles entering the section will be (q T), and hence the total number of exposures in the section in such a period is

$$N = \sum_{i=1}^{q_aT} [S(q_b/v_b) + q_b(S/v_i)]$$

$$= q_aq_b\,ST/v_b + q_bS \sum_{i=1}^{q_aT} (1/v_i)$$

In general, the variation in vehicle speeds in a stream of traffic is not great, the coefficient of variation typically being about 0.2, and it therefore follows that

$$\sum_{i=1}^{q_aT} (1/v_i) \equiv q_aT/v_a$$

Hence, it follows that the total number of exposures is approximately:

$$q_aq_bST\,[(1/v_a) + (1/v_b)]$$

Note that the corrections for:

(1) vehicles in the section at the start of the period
(2) vehicles in the section at the end of the period

are of equal magnitude and they cancel each other.

5.3.4. Discussion. The form of the expression for exposure depends upon the type of accident being considered. In order to obtain an expression for overall exposure, it is necessary to combine the exposures for the three types of accidents. To date, this has not been done, and it is clearly not a trivial task. For instance, when the driver of a vehicle loses control, the vehicle may cross the roadway for opposing traffic, and it will be a single-vehicle accident if no opposing traffic is hit and a head-on accident of one is hit. In general, vehicle-km is used as an index of overall exposure.

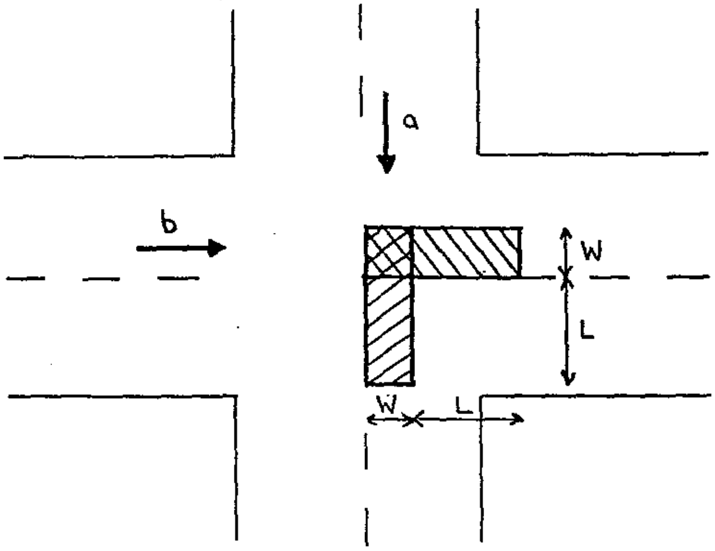
The appearance of the inverse of speeds in the expression for the head-on accident exposure implies that the higher the speeds the less is the exposure. This may seem invalid, but for a given section of road it is true. It must be remembered that in estimating exposure, one is interested in the potential number of accidents and not the risk of an accident; the risk (p) may well increase with an increase in speed at a greater rate than exposure (N) decreases, so that accidents may increase with an increase in speed.

5.4. INTERSECTION EXPOSURE FUNCTION

At an intersection, there are one or more conflicting manoeuvres which may be made. The number of exposures occurring at an intersection can be estimated by considering each pair of conflicting (crossing/merging/diverging) separately, and summing to get an overall estimate for the intersection as a whole.

Consider two conflicting movements, with flow rates q_a and q_b. Assuming average vehicle lengths and widths of L and W, respectively, and that the mean speed for both movements is v, then there is a collision area as shown in Figure 1.

FIGURE 1



The transit time through the collision area is:

$$t = (L + W)/v$$

and assuming vehicle arrivals for both movements are independent and governed by a Poisson process, it follows that the probability of a collision (assuming no evasive action) is:

$$[1 - \exp(-q_a t)]\,[1 - \exp(-q_b t)]$$

That is, the proportion of passages that might give rise to an accident is obtained from the headway distributions for the two flows, and is simply the probability of one or more vehicles from both flows wishing to occupy the same space at the same time.

During a period T, the number of exposures is:

$$(T/t)\ [1 - \exp(-q_a t)]\ [1 - \exp(-q_b t)]$$

and when q_a and q_b are both small, it is approximately equal to:

$$(T/t)\ q_a q_b$$

It should be noted that the assumption of a Poisson arrival process is not always appropriate. Where there are heavy flows or traffic signals in the vicinity, the actual headway distributions may be far from negative-exponential.

In addition, it should be noted that in this case, there is a logical basis for the "instant of time" upon which the exposure is based, unlike for the single-vehicle accident on links.

In practice, rather than summing over pairs of conflicting movements, the product of approach flows may be used. Sometimes, the square root of the product of conflicting (or approach) flows is used; the reason for this will be discussed below. Sometimes, the sum of the flows is used, but it seems clear from the analysis above that the exposure is related to the product of the flows.

5.5. ACCIDENT AND TRAFFIC FLOWS (LINKS)

A number of people have endeavoured to relate accidents directly to traffic flows.

Smeed (1949) argued from a theoretical basis that the number of deaths from accidents must be proportional to

(1) the number of vehicles on the road (single-vehicle accidents)
(2) the square of the number of vehicles (two-vehicle accidents)

Belmont (1953) tried a relationship of the form:

$$A = a\,Q + b\,Q^2$$

where:

A = number of accidents in a period
Q = volume of vehicles in that period

and found a poor agreement with empirical data, especially for very high and very low flows. He consequently considered separately the following three accident types:

(1) single-vehicle
(2) head-on
(3) rear-end

and obtained the relationship:

$$A = a\,v^{3/2}\,Q + b\,v\,Q + (c + d\,v)Q^2$$

where:

v = average traffic speed.

Satterthwaite (1981), after reviewing a considerable number of empirical studies, concluded that:

(1) the single-vehicle accident rate (per veh-km) decreases with increasing flow rate
(2) the multiple-vehicle accident rate (per veh-km) increases with increasing flow rate
(3) the total accident rate varies in a U-shaped fashion with flow rate.

As the flow rate increases, the probability of an out-of-control vehicle colliding with another vehicle must increase.

It should be noted that much of the research relating accidents to traffic volumes for sections of road has been incidental to the aim of relating accidents to physical features (e.g. roadway width, curvature, etc.) and has been for rural roads.

Lalani and Walker (1981) derived relationships of the form:

$$A = a\,Q + b\,Q^2 + c\,Q^3$$

where:

A = annual accidents
Q = average daily flow

for major urban arterial streets. With such relationships, they were able to explain 80% to 95% of the observed variation in accident occurrence.

There appears to be discrepancy between Satterthwaite's results and those of Lalani and Walker, whose results suggest accidents always increase as the flow rate increases. The discrepancy may be more apparent than real, as Lalani and Walker studied urban arterials for which the flow rates are high (i.e., they did not observe the full range of flow rate variation).

In some studies, the dependent variable is the number of accidents in a period of time, while in others it is the number of accidents per veh-km of travel. In a recent study (Silcock and Worsey, 1982), it was found that the best explanation was obtained when the dependent variable was "accidents per link" or "accidents per annum", with the link length not being (or part of) an explanatory variable. The apparent irrelevance of link length may be due to the study method, which involved subdividing routes into lengths which may have been of similar length. With little or no variation in link length and link flows, it is not surprising that link length and link flow would appear unimportant. Clearly, the results of studies must be interpreted carefully and with due account of the study method.

Several studies, including those by Silcock and Worsey (1982) and McGuigan (1982), have involved classifying roads according to factors such as land use and carriageway type, and then identifying, for each category, the relationship between accidents and other factors (e.g. flow rates, veh-km of travel). In this way, the explanatory power of the relationships is increased.

The economic evaluation package, COBA-9 (Department of Transport, 1981) uses accident rates (per veh-km of travel) for estimating the safety impacts of a project.

5.6. ACCIDENTS AND TRAFFIC FLOWS (INTERSECTIONS)

One of the earliest attempts to relate accidents to traffic flows at intersections was due to Tanner (1953), who studied 232 rural T-junctions in the UK. He found that the best fit was obtained with the relationship

$$A = 0.0045\, q_r^{0.56} \quad Q^{0.62} \quad + 0.0075\, q_l^{0.36} \quad Q^{0.88}$$

where

$A =$ annual number of accidents
$Q =$ 16-hour flow on "head of tee"
$q_r =$ 16-hour flow "right turning from stem" plus 16-hour flow left turning from "head of tee"
$q_l =$ 16-hour flow left turning from "stem" plus 16-hour flow right turning from "head of tee"

Tanner wanted to simplify the relationship, and proposed the following:

$$A = 0.0045 \sqrt{q_r Q} + 0.0075 \sqrt{q_l Q}$$

on the basis that except for the 0.88, the indices do not differ significantly from 0.5, and the 0.88 is only just significantly different.

The simplified relationship (often generalised to the "square-root law") was confirmed by a subsequent study by Colgate and Tanner (1967), but Bennett (1966) obtained results that did not fit the relationship.

A number of studies have involved relating annual accident numbers to the average daily flows entering from the major and minor roads (i.e. Q_1 and Q_2 respectively). That is, no consideration was given to the movement pattern at the intersections. For example, Leong (1973) studied 243 urban intersections in NSW (Australia), and fitted relationships of the form

$$A = R\ Q_1^a\ Q_2^b$$

The value of the parameters a and b ranged from -0.03 to 0.38 and from 0.07 to 0.49, respectively; the value depended upon the number of arms (3 or 4) and the form of intersection control (signalised or unsignalised).

Leong also obtained a simplified relationship:

$$A = R\ (Q_1\ Q_2)^a$$

where the value of parameter a ranged from 0.21 to 0.45, with the value 0.42 giving the best overall fit.

Two recent studies (Maycock and Hall, 1984; Pickering, Hall and Grimmer, 1986) have considered two particular types of intersection (4-arm roundabouts and rural T-junctions, respectively), and have investigated two forms of model:

$$(1)\ A = R\ Q^a$$
$$(2)\ A = R\ Q_1^a\ Q_2^b$$

where Q, Q_1 and Q_2 are flow functions.

For the roundabout study, three forms of flow function were tried:

(1) total inflow (the sum of the four entering flows)
(2) cross product (the product of the total entering flows on one pair of opposite arms with the total entering flows on the other pair)
(3) entering-circulating (the product of the entering and circulating flows at each entry, summed over the four arms)

For the T-junction study, a total of 10 flow functions (sum or sums of products of the six movement flows) were tried.

These studies resulted in several statistically significant models relating accidents to traffic flows, it being found that accidents are much more closely related to the square root of the product of conflicting flows than to the product or sum of the conflicting flows, thereby confirming the general validity of the "square root law" due to Tanner.

These two studies also investigated the effects of geometric variables, and derived models for accidents stratified according to accident type. For the roundabouts, it was found that changes in the geometry simply results in different proportions of the four main accident types (entering-circulating, approaching, single-vehicle and other).

Further such studies of other junction layouts and forms of control are being undertaken or planned, with the models being for predicting the number of accidents at intersections (given traffic flows and geometric details) as part of the design and appraisal processes.

5.7. RISK FUNCTION

Accidents arise from the interaction of the risk and exposure functions, and the form of the exposure functions have been discussed above. In addition, empirical studies of accidents as a function of traffic flows have revealed relationships as discussed above. Assuming that accidents, exposure and risk are all functions of traffic flow, the form of the risk function can now be inferred.

Consider the case of two conflicting movements at an intersection. There is considerable evidence supporting the "square root law":

$$A = R \sqrt{Q_1 Q_2}$$

In addition, there is a strong theoretical justification for the exposure function being of the form:

$$N = k \; Q_1 \; Q_2$$

Hence, it follows that the risk function is of the form:

$$p = (R/k) \, (1/\sqrt{Q_1 Q_2})$$

This implies that as the traffic flows increase, the risk (or probability of an accident given an exposure) declines. This is consistent with the statement of Tanner (1953) that:

> "it is by no means improbable that as the flows increase, the amount of care exercised by drivers also increases, with the result that the chance of an accident resulting from each encounter decreases."

Simpson (1973) reported that there seemed to be a disproportionately high number of accidents involving right-turning vehicles colliding with opposing straight-through vehicles during off-peak periods. During such periods, the rate of occurrence of accident opportunities is less than during peak periods, and the phenomenon observed by Simpson is readily explained by the risk decreasing as traffic flow increases.

It is common practice to adopt higher design standards for heavily trafficked intersections and routes, and this, along with greater driver vigilance, would explain the reduction in risk as traffic intensity increases. The u-shaped relationship between accidents per veh-km and traffic flows, as proposed by Satterthwaite, also implies a variation in the level of risk with variation in the traffic flow.

6. ACCIDENT OCCURRENCE AS A STOCHASTIC PROCESS

6.1. INTRODUCTION

Accident occurrence is governed by the interaction of various factors, and is subject to both temporal and spatial random variations. Hence, one cannot be sure when the next accident will occur at a particular location, nor can one be sure where the next accident will occur.

Accidents are rare events:

(1) from the UK road controlling authority's viewpoint, the number of accidents in a year is likely to be between about 1/2 to 1 (for urban and rural areas, respectively) for each mile of public road, and the number of accidents per vehicle passage is generally of the order of 1 per million;

(2) from the individual user's point of view, the average UK driver can expect to be involved in one major accident in a "driving life" (40 years at 7000 miles per annum) and it has been estimated (Road Accidents Great Britain, 1986) that about 222,000 (or about 0.4%) of the 55 million persons alive in the UK in 1985 will die as a result of a road accident.

Despite the rarity of accidents, they are undesirable and should be reduced if this can be done in a cost-effective manner.

Accidents are random events. They are not simply haphazard or aimless, but are governed by the basic laws of chance, that when some action can have more than one outcome, then:

(1) where they have an equal chance of occurring, the probability of any outcome in a single trial is the proportion which that outcome bears to all possible outcomes (proportionate law) and the outcomes observed in a number of trials will vary to some extent from the inherent proportion, but the extent of the variation will reduce as the number of trials increases (the law of averages);

(2) the probability of alternative outcomes in a single trial is the sum of their individual probabilities (the addition law) and the probability of a particular combination of outcomes in multiple, independent trials (where sequential or simultaneous) is the product of their individual probabilities (the multiplication law).

Accidents are random events from two aspects, time and location. Accidents occur randomly in time, so that the time interval between one accident and the next will vary randomly, even when the factors affecting accident occurrence are constant. Likewise, if time is divided into equal intervals, the number of accidents in each interval will vary randomly.

Accidents occur randomly in space, so that if all roads were arranged in one line, the distance between the site of one accident and the site of the next will vary randomly, and if the roads are divided into equal length sections, the number of accidents in each section will vary randomly.

Accidents are not completely random events, and temporal and spatial variations in their occurrence can be explained in part by variations in the factors involved in accident occurrence. Hence, it can be said that accidents are a function of identifiable factors, plus a random "noise" term.

6.2. ANALYSIS OF TEMPORAL VARIATIONS

6.2.1. Time Series Analysis. A series of successive observations of a phenomenon over a period of time is a time series. The interval between observations can be regular (e.g. daily, weekly, yearly) or irregular. Hence, annual accident counts for a site, a route or an area constitutes a time series.

Time series analysis is generally undertaken primarily to help discovery and measurement of the effects of the factors contributing to accident occurrence. When analysing accident count data, we must be aware of the existence of

(1) the secular trend, which extends consistently throughout the entire period under consideration

(2) cyclic fluctuations, which are cyclical variations, consistently recurring at regular intervals during the period under consideration

(3) random or stochastic variations, which occur in a completely unpredictable fashion.

Cyclical variations in accident occurrence include:

(1) seasonal variations, connected with seasons of the year;
(2) daily variations;
(3) hourly variations.

The magnitude of these cyclical variations is substantial (as shown by Figures 1 and 3 and Table 1), and must not be ignored.

There are well-established procedures for identifying cyclical variations in time series data; once identified, the effect of the cyclical fluctuation can be removed, giving "adjusted" time series data (see Figure 2).

In practice, the most widely adopted procedure for eliminating the cyclical fluctuation problem is the use of annual accident counts. It is not necessary to adopt a 1 January - 31 December year; any 12 month period can be used, so long as it is used for all sites, routes or areas.

6.2.2. Estimation of the Underlying True Accident Rate. Let x_1, x_2, ..., x_n be the observed annual accident counts for an individual site for n years. One is naturally interested in estimating the underlying true accident rate (UTAR) about which the annual accident counts vary.

The UTAR for a site (or section of road)

(1) is not known with certainty;
(2) is almost certainly not the same as the observed accident rate;
(3) can be inferred (or estimated) from the observed accident counts.

It is commonly assumed that the accident counts are governed by a Poisson process, the mean and variance of which is constant and equal to the UTAR (α, say). Now, if the accident counts $x_1, x_2, ..., x_n$ are Poisson distributed, then their sum

$$c = \sum_{1}^{n} x_i$$

is Poisson distributed, with mean and variance equal to ($n\alpha$). Hence, the probability that the mean of the accident counts x is equal to (c/n) is

$$P(x = (c/n)) = (n\alpha)^c \exp(-n\alpha)/c!$$

The chi-square integral and the cumulative Poisson distribution are related:

$$1 - P(\chi^2/v) = \sum_{0}^{c-1} (\alpha)^j \exp(-\alpha)/j!$$

where $\alpha = \chi^2/2$
$c = v/2$

Hence, it can be stated that

$$\alpha_l \leq \alpha \leq \alpha_u$$

with a level of confidence of (1-2k), where

$$\alpha_l = \chi^2 [k \mid v = 2c] / (2n)$$

$$\alpha_u = \chi^2 [(1-k) \mid v = 2c + 2] / (2n)$$

Using these relationships, confidence limits for α may be obtained for various values of the observed rate of occurrence (c/n) and time series duration (n). From a plot of the confidence limits, it can be seen that

(1) as the time series duration increases, the estimate of the value of α becomes more precise (ie. the width of the confidence interval decreases)

(2) for $n < 5$ approximately the rate of increase in precision is markedly greater than for larger values of n (ie. the optimum period for statistical reliability in estimating the UTAR is about 5 years).

If it is felt that the UTAR is changing with time (ie. that accidents are governed by a non-stationary stochastic process), then a greater number of observations will be required to identify precisely the form of variation of the mean and/or variance of the stochastic process. That is, a longer time period is required for a non-stationary stochastic process that for a stationary one.

For a more detailed discussion of this topic, see Nicholson 1986b and 1987.

6.2.3. The Randomness of Accident Counts. Statistical analysis procedures are based on the assumption that the data is governed by a random process. There is some evidence (Nicholson, 1986a) that accident counts are not always random.

The randomness of accident counts can be assessed, by analysing the order in which observations are obtained, using the "runs test of randomness". Such an analysis provides information not available from an analysis of the frequency of events.

The runs test of randomness is a standard non-parametric test, which enables one to assess the probability that a sequence of observations (accident counts, say) were produced by a random process. With some modification (as described in Nicholson, 1986a), the test can be used to identify, in addition, the nature of non-randomness. That is, it can detect and distinguish between the following sources of non-randomness in annual accident counts:

(1) a secular trend

(2) a cyclic variation (an over-corrected process)

(3) a discontinuity

The test involves

(1) identifying runs above and below a varying specified level;

(2) establishing the 90% or 95% confidence limits for the number of runs (for each value of the specified level);

(3) if the observed number of runs is too high or too low (ie. lies outside the confidence limits), rejecting the null hypothesis that the accident count sequence is random.

6.2.4. The Variability of Accident Counts. It has been assumed (in section 6.2.2) that accident counts vary according to a Poisson process. In fact, it has been shown (Nicholson, 1985) that there are grounds for doubting the general validity of that assumption; the accident counts for some sites are too variable to be well-described by the Poisson distribution (for which the variance equals the mean), while at other sites the accident counts are too regular (or insufficiently variable).

If the accident counts are very irregular, use of the Poisson distribution may well result in mistaking an accident count fluctuation for a change in the UTAR. This may well result in a waste of resources associated with investigating and treating sites. If the accident counts are very regular, use of the Poisson distribution may result in mistaking a change in the UTAR for an accident count fluctuation. This may well result in investigations and/or treatment not being undertaken when it is warranted, with a consequent waste of another resource, good health.

When analysing accident count data, one should check the variability of the counts. If one uses the confidence limits (section 6.2.2) based on the Poisson assumption, then it should be recognised that the level of precision for the UTAR is:

(1) over-estimated if the index of dispersion (variance/mean) is >1;

(2) under-estimated if the index of dispersion is <1.

It seems that a substantial proportion (approximately 25%) of sites have either too much or too little variability for the Poisson assumption to be completely valid.

It appears that there are sites that have an UTAR noticeably lower than do other sites, but which are more likely to experience a large number of accidents in a short period than are those other sites. Given public awareness of spates of accident at particular locations, public and/or political pressure may mount for remedial action at sites prone to spates of accidents whereas it may well be better (in terms of reducing the sum of accidents at all sites, in the long term) to do remedial work at the other sites. There may be a conflict between adopting the technically best option and easing public disquiet.

6.3. ANALYSIS OF SPATIAL VARIATIONS

An alternative to observing a phenomenon (eg. accidents) at a site, along a route or within an area, at intervals of time and obtaining time series data, involves observing the phenomenon at several sites, along several routes or within several areas, at a point in time. This alternative approach gives <u>cross-section data</u>, which can be analysed in order to discover and estimate the effects of the factors contribution to accident occurrence.

With cross-section analysis, one must beware of omitting important explanatory variables and incorrectly concluding that the variation in accident occurrence is due to variations in the explanatory variables that are included.

When undertaking cross-section analysis, one must take account of the temporal variations in accident occurrence (especially the cyclical and random variations).

If one has accident counts for a number of locations for the same period (one or more 12 month periods, in order to avoid the cyclical variation problem), then one can identify the mean count and the level of dispersion of counts about the mean.

The simplest measure of dispersion is the <u>range</u>, but a major drawback associated with it is the absence of information about the frequency of counts at each point in the range.

Another measure of dispersion is the <u>relative mean deviation</u>:

$$RMD = (1/N) \sum_{1}^{N} |c_i - \bar{c}| / \bar{c}$$

where c_i = accident count for the i-th site (i = 1,...N)
c = mean accident count = $\Sigma c_i/N$

A weakness with the RMD measure is that there may be substantial changes in the frequency distribution of accident counts, without any change in the RMD.

A commonly used measure of dispersion is the <u>variance</u>:

$$V = (1/N) \sum_{1}^{N} (c_i - \bar{c})^2$$

Again, there may be substantial changes in the frequency distribution of accident counts without any change in V. There is an additional problem, namely that the same proportional change in the accident count at all N sites will give a change in the variance, although the shape of the accident count frequency distribution would be essentially unchanged. This problem is overcome by using the coefficient of variation:

$$CV = \sqrt{V}/\bar{c}$$

Other more sophisticated and complicated indices of dispersion are available.

The reason for being interested in the level of dispersion of the accident count distribution over various sites is that it indicates the extent tot which accidents are clustered. If the dispersion is low (ie. accidents tend to be concentrated at a few sites or blackspots), then a blackspot programme is appropriate. If the dispersion is high, then an area-action programme is more appropriate. A medium level of dispersion may well indicate that a route-action programme is appropriate.

The use of accident counts for short periods (1 to 3 years, say) will lead to different sites seeming to be blackspots in different periods, due to temporal variations in accident occurrence at each site. A site may appear to be a blackspot in one short period, because that period coincided by chance with a peak accident count, but in a subsequent period not appear to be a blackspot. There is thus a need to use a time period that gives reasonable statistical reliability (5 years, say).

If a route is subdivided into several equal-length sections, then one can analyse the accident count distribution. If

c_i = accident count for the i-th section

then any section with an accident count greater than

$$\bar{c} + R \sqrt{V}$$

where R = some coefficient (unity, say)

should perhaps be investigated in detail. Intersection could be identified for detailed investigation in a similar manner.

If zero-accident sites are excluded, then there is some evidence (Abbess, Jarrett and Wright, 1981, Andreassen, 1986, Maher, 1987) that accident counts for a year are distributed (spatially) according to the Negative Binomial distribution. That is, the proportion of sites with c accidents in the year is

$$P\ (c) = [\Gamma(a+c)/(\Gamma(c+1)\Gamma(a))]\ [1/(1+b)\ ]^c\ [b/(1+b)]^a$$

where a and b are parameters of the distribution. A feature of the negative binomial distribution is that the variance

$$= a\ (1 + b)/b^2$$

is greater than the mean

$$= a/b$$

The distribution does not fit well observations of the proportion of sites having zero accidents; this proportion can be very high (of the order of 90%). Hence its use should be restricted to the range c = 1, 2, ..., etc.

The negative binomial distribution arises from the assumptions that:

(1) accident counts at an individual site vary about the underlying true accident rate (UTAR) according to the Poisson distribution;

(2) the UTAR's vary from site to site according to a Gamma distribution.

That is, the probability of the UTAR of a site being α is

$$P\ (\alpha) = b\ (b\alpha)^{\alpha-1}\ \exp\ (-b\alpha)\ /\ \Gamma(a)$$

and the probability of the accident count at the site being c, given the UTAR is α, is

$$P\ (c/\alpha) = \alpha^{c}\ \exp\ (-\alpha)\ /\ c!$$

The negative binomial distribution is obtained as follows:

$$P\ (c) = \int_0^{\infty} P\ (c \mid \alpha)\ P(\alpha)\ d\alpha$$

This model is suspect, because it seems that the Poisson assumption is not generally valid.

Figure 1: Quarterly casualties, unadjusted: all severities: GB: 1969–1986

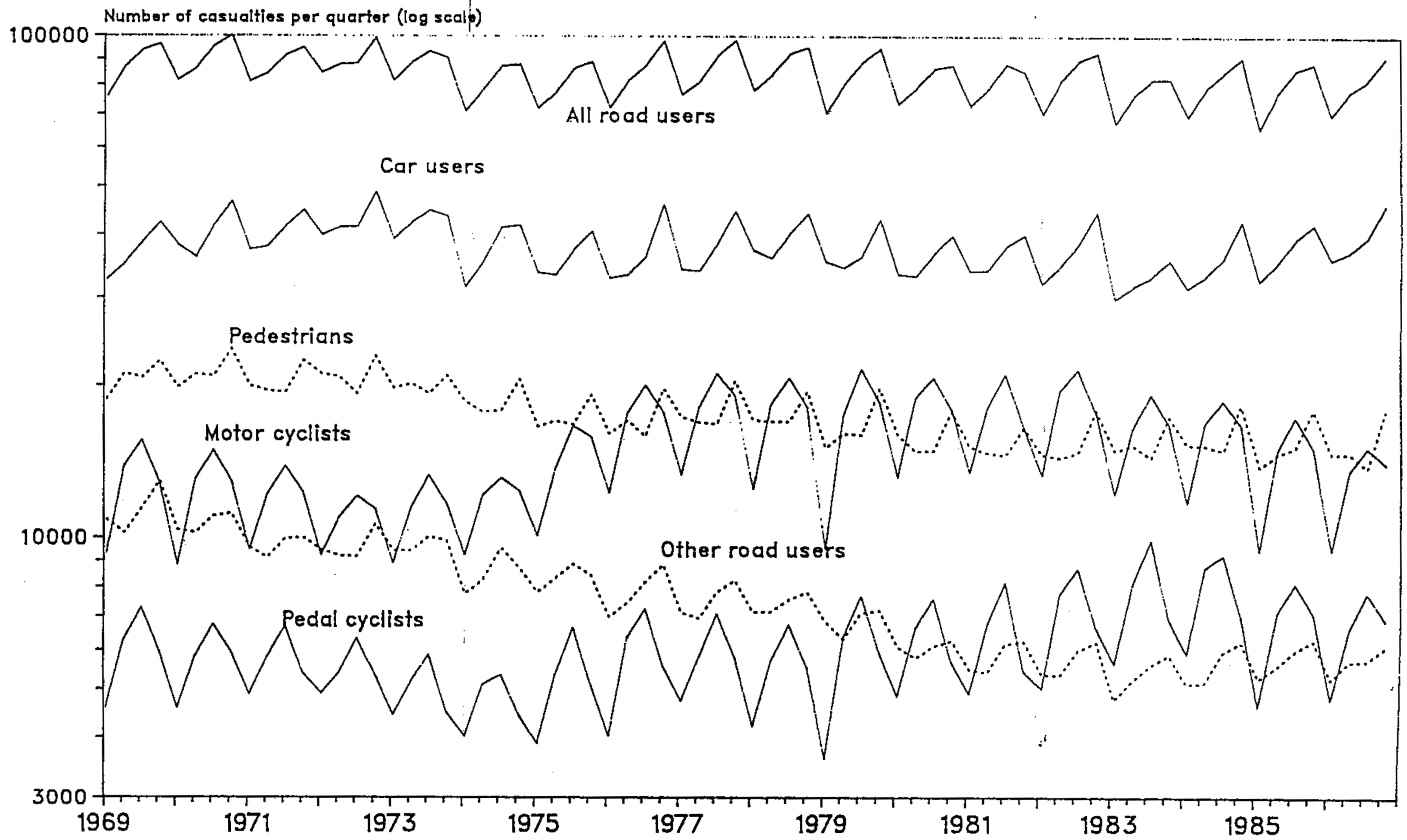


Figure 2: Quarterly casualties, seasonally adjusted: all severities: GB: 1969–1986

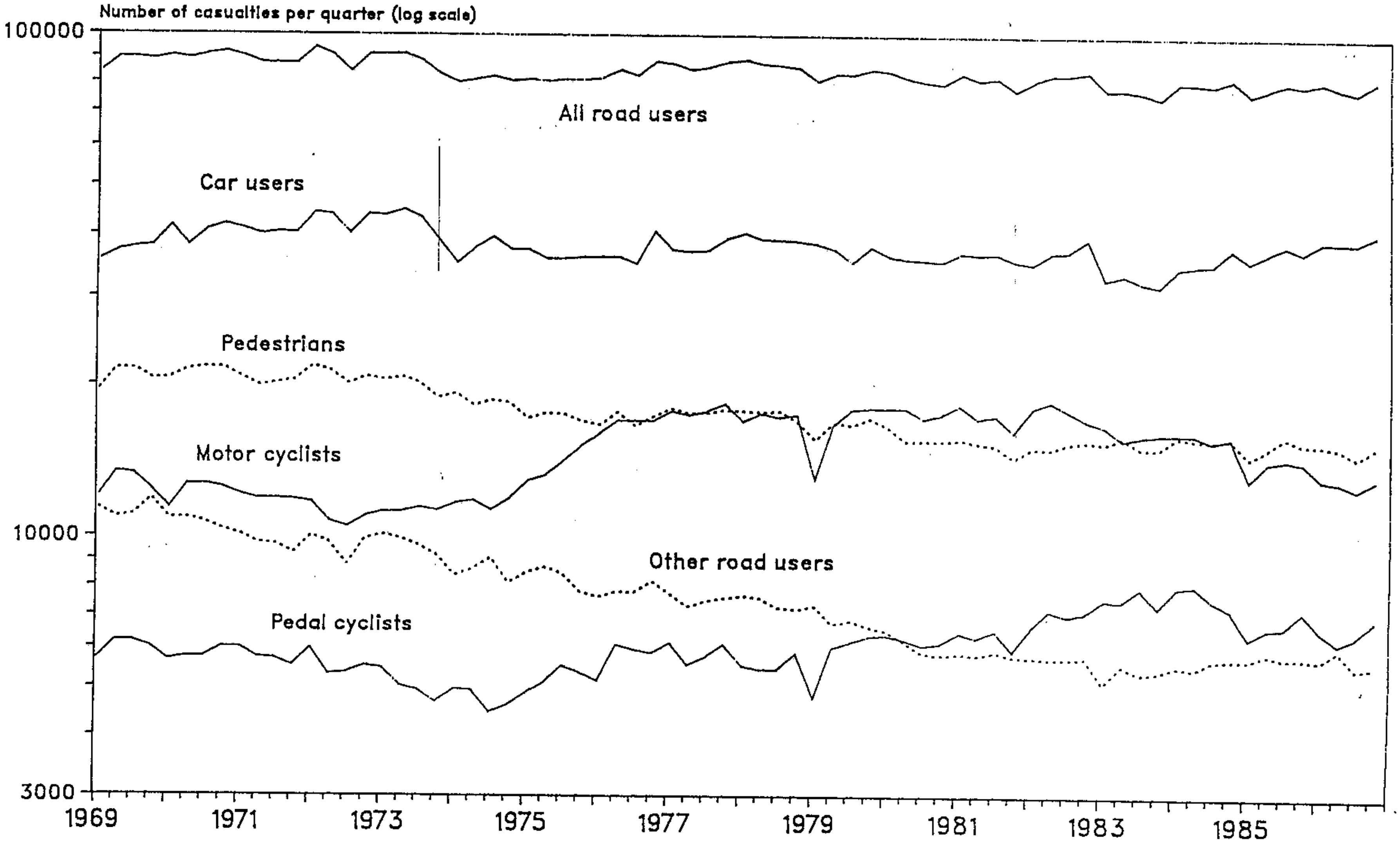
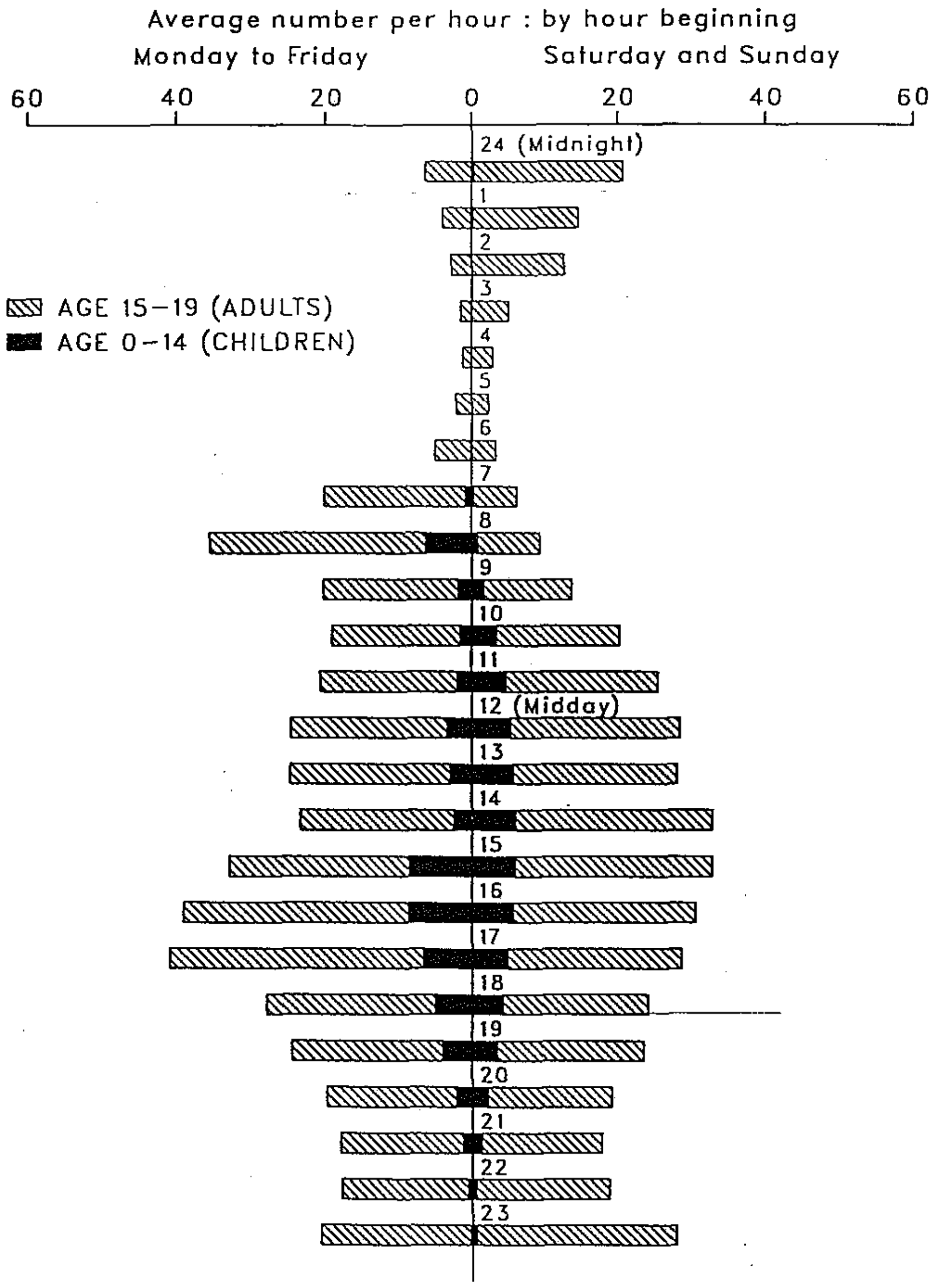


FIGURE
3: Casualties by hour of day and day of week: 1986



Casualties: by day, road user type and hour of day: 1986

(a) Monday to Thursday

Hour beginning	Pedes- trians	Pedal cyclists	TWMV users	Car users	All road users[1]
Midnight	211	48	311	1,587	2,281
01:00	110	21	106	1,078	1,388
02:00	78	9	59	676	894
03:00	29	3	28	340	459
04:00	19	11	38	319	481
05:00	36	59	160	429	812
06:00	132	228	389	934	1,960
07:00	678	1,181	2,111	2,816	7,343
08:00	2,855	1,953	2,730	5,155	13,693
09:00	1,523	737	1,183	3,226	7,689
10:00	1,495	568	925	2,971	7,143
11:00	1,773	667	1,132	3,531	8,279
12:00	2,524	913	1,595	3,597	9,731
13:00	2,237	856	1,831	3,690	9,715
14:00	1,782	695	1,475	3,571	8,558
15:00	3,731	1,104	1,726	4,336	12,090
16:00	4,154	2,004	2,688	4,963	15,058
17:00	3,689	2,248	3,585	5,654	16,007
18:00	2,344	1,391	2,180	3,988	10,399
19:00	1,895	1,084	2,104	3,844	9,288
20:00	1,230	620	1,655	3,569	7,347
21:00	955	416	1,532	3,340	6,497
22:00	838	293	1,439	3,832	6,655
23:00	973	215	1,200	4,275	6,979
All hours[2]	35,291	17,324	32,183	71,721	170,747

(b) Friday

Number of casualt

Hour beginning	Pedes- trians	Pedal cyclists	TWMV users	Car users	All r users
Midnight	94	18	126	646	9
01:00	53	7	64	469	6
02:00	38	6	28	355	4
03:00	12	2	13	164	2
04:00	10	1	12	91	1
05:00	10	14	42	102	2
06:00	40	62	113	232	5
07:00	183	285	570	738	1,9
08:00	743	433	683	1,293	3,3
09:00	388	179	316	884	2,0
10:00	435	140	262	935	2,0
11:00	514	163	321	997	2,3
12:00	753	268	484	1,162	3,0
13:00	651	257	569	1,148	2,9
14:00	628	201	458	1,301	2,9
15:00	1,260	398	701	1,598	4,30
16:00	1,289	556	934	1,831	4,92
17:00	998	526	904	1,765	4,42
18:00	719	317	617	1,368	3,16
19:00	612	251	564	1,404	2,95
20:00	464	157	498	1,382	2,60
21:00	411	105	428	1,378	2,42
22:00	419	76	443	1,533	2,55
23:00	894	86	618	2,561	4,31
All hours[2]	11,618	4,509	9,768	25,338	55,44

(c) Saturday

Hour beginning	Pedes- trians	Pedal cyclists	TWMV users	Car users	All road users[1]
Midnight	307	35	264	1,318	1,975
01:00	174	13	124	1,100	1,477
02:00	153	7	88	987	1,275
03:00	42	5	33	366	471
04:00	10	3	16	223	271
05:00	13	10	24	182	255
06:00	21	15	57	205	363
07:00	32	65	147	423	747
08:00	102	88	171	629	1,098
09:00	240	126	226	920	1,696
10:00	499	167	304	1,183	2,383
11:00	726	244	488	1,519	3,217
12:00	746	260	580	1,487	3,308
13:00	721	257	633	1,480	3,299
14:00	735	290	631	1,569	3,426
15:00	840	279	679	1,704	3,708
16:00	775	285	630	1,645	3,523
17:00	654	270	568	1,607	3,258
18:00	430	172	449	1,310	2,519
19:00	457	136	431	1,433	2,608
20:00	363	97	395	1,368	2,296
21:00	281	72	313	1,294	2,027
22:00	332	43	339	1,359	2,155
23:00	737	63	539	2,216	3,699
All hours[2]	9,390	3,002	8,129	27,528	51,055

(d) Sunday

Hour beginning	Pedes- trians	Pedal cyclists	TWMV users	Car users	All road users[1]
Midnight	342	44	286	1,467	2,224
01:00	192	13	120	1,126	1,506
02:00	181	8	98	1,014	1,349
03:00	31	3	31	543	632
04:00	12	1	12	257	301
05:00	9	4	21	153	211
06:00	4	4	43	191	262
07:00	17	24	47	270	389
08:00	23	34	46	371	541
09:00	68	81	112	~~506~~	~~816~~
10:00	177	162	233	830	1,502
11:00	290	190	325	1,153	2,048
12:00	385	209	478	1,363	2,513
13:00	309	184	427	1,438	2,449
14:00	459	221	650	2,093	3,509
15:00	367	192	571	1,816	3,084
16:00	382	174	549	1,688	2,892
17:00	341	156	451	1,462	2,517
18:00	302	139	440	1,277	2,243
19:00	279	125	374	1,188	2,057
20:00	205	58	325	1,017	1,645
21:00	157	58	283	928	1,489
22:00	219	41	295	1,236	1,859
23:00	340	38	294	1,478	2,239
All hours[2]	5,091	2,163	6,511	24,865	40,277

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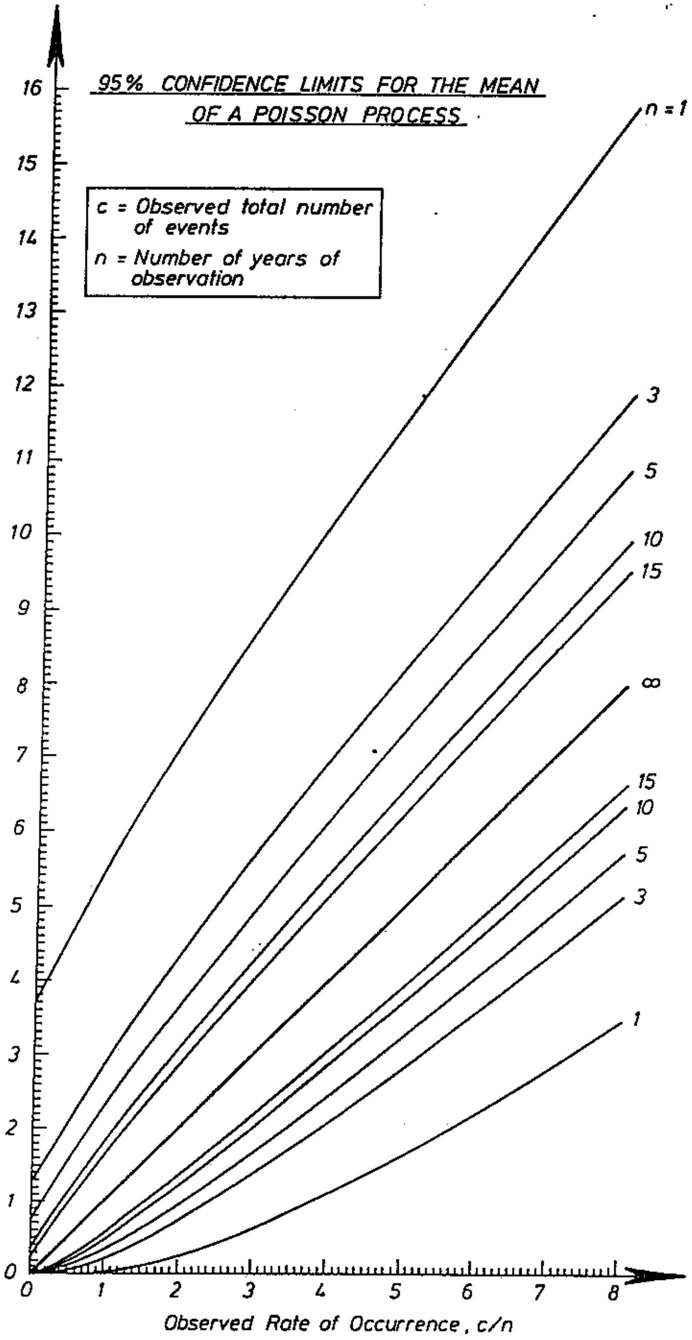
[1] Includes bus, coach, goods and other vehicle users and road user unknown.
[2] Includes time not reported.

TABLE 1

FIGURE 4


95% CONFIDENCE LIMITS FOR THE MEAN
OF A POISSON PROCESS
c = Observed total number of events
n = Number of years of observation
n = 1
3
5
10
15
∞
15
10
5
3
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0
1
2
3
4
5
6
7
8
Observed Rate of Occurrence, c/n

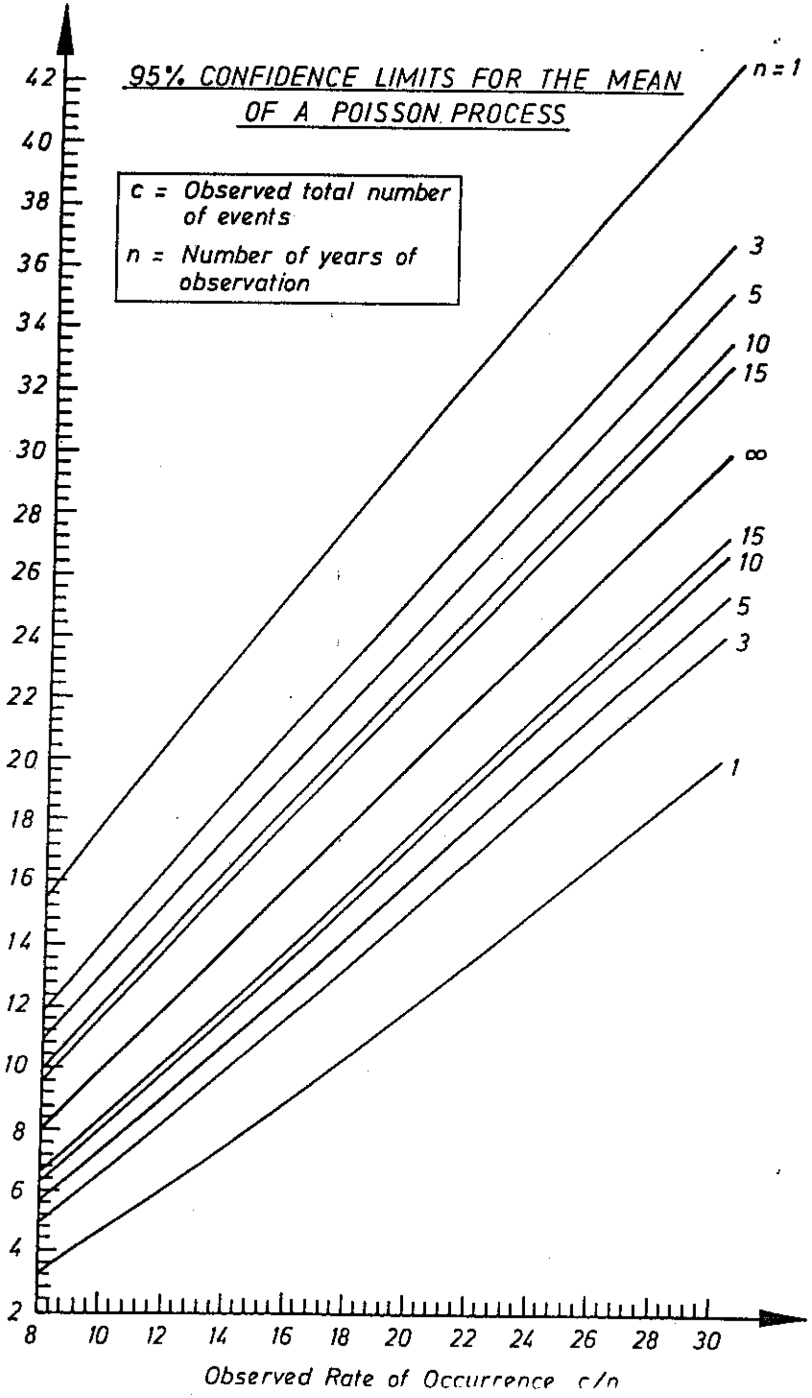
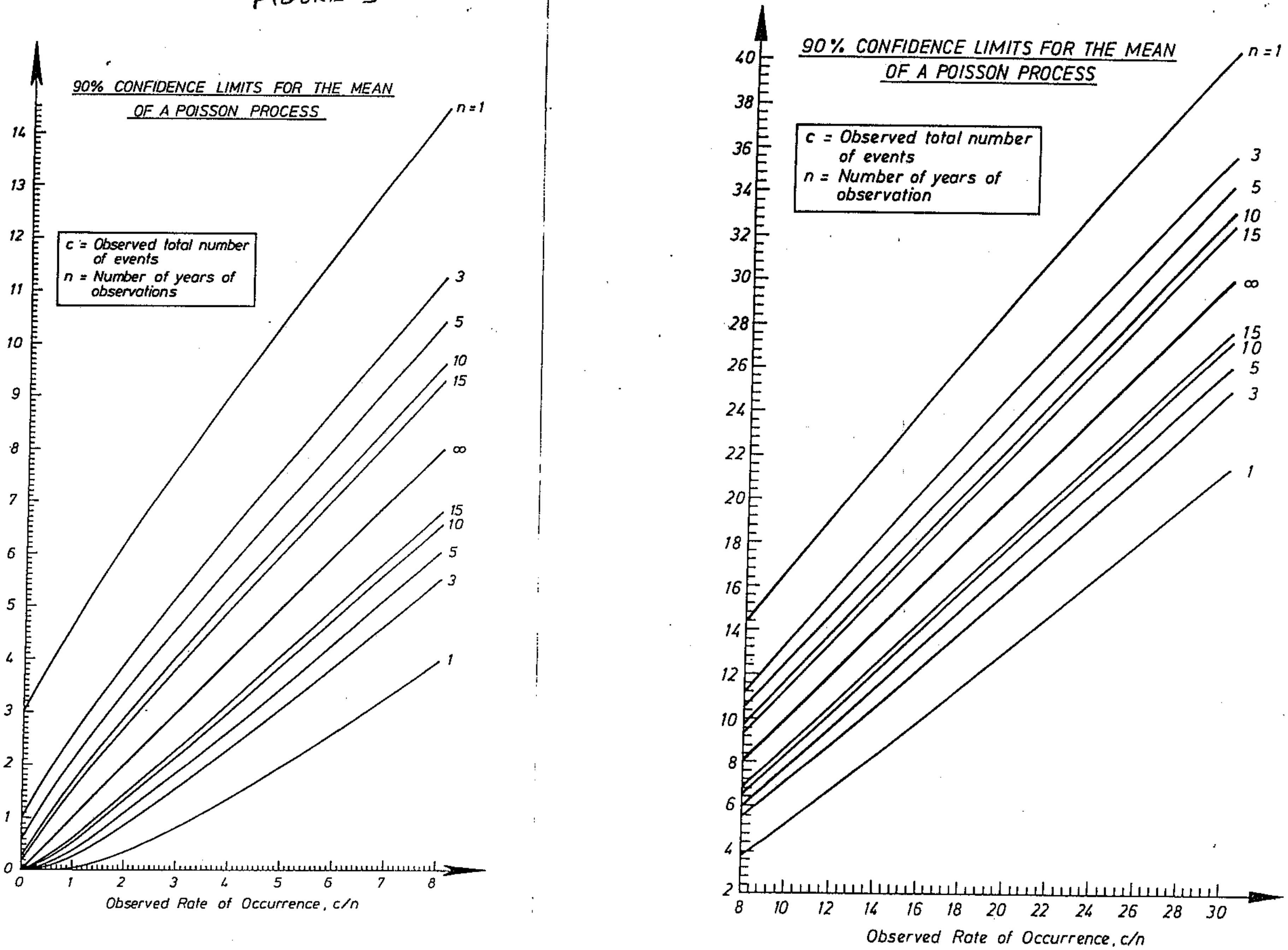

95% CONFIDENCE LIMITS FOR THE MEAN
OF A POISSON PROCESS
c = Observed total number of events
n = Number of years of observation
n = 1
3
5
10
15
∞
15
10
5
3
1
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
8
10
12
14
16
18
20
22
24
26
28
30
Observed Rate of Occurrence c/n

FIGURE 5


90% CONFIDENCE LIMITS FOR THE MEAN OF A POISSON PROCESS
c = Observed total number of events
n = Number of years of observations
n = 1
3
5
10
15
∞
15
10
5
3
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0
1
2
3
4
5
6
7
8
Observed Rate of Occurrence, c/n
90% CONFIDENCE LIMITS FOR THE MEAN OF A POISSON PROCESS
c = Observed total number of events
n = Number of years of observation
n = 1
3
5
10
15
∞
15
10
5
3
1
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
8
10
12
14
16
18
20
22
24
26
28
30
Observed Rate of Occurrence, c/n

7. ACCIDENT DATA-BASE

7.1. THE ACCIDENT REPORTING SYSTEM

It is common practice in developed countries for all injury accidents to be reported. In a few countries (e.g. Germany) non-injury accidents must also be reported, if the value of the property damage exceeds some threshold.

It is common practice for Traffic Police (or Traffic Officers) attending injury accidents to complete a detailed report, using a standard form. In the U.K. the standard form is known as STATS 19 (copy attached).

In some areas the standard form (or a reduced version) may be completed for non-injury accidents attended by the Traffic Officer.

When an officer does not attend the accident, the form must be completed on the basis of the information provided by the participants, should they choose to report the accident.

Insurance companies require people insured with them to report accidents which might lead to a claim being made. The data collected by the insurance companies are invariably less complete and detailed than the official accident records. It may well be that a greater proportion of accidents are reported to insurance companies than to the Traffic Police.

Another possible source of information is medical records, where any participant has required and sought medical attention. Those medical records may reside at hospitals or with the individual physicians who treat the injured.

The reporting rate can be substantially less than 100%, and can vary systematically according to

(1)	the accident location -	the more remote the location, the less likely to be reported (other things being equal);
(2)	the accident severity -	for fatal accidents the reporting rate is 100% (or very nearly 100%) but the reporting rate decreases with accident severity;
(3)	the user class of the - participants	accidents between cyclists, or between cyclists and pedestrians, are less likely to be reported.

It should be noted that the three items above are themselves inter-related.

In deciding upon what is an appropriate reporting system, one should take account of:

(1) the use to be made of the data;
(2) the capability of the Traffic Officer.

Accident researchers very often bemoan the lack of detailed information in accident reports. Traffic Officers may complain about the excessive effort required to collect the data that is already collected. Some of the data sought by some researchers would require a high level of expertise (as well as extra effort) on the part of the Traffic Officer. It must also be noted that the accident reporting system is part of the legal system; prosecutions may occur. There is clearly a need to find a suitable balance between the requirements of the researcher, the practising traffic engineer and the traffic law enforcement agency, taking full account of the capability of the reporting officer.

7.2. SYSTEM EFFICIENCY

A number of items are essential to the efficiency of the system:

(1) Concise referencing of the accident location, using grid referencing (especially in urban areas) or distances to established markers (for accidents or highways).
(2) Accurate referencing of the accident location - if grid referencing is employed and it is desired to identify specific intersections in an urban area where accidents have occurred, then the base map may have to be to a scale of 1:10000 or better, and the grid referencing determined accordingly.
(3) Accurate, plain language description of the accident location.
(4) Accurate, plain language description of the accident - a sketch of the accident situation, showing the position of the vehicles involved and the manoeuvres they were making, is very useful.
(5) Road classification.
(6) Local Authority (or district) identifier.

The Institution of Highways and Transportation (1987) lists whose items of information (see chapter 3 of course notes) which should be extracted from the STATS 19 data-base and supplemented with the above information and any other "local requirements". The STATS 19 data contains some unnecessary details, which should be excluded from the local authorities' data-bases.

Finally, the raw basic data must be validated (i.e. checked for completeness and accuracy). Checks for inconsistency should be implemented (e.g. ensuring that the number of casualty records matches the number of casualties).

7.3. DATA MANAGEMENT

The first aspect is data storage, and there are several options available:

(1) copies of the traffic accident reports (e.g. STATS 19) filed in date, serial number or road order;
(2) brief summary cards (manually prepared from traffic accident reports, with or without additional local information) and filed according to date, serial number or road;
(3) punched cards, suitable for manual or mechanical sorting (containing data as in item 2 and similarly filed);
(4) computer files (magnetic tape or disks).

With the first option, the retrieval process is time consuming and complex, and tends to be little used except as part of a special investigation. That is, it is not very well suited to being part of a comprehensive system for systematic (or routine) accident investigation.

The second and third options are very labour-intensive, as they involve transferring data from traffic accident reports onto special cards. Option 3 does enable mechanical sorting, although not as rapidly or as flexibly as does option 4, which is now widely used.

With the widespread use of computer files, the matter of data entry into those files has become important, and the traffic accident report forms in common use, having been devised prior to the ready availability of computers, are generally unsuitable as an "input document". It is often necessary to either revise the accident report form or use a purpose-designed input document, to which the data must be transferred.

The matter of who should have access to the accident data must be addressed, and an important issue is one of confidentiality. In addition, the integrity of the database must be protected (i.e. only authorised persons should be able to input or amend data).

There are various ways in which road accident data can be presented, and the choice of form of output depends upon the following:

(1) for whom the data is intended (e.g. traffic engineers, lawyers, public);
(2) the use to which it will be put (e.g. traffic design, legal defence, planning objections);
(3) the precise data requirement (e.g. technical details, summary data, plain language).

The most common forms of output are:

(1) cross tabulations and listings;
(2) manual plots (e.g. pins in maps);
(3) automatic plots (e.g. plotting on transparent sheets for laying over maps).

Plots may be produced for selected accident types, just as for the production of tables and lists.

The frequency of output can be:

(1) periodic or regular (for routine monitoring purposes);
(2) as required (for special investigations).

A computerised system can undertake some statistical analysis of the data for output, and can draw attention to those sites (or routes or areas) that have an unusually large number of accidents during a period (or per unit of exposure, if traffic flow data has been input). Such sites should then be subjected to a detailed study, to assess the scope for reducing accidents.

7.4. DEFICIENCIES IN THE DATA-BASE

It must be remembered that the data-base includes only a proportion of the accidents which must be reported, and only a proportion of accidents should be reported. Thus, if

p_1 = proportion of accidents that should be reported
p_2 = proportion of accidents that should be reported that are reported

then the data-base contains information about only (p_1 p_2) of the accidents that occur.

The number of property-damage-only accidents may well be about 10 times more numerous than injury accidents (i.e. p_1 is about 1/11) and only about 60% of injury accidents are reported (i.e. p_2 is about 6/10). Hence, the data-base, upon which a traffic engineer must initially judge whether a site, route or area is unduly hazardous, is only about a 5% sample of all accidents.

The small size of the sample is made worse by the high probability of it having a bias, due to the systematic variation of the value of p_2 for accidents involving particular user classes.

Local information can be very useful; the traffic officers and ambulance staff who attend frequent accidents at the same site, the highways (or road) maintenance staff who frequently clear up and repair damage at the same site, and residents in the vicinity of such a site, are all sources of information about the frequency and nature of accidents at the site.

The information obtained from such sources must be judged with extreme and expert care, however, as there may be considerable bias in the information provided. Nevertheless, such information should be considered for use as a supplement to the limited accident data generally available.

Department of Transport

ACCIDENT RECORD ATTENDANT CIRCUMSTANCES

1·1 RECORD TYPE (1 2) 1 ☐
1 New accident record
5 Amended accident record

1·2 POLICE FORCE (3 4) ☐☐

1·3 ACCIDENT REF NO (5 6 7 8 9 10 11) ☐☐☐☐☐☐☐

1·4 SEVERITY OF ACCIDENT (12) ☐
1 Fatal 2 Serious 3 Slight

1·5 NUMBER OF VEHICLES (13 14 15) ☐☐☐

1·6 NUMBER OF CASUALTY RECORDS (16 17 18) ☐☐☐

1·7 DATE Day (19 20) ☐☐ Month (21 22) ☐☐ Year (23 24) ☐☐

1·8 DAY OF WEEK (25) ☐
1 Sunday 2 Monday
3 Tuesday 4 Wednesday
5 Thursday 6 Friday
7 Saturday

1·9 TIME Hrs (26 27) ☐☐ Mins (28 29) ☐☐
24 hour

1·10 LOCAL AUTHORITY (30 31 32) ☐☐☐

1·11 LOCATION (33 34 35 36 37) ☐☐☐☐☐ (38 39 40 41 42) ☐☐☐☐☐
10 digit reference No Easting Northing

1·12 1st ROAD CLASS (43) ☐
1 Motorway
2 A (M)
3 A
4 B
5 C
6 Unclassified
7 } Local
8 } Authority
9 } use only

1·13 1st ROAD NUMBER (44 45 46 47) ☐☐☐☐

1·14 CARRIAGEWAY TYPE OR MARKINGS (48) ☐
1 Roundabout (on circular highway)
2 One way Street
3 Dual carriageway - 2 lanes
4 Dual carriageway - 3 or more lanes
5 Single carriageway - single track road
6 Single carriageway - 2 lanes (one each direction)
7 Single carriageway - 3 lanes (two way capacity)
8 Single carriageway - 4 or more lanes (two way capacity)
9 Unknown

1·15 SPEED LIMIT (49 50 51) 0 ☐☐
mph

JUNCTION ACCIDENTS ONLY

1·16 JUNCTION DETAIL (52 53) 0 ☐
0 Not at or within 20 metres of junction
1 Roundabout
2 Mini - roundabout
3 'T' or staggered junction
4 'Y' junction
5 Slip road
6 Crossroads
7 Multiple junction
8 Using private drive or entrance
9 Other junction

1·17 JUNCTION CONTROL (54) ☐
1 Authorised person
2 Automatic traffic signal
3 Stop sign
4 Give way sign or markings
5 Uncontrolled

1·18 2nd ROAD CLASS (55) ☐
1 Motorway
2 A (M)
3 A
4 B
5 C
6 Unclassified
7 } Local
8 } Authority
9 } use only

1·19 2nd ROAD NUMBER (56 57 58 59) ☐☐☐☐

1·20 PEDESTRIAN CROSSING FACILITIES (60 61) 0 ☐
0 No crossing facilities within 50 metres
1 Zebra
2 Zebra crossing controlled by school crossing patrol
3 Zebra crossing controlled by other authorised person
4 Pelican
5 Other light controlled crossing
6 Other sites controlled by school crossing patrol
7 Other sites controlled by other authorised person
8 Central refuge - no other controls
9 Footbridge or subway

1·21 LIGHT CONDITIONS (62) ☐
DAYLIGHT
1 Street lights 7 metres or more high
2 Street lights under 7 metres high
3 No street lighting
4 Daylight street lighting unknown
DARKNESS
5 Street lights 7 metres or more high lit
6 Street lights under 7 metres high lit
7 No street lighting
8 Street lights unlit
9 Darkness street lighting unknown

1·22 WEATHER (63) ☐
1 Fine (without high winds)
2 Raining (without high winds)
3 Snowing (without high winds)
4 Fine with high winds
5 Raining with high winds
6 Snowing with high winds
7 Fog (or mist if hazard)
8 Other
9 Unknown

1·23 ROAD SURFACE CONDITION (64) ☐
1 Dry
2 Wet / Damp
3 Snow
4 Frost / Ice
5 Flood (surface water over 3 cms (1 inch) deep)

1·24 SPECIAL CONDITIONS AT SITE (65) ☐
0 None
1 Automatic Traffic Signal - out
2 Automatic Traffic Signal partially defective
3 Permanent road signing defective or obscured
4 Road works present
5 Road surface defective

1·25 CARRIAGEWAY HAZARDS (66) ☐
0 None
1 Dislodged vehicle load in carriageway
2 Other object in carriageway
3 Involvement with previous accident
4 Dog in carriageway
5 Other animal in carriageway

1·26 OVERTAKING MANOEUVRE PATTERNS (67) ☐
No longer required by the Department of Transport

1·27 DTp SPECIAL PROJECTS (68 69 70 71) ☐☐☐☐

VEHICLE RECORD

2·1 RECORD TYPE 2☐
1 2

1 New vehicle record
5 Amended vehicle record

2·2 POLICE FORCE ☐☐
3 4

2·3 ACCIDENT REF NO ☐☐☐☐☐☐☐
5 6 7 8 9 10 11

2·4 VEHICLE REF NO ☐☐☐
12 13 14

2·5 TYPE OF VEHICLE ☐☐
15 16

01 Pedal cycle
02 Moped
03 Motor scooter
04 Motor cycle
05 Combination
06 Invalid Tricycle
07 Other three-wheeled car
08 Taxi
09 Car (Four wheeled)
10 Minibus/Motor caravan
11 PSV
12 Goods not over 1½ tons UW (1·52 tonnes)
13 Goods over 1½ tons UW (1·52 tonnes)
14 Other motor vehicle
15 Other non motor vehicle

2·6 TOWING AND ARTICULATION ☐
17

0 No tow/articulation
1 Articulated vehicle
2 Double/multiple trailer
3 Caravan
4 Single trailer
5 Other tow

2·7 MANOEUVRES ☐☐
18 19

01 Reversing
02 Parked
03 Waiting to go ahead but held up
04 Stopping
05 Starting
06 U Turn
07 Turning left
08 Waiting to turn left
09 Turning right
10 Waiting to turn right
11 Changing lane to left
12 Changing lane to right
13 Overtaking moving vehicle on its offside
14 Overtaking stationary vehicle on its offside
15 Overtaking on nearside
16 Going ahead left hand bend
17 Going ahead right hand bend
18 Going ahead other

2·8 VEHICLE MOVEMENT COMPASS POINT ☐☐
20 21
From To

1 N
2 NE
3 E
4 SE
5 S
6 SW
7 W
8 NW
or 00 Parked – not at kerb
☐0 Parked – at kerb

2·9 VEHICLE LOCATION AT TIME OF ACCIDENT ☐☐
22 23

01 Leaving the main road
02 Entering the main road
03 On main road
04 On minor road
05 On service road
06 On lay-by or hard shoulder
07 Entering lay-by or hard shoulder
08 Leaving lay-by or hard shoulder
09 On a cycleway
10 Not on carriageway

2·10 JUNCTION LOCATION OF VEHICLE AT FIRST IMPACT ☐
24

0 Not at junction (or within 20 metres/22 yards)
1 Vehicle approaching junction/vehicle parked at junction approach
2 Vehicle in middle of junction
3 Vehicle cleared junction/vehicle parked at junction exit
4 Did not impact

2·11 SKIDDING AND OVERTURNING ☐
25

0 No skidding, jackniting or overturning
1 Skidding
2 Skidded and overturned
3 Jackknifed
4 Jackknifed and overturned
5 Overturned

2·12 HIT OBJECT IN CARRIAGEWAY ☐☐
26 27

00 None
01 Previous accident
02 Road works
03 Parked vehicle – lit
04 Parked vehicle – unlit
05 Bridge (roof)
06 Bridge (side)
07 Bollard/refuge
08 Open door of vehicle
09 Central island of roundabout
10 Kerb
11 Other object

2·13 VEHICLE LEAVING CARRIAGEWAY ☐
28

0 Did not leave carriageway
1 Left carriageway nearside
2 Left carriageway nearside and rebounded
3 Left carriageway straight ahead at junction
4 Left carriageway offside onto central reservation
5 Left carriageway offside onto central reservation and rebounded
6 Left carriageway offside crossed central reservation
7 Left carriageway offside
8 Left carriageway offside and rebounded

2·14 HIT OBJECT OFF CARRIAGEWAY ☐☐
29 30

00 None
01 Road sign/Traffic signal
02 Lamp post
03 Telegraph pole/Electricity pole
04 Tree
05 Bus stop/Bus shelter
06 Central crash barrier
07 Nearside or offside crash barrier
08 Submerged in water (completely)
09 Entered ditch
10 Other permanent object

2·15 VEHICLE PREFIX/SUFFIX LETTER ☐
31

PREFIX/SUFFIX LETTER or one of the following codes –

0 More than twenty years old (at end of year)
1 Unknown/cherished number/not applicable
2 Foreign/diplomatic
3 Military
4 Trade plates

2·16 FIRST POINT OF IMPACT ☐
32

0 Did not impact
1 Front
2 Back
3 Offside
4 Nearside

2·17 OTHER VEHICLE HIT (VEH REF NO) ☐☐☐
33 34 35

2·18 PART(S) DAMAGED ☐☐☐
36 37 38

0 None
1 Front
2 Back
3 Offside
4 Nearside
5 Roof
6 Underside
7 All four sides

2·19 NO OF AXLES ☐
39

0 Not goods vehicle
2 2 axles
3 3 axles
4 4 axles
5 5 or more axles

} Goods Vehicles only

2·20 MAXIMUM PERMISSIBLE GROSS WEIGHT ☐☐
40 41

Metric tonnes (Goods vehicle only)

2·21 SEX OF DRIVER ☐
42

1 Male
2 Female
3 Not traced

2·22 AGE OF DRIVER ☐☐
43 44

(Years, estimated if necessary)

2·23 BREATH TEST ☐
45

0 Not applicable
1 Positive
2 Negative
3 Not requested
4 Failed to provide
5 Driver not contacted at time

2·24 HIT AND RUN ☐
46

0 Other
1 [illegible]

2·25 DTp SPECIAL PROJECTS ☐☐☐☐
47 48 49 50

3·1 RECORD TYPE 1 2 [3]☐
1 New casualty record
5 Amended casualty record

3·2 POLICE FORCE 3 4 ☐☐

3·3 ACCIDENT REF NO. 5 6 7 8 9 10 11 ☐☐☐☐☐☐☐

3·4 VEHICLE REF NO. 12 13 14 ☐☐☐

3·5 CASUALTY REF NO. 15 16 17 ☐☐☐

3·6 CASUALTY CLASS 18 ☐
1 Driver or rider
2 Vehicle or pillion passenger
3 Pedestrian

3·7 SEX OF CASUALTY 19 ☐
1 Male
2 Female

3·8 AGE OF CASUALTY 20 21 ☐☐
(Years, estimated if necessary)

3·9 SEVERITY OF CASUALTY 22 ☐
1 Fatal
2 Serious
3 Slight

3·10 PEDESTRIAN LOCATION 23 24 ☐☐
00 Not pedestrian
01 In carriageway crossing on pedestrian crossing
02 In carriageway crossing within zig-zag lines approach to the crossing
03 In carriageway crossing within zig-zag lines exit the crossing
04 In carriageway crossing elsewhere within 50 metres of pedestrian crossing
05 In carriageway crossing elsewhere
06 On footway or verge
07 On refuge or central island or reservation
08 In centre of carriageway not on refuge or central island
09 In carriageway not crossing
10 Unknown

3·11 PEDESTRIAN MOVEMENT 25 ☐
0 Not pedestrian
1 Crossing from drivers nearside
2 Crossing from drivers nearside–masked by parked or stationary vehic
3 Crossing from drivers offside
4 Crossing from drivers offside–masked by parked or stationary vehic
5 In carriageway stationary–not crossing (standing or playing)
6 In carriageway stationary–not crossing (standing or playing)–
masked by parked or stationary vehicle
7 Walking along in carriageway facing traffic
8 Walking along in carriageway back to traffic
9 Unknown

3·12 PEDESTRIAN DIRECTION 26 ☐
Compass point bound
1 N
2 NE
3 E
4 SE
5 S
6 SW
7 W
8 NW
or 0 – Pedestrian – standing still

3·13 SCHOOL PUPIL CASUALTY 27 ☐
0 Not a school pupil
1 Pupil on journey to/from school
2 Pupil NOT on journey to/from school

3·14 SEAT BELT USAGE 28 ☐
0 Not car or van
1 Safety belt in use
2 Safety belt fitted–not in use
3 Safety belt not fitted
4 Child safety belt/harness fitted-in use
5 Child safety belt/harness fitted-not in use
6 Child safety belt/harness not fitted
7 Unknown

3·15 CAR PASSENGER 29 ☐
0 Not car passenger
1 Front seat car passenger
2 Rear seat car passenger

3·16 PSV PASSENGER 30 ☐
0 Not a PSV passenger
1 Boarding
2 Alighting
3 Standing passenger
4 Seated passenger

3·17 DTp SPECIAL PROJECTS 31 32 33 34 ☐☐☐☐

IMPORTANT FACTORS FROM STATS 19 FOR CORE DATA BASE

	Item	Column No
(i)	**Basic accident description**	
	Reference	1.3
	Severity of accident	1.4
	No. of vehicles	1.5
	No. of casualties	1.6
	Date	1.7
	Day	1.8
	Time	1.9
	Location	1.11
	with augmentation for local use	1.31
	Contributory Factors—if collected by Police especially 11, 20–26, 34, 35, 61, & 62	
(ii)	**Road features**	
	Class of road and no.	1.12,1.13 1.18,1.19
	Carriageway type or markings	1.14
	Speed limit	1.15
	Junction type and control	1.16,1.17
(iii)	**Environmental features**	
	Light conditions	1.21
	Weather	1.22
	Surface condition	1.23
	Special conditions	1.24
	Carriageway hazards	1.25
(iv)	**Vehicle features**	
	Type	2.5
	Manoeuvres	2.7
	Movements	2.8
	Vehicle location	2.9
	Junction location	2.10
	Skidding	2.11
	Hit object	2.12,2.14
(v)	**Driver features**	
	Sex	2.21
	Age	2.22
	Breath test	2.23
	Hit and run	2.24
(vi)	**Casualty details**	
	Class	3.6
	Sex	3.7
	Age	3.8
	Severity of injury	3.9
	Pedestrian location	3.10
	Pedestrian movement	3.11
	Pedestrian direction	3.12
	School pupil	3.13

Notes

1. As well as aiding identification of opportunity to apply engineering remedial measures the above factors also facilitate identification of opportunity for enforcement and education, publicity and training measures.
2. When a good working relationship exists between police and final verification agency, particularly when the latter is responsible for accident investigation, data is likely to be more accurate.

8. IDENTIFICATION OF HAZARDOUS SITES, ROUTES AND AREAS

8.1. INTRODUCTION

The first analytical step in the development of an accident reduction programme is the identification of hazardous sites, routes and areas, which may then be investigated in detail, with a view to diagnosis of the accident problem and identification of an appropriate remedial action.

There are numerous potential indicators of the level of hazard. For instance, Taylor and Thompson (1977) started with 24 potential indicators and after detailed consideration of each, reduced the number to nine. These were included in a formula for calculating a "hazardousness index", which included items such as:

(a) driver expectancy (this requires subjective evaluation on a "good" to "bad" scale);

(b) sight distance and traffic conflicts (these are relatively objective indicators, but they entail a large amount of special data collection);

(c) various accident-based indicators (e.g. number of accidents per year, accident severity).

Surveys of practice in the USA (Zegeer, 1982) and the UK (Silcock and Smyth, 1984) reveal that the vast majority of roading/highway authorities rely upon accident-based indicators alone. It is likely that this situation will continue for some time, as data relating to accidents (particularly injury accidents) are routinely collected in many countries, and very few authorities (if any) have the resources to collect routinely information on traffic conflicts and such like.

Zegeer found that all authorities in the USA employ one or more methods for identifying hazardous locations on inter-state and state roads, and about 80% also seek to identify hazardous locations on local roads. Silcock and Smyth found that about 82% of the responding authorities in the UK employ some method of hazardous location identification. Assuming that all the non-responding authorities do not, it follows that about 67% of authorities in the UK do.

Ordinarily, a two-stage process is used:

(1) firstly, the accident history of all locations is reviewed, to select a limited number of apparently dangerous locations for further examination;

(2) secondly, the selected locations are examined in detail, in order to devise cost-effective remedial treatments for some.

The chapter is concerned with the first stage only.

8.2. IDENTIFICATION OF HAZARDOUS SITES

8.2.1. Choice of Criterion. Sites are particular locations, such as intersections, access points to major traffic generators, short lengths of road containing a distinctive feature (e.g. a bend).

A number of criteria may be employed for identifying blackspots, four of the most common being:

(1) the number of accidents (or accidents per km) in a given period exceeding some arbitrary threshold value (this criterion takes no account of exposure);

(2) the rate of accidents (per veh-km or per veh) for a given period exceeding some arbitrary threshold value (this criterion does take account of exposure);

(3) the number and rate of accidents both exceeding their respective arbitrary threshold values;

(4) the rate of accidents exceeding a critical value derived from statistical analysis of accident rates for all sites (this is commonly termed the "rate-quality control method").

It is often argued (IHT, 1987; DTp, 1986) that it is unwise to rely solely on either the number or rate of accident criteria, as:

(1) the number of accident criterion on its own will lead to site selection biased towards sites on high-volume roads and having a large number of accidents;

(2) the rate of accidents criterion on its own will lead to site selection biased towards sites on low-volume roads and having relatively few accidents.

Hence, the third criterion has gained much support, as it ensures that the high risk (accidents per exposure) sites, where there are relatively many accidents that may be saved, will be investigated in detail.

The fourth criterion involves assuming that the accident rates for different sites are distributed according to some probability distribution, assuming a critical level of confidence (between 95% and 99.5%, say), and then finding the critical accident rate, such that only a proportion (0.5% to 5%, say) of sites will have a higher rate and thus be deemed blackspots.

There seems to be no good reason for not extending the procedure to consider accident numbers as well as accident rates, to overcome the bias problem associated with the use of only one or the other. The advantage of the statistical approach is that it reduces the amount of arbitrariness in setting threshold values.

One can stratify accidents according to severity, in an effort to identify those sites having a high number and/or rate of serious accidents.

Zegeer (1982) found that of the 51 state roading authorities in the USA:

(1) 89% and 73% use 'number of accidents' on major and minor (local) roads, respectively;

(2) 84% and 50% use 'rate of accidents' or 'rate-quality control' on major and minor roads, respectively;

(3) 65% and 45% stratify according to severity (major and minor roads, respectively).

8.2.2. Choice of Road Length. When seeking to identify unusually hazardous sites, it is necessary to sub-divide roads into sections; with intersections, it is necessary to decide what length of each approach road should be included in the intersection. It is common practice to consider the 20-30 m of adjoining approach road is part of the intersection. With the sub-division of roads into sections, practice varies considerably.

The factors that should be taken into account when choosing section lengths include:

(1) roadway and traffic characteristics should be fairly uniform within a section;

(2) the section length should be in keeping with the level of precision and degree of error in reporting accident location;

(3) the length of influence of a hazard may be considerable, with vehicles losing control at a hazardous feature colliding with an object some considerable distance downstream;

(4) statistical reliability.

With respect to statistical reliability, it is clear that as the section length gets very small, then the probability of zero or one accident in the period must tend towards unity. As the section length gets very large, the effect of isolated hazardous features will be submerged and lost. Zegeer (1982) states that accident rates

> "become unstable and of questionable value for highway segments of short length (i.e. less than 0.3 mile) and/or with low traffic volumes (i.e. less than 500 veh per day), even when several years of accident and volume data are used."

Zegeer found that practice in the USA is very variable, with section lengths varying from 0.03 km to about 0.5 km for 'spot' lengths, and from 0.5 km to about 2.5 km for 'section' lengths. He recommended using about 0.5 km for 'spot' lengths and 2.5 for 'section' lengths, both lengths being substantially greater than generally used in the USA.

The survey of UK practice (Silcock and Smyth, 1984) did not elicit much information about lengths of roads used, but it seems that lengths as small as 0.03 km are used.

8.2.3. Choice of Time Period. The factors affecting the choice of time period include:

(1) avoiding having environmental and other trends affecting results;

(2) using annual accident count data, to avoid the effects of cyclical variation in accident occurrence;

(3) computer storage and processing costs;

(4) using a short period, in order to detect quickly any sudden changes in the accident rate (per unit time);

(5) using a longer period to improve statistical reliability (i.e. smoothing the effects of short-term fluctuations in accident occurrence).

Zegeer found that in the USA, the time period ranged from one to five years, with one and three years being most popular. According to Silcock and Smyth, in the UK the time period ranges from as little as one month up to five years, with three years being clearly the most popular, followed by one year.

Zegeer recommended the use of two time periods, namely one and three years. Analysis of actual accident count data and the precision of interval estimates of the means of Poisson processes (Nicholson, 1986b and 1987) reveals that from the statistical reliability viewpoint, a five year period is most suitable (see Chapter 6 of the course notes). Sabey (1985) has also expressed the view that five years is a most suitable time period.

8.3. IDENTIFICATION OF HAZARDOUS ROUTES

The criterion may be one or more of the following:

(1) the accident number exceeding some threshold value (this ignores variations in route lengths and traffic flows);

(2) the accident number per km exceeding some threshold value (this ignores variations in traffic flows);

(3) the accident rate (per veh-km) exceeding some threshold value.

Despite the limitations of using veh-km as a measure of exposure (see Chapter 5 of the notes), the third criterion is widely used. In order to avoid the bias problem, the use of criteria 2 and 3 together is recommended.

Whereas in hazardous site identification, there is a tendency to use short lengths of road, with hazardous route selection, the analysis of accident data will generally be based on relatively long lengths (from one to several km).

The comments about the choice of time period (section 8.2.3) apply here as well, although the statistical reliability factor is not as critical; although accident counts for individual sites may be very variable, the accident counts for an aggregation of sites (e.g. a route) is likely to be less variable, meaning that a shorter time period is required for equivalent precision. This is clear from the charts for estimating the confidence limits for the UTAR (Chapter 6 of the course notes); the greater the observed accident rate, the greater the precision for the same observation period, so that the same precision can be obtained with a shorter observation period.

8.4. IDENTIFICATION OF HAZARDOUS AREAS

This is a relatively new area of activity, and there is some doubt about the criteria that ought to be employed for identifying hazardous areas. A number of criteria are possible:

(1) the number of accidents per square km per year (this does not take account of variations in the length of road and traffic flows);

(2) the number of accidents per head of population (this also takes no account of road length and traffic flows);

(3) the number of accidents per km of road (this takes no account of traffic flows);

(4) the number of accidents per vehicle owned by or available to the population (this attempts to take account of traffic flows in a crude manner).

The areas are generally of the order of 5 square km or larger. While the comments on section length (section 8.2.2) do not apply, those on the time period (section 8.2.3) generally do. Again, given the aggregation of accident data for many sites, a shorter time period may be used than for the identification of hazardous sites, and still have comparable statistical reliability.

8.5. IDENTIFICATION OF SITES FOR MASS-ACTION

Here the goal is to find sites where there are substantial numbers of accident and numbers of accidents per exposure, where the accidents:

(1) are of a particular type (e.g. skidding accidents);
(2) involve a particular movement (e.g. overtaking);
(3) occur at a particular time of day;
(4) involve a particular class of road user.

Since it is a matter of identifying sites, rather than routes or areas, the previous comments (sections 8.2.2 and 8.2.3) about section length and time period are applicable.

8.6. EFFICIENCY OF IDENTIFICATION PROCEDURES

The goal of a hazardous site, route or area identification procedure is to identify both those that warrant detailed investigation, and those that do not.

Now, four possibilities exist, namely that:

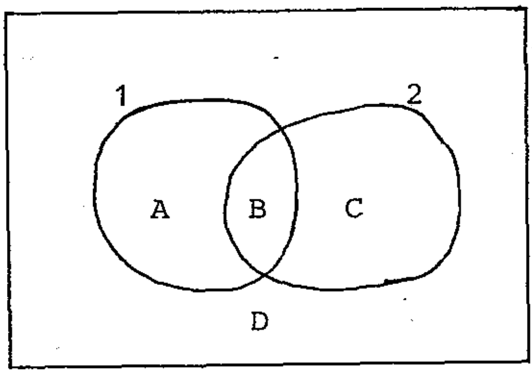
(1) a truly hazardous site will not be identified as such (a false negative);

(2) a truly non-hazardous site will not be identified as such (a false positive);

(3) a truly non-hazardous site will be identified as such (a correct negative);

(4) a truly hazardous site will be identified as such (a correct positive).

The Venn diagram (Figure 1) illustrates the situation. The box symbolises the collection of all sites. The set of all truly hazardous sites corresponds to the area within cordon 1. The set of sites selected for detailed examination is enclosed by cordon 2. The ideal identification procedure would be one for which cordons 1 and 2 coincide exactly, but in general cordons 1 and 2 will delineate three distinct sets (false negatives, correct positives and false positives) with the set lying outside both cordons but within the box being correct negatives.



A = false negatives

B = correct positives

C = false positives

D = correct negatives

Figure 1.

Due to the fluctuation of the annual accident counts about the underlying true accident rate (UTAR), there is uncertainty regarding the UTAR. The observed accident rate over a period may be considerably greater or less than the UTAR. Now, in the identification of hazardous locations, one wants to identify the sites with the high UTAR's, but is forced to make the decision (whether the site is unusually hazardous) on the basis of the observed accident rate. Now if

α = underlying true accident rate (accidents per year)

$\hat{\alpha}$ = observed accident rate

k = threshold underlying true accident rate

$\hat{k}$ = threshold observed accident rate

then there are four possible cases:

(1) $\alpha > k$ and $\hat{\alpha} > \hat{k}$, a correct positive

(2) $\alpha > k$ and $\hat{\alpha} < \hat{k}$, a false positive

(3) $\alpha < k$ and $\hat{\alpha} > \hat{k}$, a false negative

(4) $\alpha < k$ and $\hat{\alpha} < \hat{k}$, a correct negative

The efficiency of the identification procedure depends upon the following considerations:

(1) the number of positives (whether correct or false) that must be examined in detail should be commensurate with the resources available for such examination;

(2) the proportion of positives and negatives that are correct should be as large as practicable, with as few false positives and negatives as is practicable.

Consider the situation where we have a large number of sites, each with its own UTAR, α_i, and the criterion being used is that the observed number of accidents in n years should exceed $(n\hat{k})$. Assuming that the accident counts at every site are Poisson-distributed about the UTAR, then for an n-year period, the expected number of accidents at the ith site is $(n\alpha_i)$, and the probability of $(n\hat{k})$ or more accidents in the n-year period is

$$1 - [\Pr(0) + \Pr(1) + \ldots + \Pr(n\hat{k} - 1)]$$

$$= 1 - \sum_{x=0}^{n\hat{k}-1} (n\alpha_i)^x \exp(-n\alpha_i) / x!$$

Clearly, the probability of $(n\hat{k})$ or more accidents in n years:

(1) decreases as $(n\hat{k})$ increases, for a given n and α_i;

(2) decreases as α_i decreases, for a given n and $\hat{k}$.

By varying the value of n and $\hat{k}$, the efficiency of the identification procedure can be altered.

Consider the case of 250 sites, 50 with UTAR = 6 and 200 with UTAR = 3. The problem is to identify the 50 hazardous sites, using a 3-year observation period, say. If $\hat{k}$ is set at 4, then it follows that the probability of 12 or more accidents in 3 years is:

(1) about 0.2 for $\alpha = 3$.
(2) about 0.9 for $\alpha = 6$.

Hence, about 85 sites would be selected:

(1) about 0.2 x 200 = 40, with $\alpha = 3$;
(2) about 0.9 x 50 = 45, with $\alpha = 6$.

Of the 85 sites, only about 50% will be truly hazardous, and 10% of the truly hazardous sites will not be selected for examination.

If $\hat{k}$ is set at 5, then it follows that the probability of 15 or more accidents in 3 years is:

(1) about 0.05 for $\alpha = 3$;
(2) about 0.75 for $\alpha = 6$.

Hence, about 48 sites would be selected:

(1) about 0.05 x 200 = 10, with $\alpha = 3$;
(2) about 0.75 x 50 = 38, with $\alpha = 6$.

Of the 48 sites, about 80% will be truly hazardous, and about 25% of the truly hazardous sites will not be selected for examination. Clearly, raising the threshold observed accident rate:

(1) reduces the number of sites selected;
(2) increases the probability that selected sites are truly hazardous;
(3) increases the probability that truly hazardous sites will not be selected.

Careful consideration should be given to setting the threshold observed accident rate.

If $\hat{k}$ is set at 4, and a 5-year observation period is used, then the probability of 20 or more accidents is:

(1) about 0.10 for $\alpha = 3$;
(2) about 0.95 for $\alpha = 6$.

Hence, about 68 sites would be selected:

(1) about 0.10 x 200 = 20, with $\alpha = 3$;
(2) about 0.95 x 50 = 48, with $\alpha = 6$.

Of the 68 sites, about 70% will be truly hazardous, and only 4% of the truly hazardous sites will not be selected for examination. The benefit of a longer observation period is obvious!

In reality, the distribution of the UTAR over the population of sites is not as simple as assumed in the above example. Hauer and Persaud (1984) assumed that the UTAR is distributed according to the Gamma distribution, with accident counts being Poisson- distributed about the UTAR's (see Chapter 6 of the notes). They derived expressions for the expected number of sites selected, correct positives, etc, upon which information the efficiency of the identification procedure can be judged.

Finally, it should be noted that altering the threshold observed accident rate (sometimes called the 'reaction level') gives an increase in the size of one type of error and a decrease in the size of the other type of error, but an increase in the observation period leads to reductions in both types of error.

8.7. RANKING OF LOCATIONS FOR TREATMENT

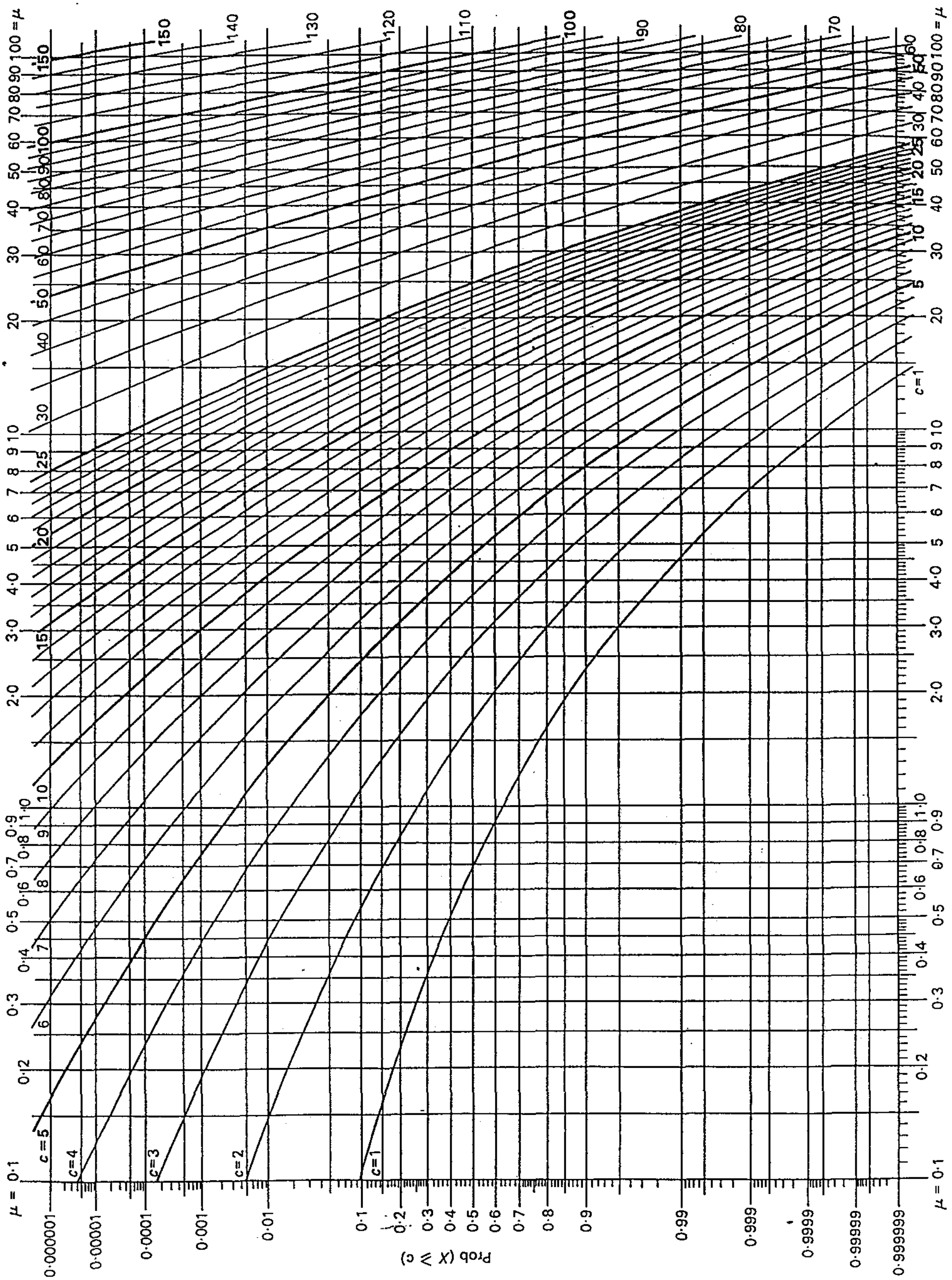
Statistical analysis of accident data will give a list of locations which should be examined in more detail, with the apparently more hazardous locations higher up the list than the apparently less hazardous ones. Detailed examination may well reveal that at a very hazardous location, there is no discernible pattern to the accidents, and the identification of a cost-effective remedial treatment will be hard. Conversely, a much less hazardous location may exhibit a very clear accident pattern and it may be quite easy to identify a cost-effective remedial treatment. Hence, we have what may be termed "hard locations" and "easy locations".

The priority ordering for remedial treatment does not depend on the apparent level of hazard alone; it is necessary to consider other factors, including

(1) how "easy" or "hard";
(2) resource constraints (for both investigation and implementation);
(3) pressure from politicians, public and/or media.

Poisson probability chart

Prob ($X \geqslant c$)



9. PROBLEM DIAGNOSIS VIA ANALYSIS OF ACCIDENT DATA

9.1. INTRODUCTION

One of the principal ways of designing and implementing preventative measures designed to reduce road accidents is by the detailed analysis of accident data. This involves obtaining details of an accident site, the situation, area, length of road, and road users in order to formulate a remedial measure or set of measures (i.e to ascertain the prime contributory factors which relate to, and help to explain, the various road users' "failure to cope" immediately prior to accidents).

There are 4 basic elements to in-depth analysis according to DTp (1986). These are:

a) the production of the basic data;
b) logical assembly of the data into a readable/understandable form;
c) on-site analysis of data and characteristics;
d) assessment of human factors and "failure to cope".

9.2. BASIC DATA

The collection of certain types of basic data has been described in previous lectures. Stats 19 is the most commonly used accident data base in GB. Other important data to be collected include police records, witness and participant statements, a detailed description of the location of the accidents, vehicle/pedestrian flows and manoeuvres etc. Obviously in some cases much of the data collected will be superfluous or prior knowledge of the site will mean that less data need be collected.

9.3. DATA PRESENTATION AND ANALYSIS

A number of methods are available:

a) Computer printouts of accident data;
b) Non-site-specific maps of accident distribution
c) Accident/collision diagrams;
d) Tabular portrayal of accident diagrams.

These are considered in turn below:

Computer printouts of accident data
Accident data are generally stored on computer and simple printouts for each accident or set of accidents can be produced. Accidents occurring at a particular location, or to a particular group of people can be tabulated to indicate common features or possible contributory factors.

Non-site-specific maps of accident distribution
These can be plotted for an area or road section. Very often done by computer mapping packages linked up to Stats 19 data bases (grid reference location of the accident is one of the variables on Stats 19). Accidents can be plotted according to

any of the variables chosen from the Stats 19 database, for instance pedestrian accidents, right turning accidents etc. These types of maps give a general preliminary indication of the accident situation in an area and can be indicative of the preventative measures required, though further more detailed study is often needed.

Accident/collision diagrams
These give an immediate visual indication of location, site characteristics, common manoeuvres etc. Information from damage only reports and conflict studies can be added if available. Production of such diagrams also generally means carrying out a site visit.

Example 1 (from DTp,1986).

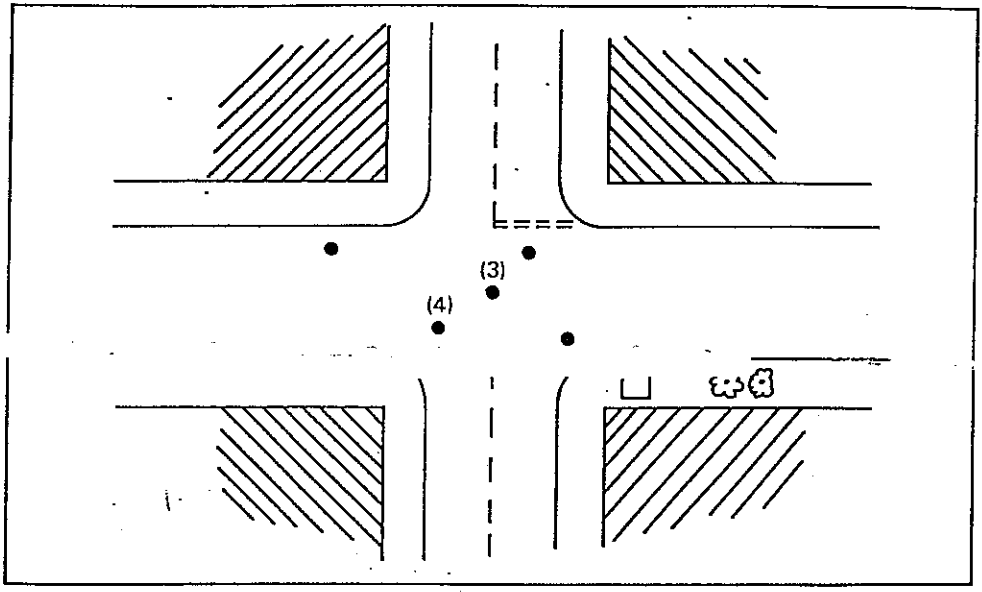
Figure 1 shows the location of a number of accidents occurring at a crossroads. Using accident information it is possible to determine the vehicle approach and intended departure paths and so produce a collision diagram for the site as in Figure 2.

This gives a neat visual picture which the investigator can use as the basis for interpreting the accident situation at the site. It also provides the basis for the design of an 'on-site' detailed conflict study should examination in-depth later prove this to be necessary.

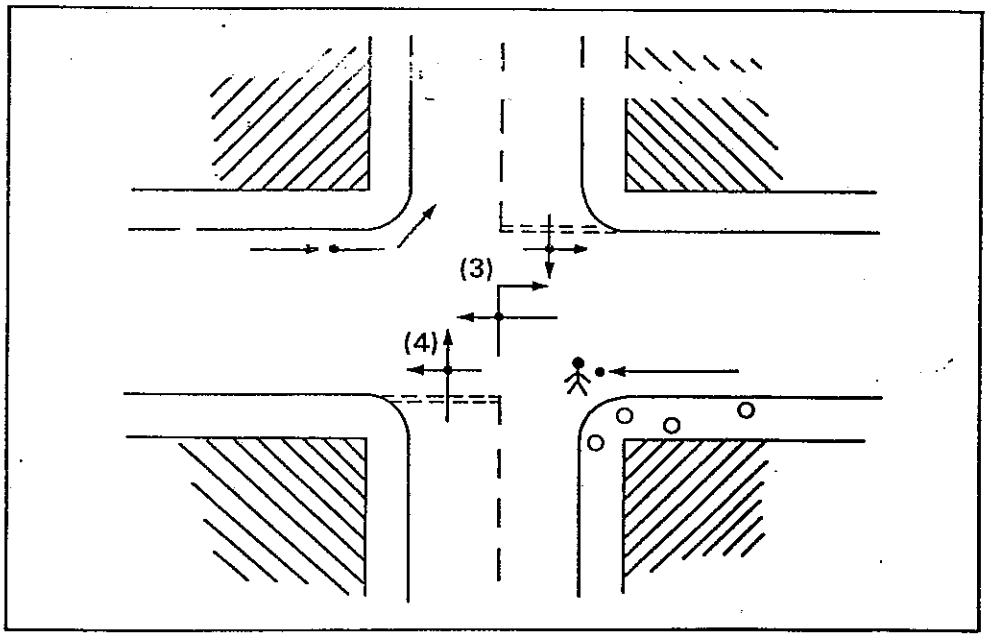
It is important to remember when classifying each accident within a cluster for the purpose of preliminary examination that road accidents are random multifactor events to which it is impossible to assign a single cause. To try to do so simply masks the underlying factors which are so often indicative of simple low cost remedial action.

Theoretically, an accident may be classified according to any one of the infinite set of underlying factors related to it, and in practice the investigator may assign an accident to any one of a wide variety of accident types based upon the known underlying factors related to that accident. For example, a collision of the type portrayed in Figure 3 may be assigned to any one of the following accident types:

1. Approach visibility restricted
2. Violation of a mandatory sign
3. Overshooting give way line
4. Collision on restart from give way line
5. Obscured give way sign
6. Give way line concealed by uneven surface profile
7. Lack of junction conspicuity from side road
8. Continuous perspective lines from side road
9. Misjudgement of speed of main road vehicles
10. Acceptance of too small a gap due to excessive waiting period
11. Excessive speed of main road vehicle
12. Overtaking on the approach to a junction
13. Parking on main road (reducing visibility)
14. Wet surface obliterates give way lines
15. Lack of adequate skid resistance
16. Uneven lighting on main road conceals main road vehicles
17. Dazzle from brilliant shop window lighting
18. Slow take off due to gradient on approach to give way line
19. Collision with two-wheeler vehicles on main road
20. Obstructed entrance into opposite side road

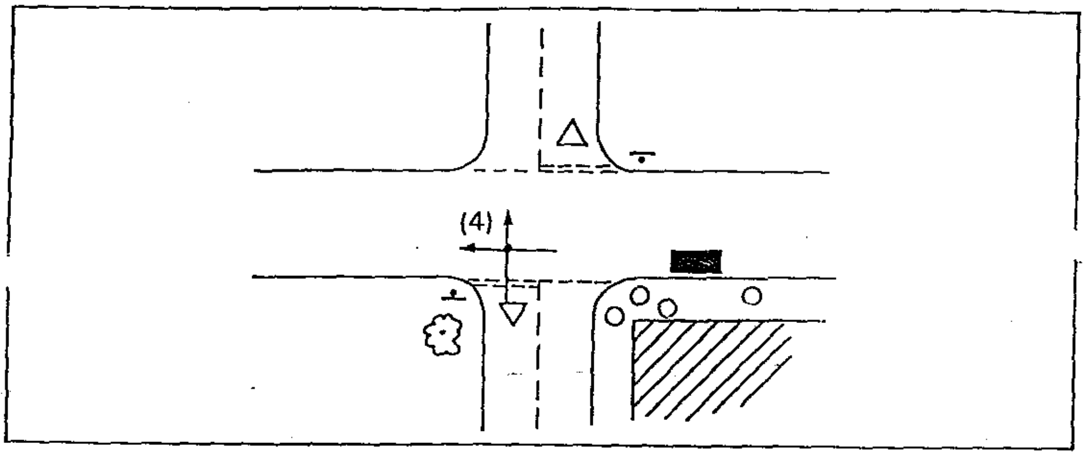


Accident Plot
FIG. 1



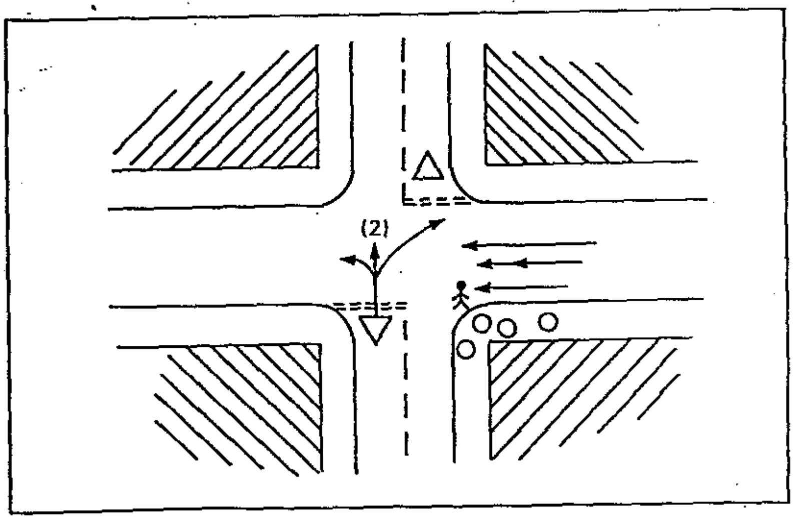
Collision Diagram

Fig. 2



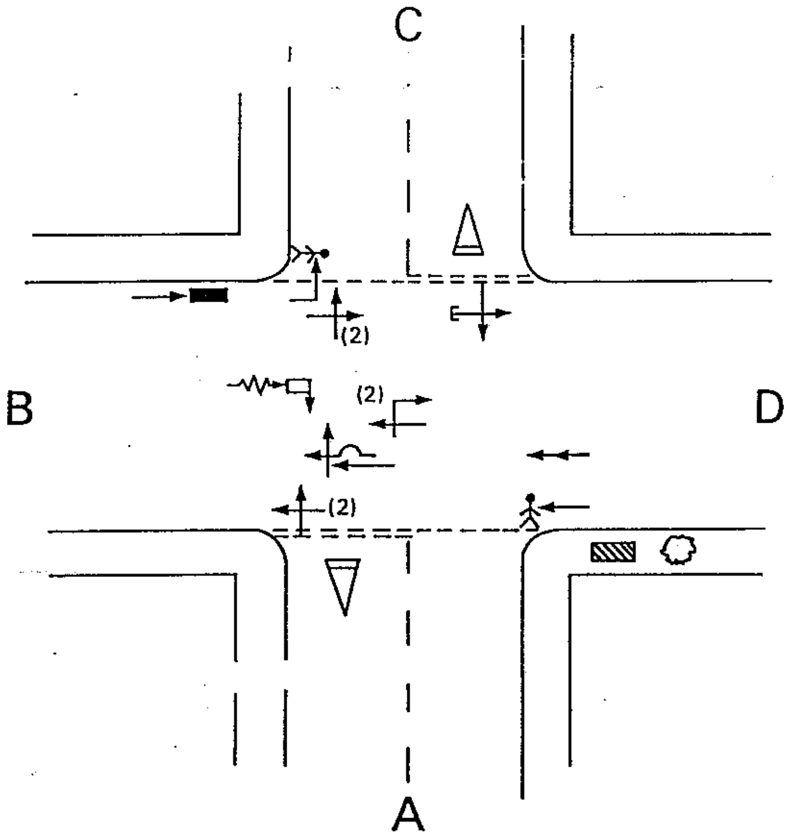
A single basic collision type capable of classification according to a wide variety of underlying factors

Fig. 3



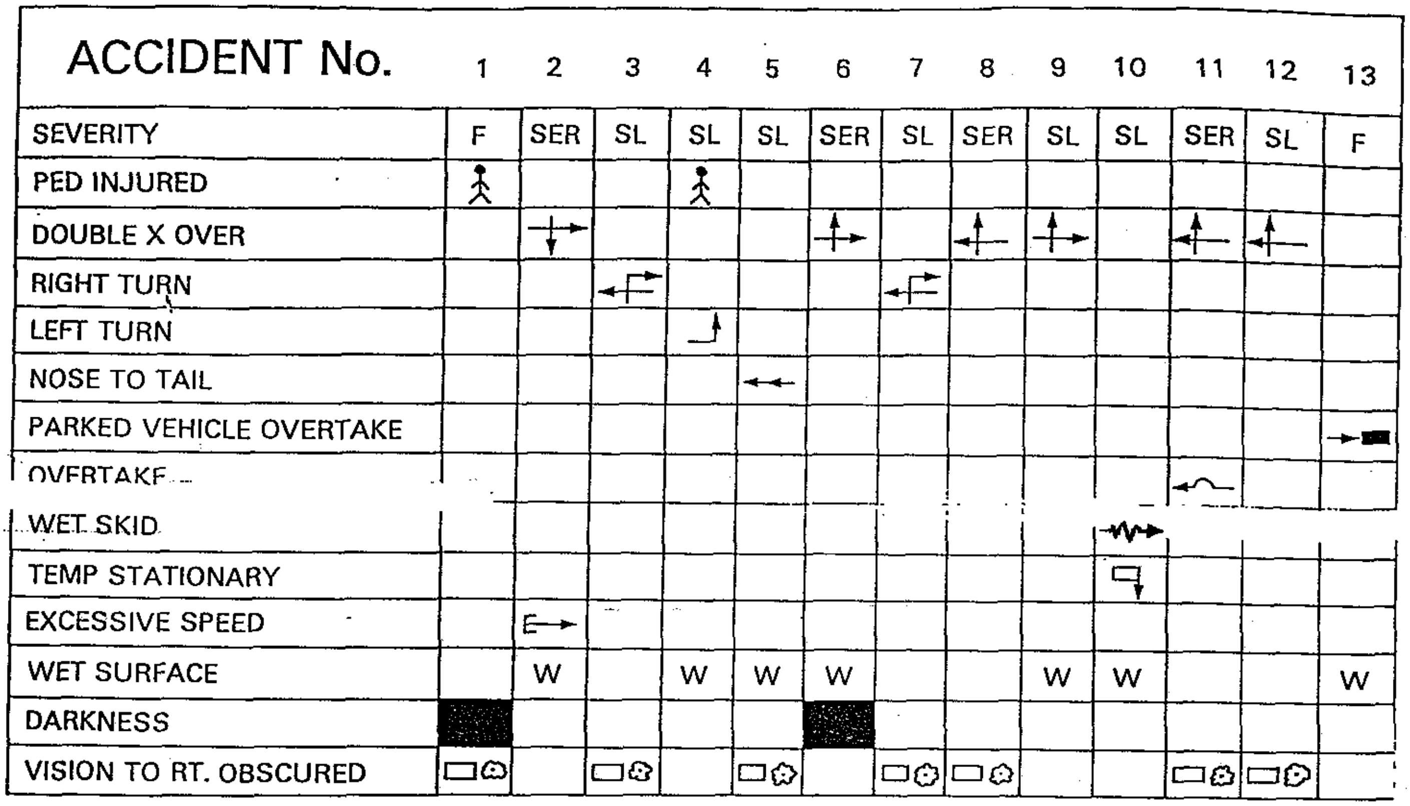
A variety of basic collision types capable of classification according to a single accident type.

Fig. 4



Typical collision diagram for an accident cluster revealing no clear accident pattern.

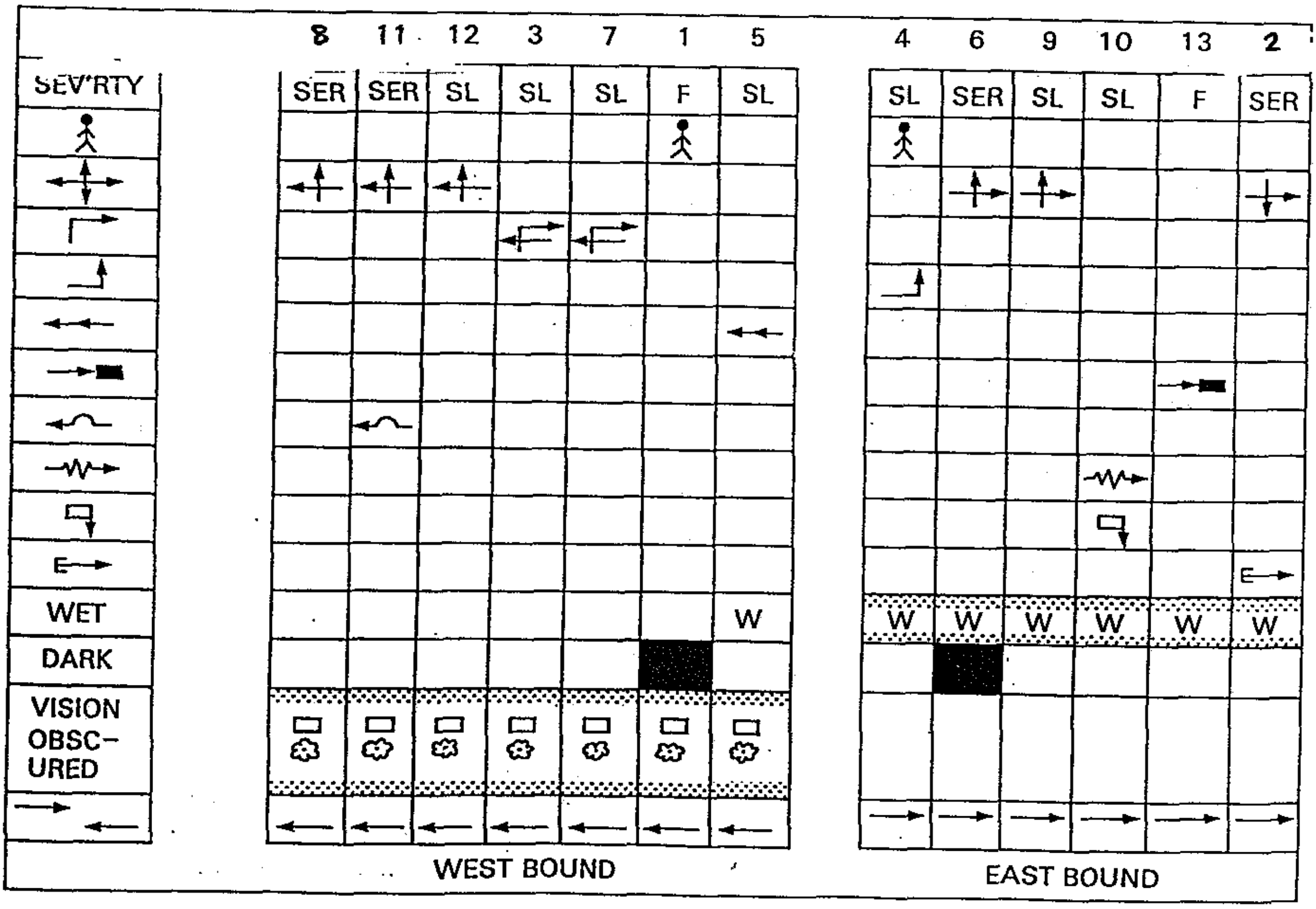
Fig. 5



ACCIDENT No.	1	2	3	4	5	6	7	8	9	10	11	12	13
SEVERITY	F	SER	SL	SL	SL	SER	SL	SER	SL	SL	SER	SL	F
PED INJURED	🚶			🚶									
DOUBLE X OVER		┼				┼		┼	┼		┼	┼	
RIGHT TURN			↱				↱						
LEFT TURN				↲									
NOSE TO TAIL					←←								
PARKED VEHICLE OVERTAKE													→■
OVERTAKE											←⌒		
WET SKID										~→			
TEMP STATIONARY										↴			
EXCESSIVE SPEED		E→											
WET SURFACE		W		W	W	W			W	W			W
DARKNESS	■					■							
VISION TO RT. OBSCURED	▭✿		▭✿		▭✿		▭✿	▭✿			▭✿	▭✿	

Accident Grid
showing known factors

Fig. 6



	8	11	12	3	7	1	5	4	6	9	10	13	2
SEV'RTY	SER	SER	SL	SL	SL	F	SL	SL	SER	SL	SL	F	SER
🚶						🚶		🚶					
┼	┼	┼	┼						┼	┼			┼
↱				↱	↱								
↲								↲					
←←							←←						
→■												→■	
←⌒		←⌒											
~→											~→		
↴											↴		
E→													E→
WET							W	W	W	W	W	W	W
DARK						■			■				
VISION OBSC-URED	▭✿	▭✿	▭✿	▭✿	▭✿	▭✿	▭✿						
→ ←	←	←	←	←	←	←	←	→	→	→	→	→	→
	WEST BOUND							EAST BOUND					

Revised Accident Grid from Fig. 6
showing Dominant Accident Type

Fig 7

This list is by no means exhaustive, but it does serve to show that a single collision type can be classified according to a very wide variety of accident types (or underlying factors). Many of these factors do not appear in the 'stats 19' information, which is used for routine processing, and can only be obtained by a systematic site survey followed by a reconstruction of the events leading up to each accident.

Just as a single basic collision type can be classified according to a wide variety of accident types, so can a wide variety of collision types often be reclassified according to a single accident type. For example, using Figure 4 as the basis for discussion, all 4 drivers emerging from the side road stopped at the give way line but were involved in a collision on restart. Among the many underlying factors relating to the individual accidents was one which was common to all of them, namely "view to the right obstructed by street furniture". In the case of the nose-to-tail collision, for example, the second vehicle collided with the first when it braked hard to avoid a third vehicle which emerged from the side road masked by street furniture. Thus, there were 5 basic collision types comprising 6 accidents in all, which possessed "obstructed view to the right" as a factor. All 6 accidents can, therefore, be assigned to the same class, namely "view to the right obstructed". This is clearly a classification which is indicative of remedial action.

It is worth noting in passing that if the accident cluster in Figure 4 had been classified in the traditional manner, namely:

2 double cross overs
1 right turn
1 left turn
1 nose-to-tail
1 pedestrian

no distinct pattern would have been revealed, and certainly no indication of the remedial action required would have been provided.

Tabular portrayal of accident/collision diagrams
Figure 5 shows a collision diagram of a fairly typical 3 year accident cluster, of the type often dealt with by local authorities. On the face of it there is no discernable pattern of accidents. In order to make a simple effective remedial treatment the accident investigator needs to be able to establish a dominant accident type. To help in this aim it is useful to set up a tabular portrayal (or 'accident factor grid') of the accidents occurring in Figure 5. This is shown in Figure 6.

Generally speaking it is advisable to keep to traditional symbols, though those used vary from country to country, and area to area.

If it is not immediately obvious from the grid above what is happening at the site, a helpful technique is to rearrange the vertical lines (use scissors!) until a pattern which either suggests the remedial action required or at least suggests some further line of investigation is obtained. Figure 7 shows one such rearrangement which gives a clearer idea of what is happening, and shows two dominant accident types, and clearly indicated the precise remedial action required.

9.4. HUMAN FACTORS

In previous lectures the role of human factors in road traffic accidents has been touched upon. Driver error is often linked to deficiencies in the road network which place an extra demand on the drivers' ability. Also, even in circumstances where human error has been judged to be the sole contributor, it may be possible to influence driver behaviour by engineering means.

By relating observations of the site characteristics with the dominant features in police accident reports, it is often possible to identify defects in the road system which need remedying. But, other means of influencing behaviour require a knowledge of the problems encountered by drivers involved in accidents. Ideally this information would be obtained by interviewing the drivers involved. The opportunity to do this is unlikely to be available to local authority investigators who will have to rely on the details contained in the police accident reports. Only a few studies, such as the AA funded accident analysis project carried out at the Institute for Transport Studies between 1987-1989, have the means to carry out large numbers of interviews with accident participants.

9.5. IN-DEPTH ANALYSIS

This should progress as follows:

a) Interpret facts in the light of knowledge gained from preliminary study and systematic site survey.

b) Produce sequential narrative of the probable events leading up to each accident through the eyes of the road users concerned.

c) Pick out these details peculiar to each accident which warrant further study.

When confronted with a typical accident cluster it would be impossible as well as uneconomic to investigate in-depth each accident in a cluster. It is necessary therefore to identify a dominant accident type or types upon which the investigator can concentrate his/her attention. Three different types of accidents can be identified:

a) Dominant accident types - these should contain as many of the individual accidents in a cluster as is possible.

b) Minor accident types - i.e groups of 2 or 3 accidents of a similar type within the cluster.

c) Miscellaneous accidents - an accident cluster will often contain one or more 'odd-ball' accidents which occur very infrequently, and make them unreliable for statistical purposes.

Most accident clusters are capable of being reduced to one or occasionally two dominant accident types suitable for study in-depth by taking the historic data from a sufficiently long period of time. Normally 3 to 5 years is adequate.

Dominant accident types provide the most reliable guide to the remedial action required, because they are likely to be most representative of future accidents at the site. Minor accident types are much less reliable, and should only be used with caution when determining remedial action. The incidence of miscellaneous accidents is so unpredictable as to make them virtually useless for the purpose of determining remedial action, and they should not normally be taken into account.

9.6. AREA WIDE ANALYSIS

Sometimes accident investigators consider accidents occurring over a wider area than just an individual junction or section of road. If a pattern of accidents can be discerned at a wider level then there is no reason why a preventative measure or set of measures cannot be applied to solve the problem. Identification of a dominant accident type can be achieved for an area using the same types of techniques as described above, though it is sometimes more complicated and difficult. Preventative measures can then be designed and applied, for example the rerouting of through traffic away from residential areas to reduce pedestrian accidents, or the prevention of right turns into an estate, except at junctions where it is considered safe (or can be made safe by the implementation of measures such as mini-roundabouts).

A trial project (the TRRL Urban Safety Project) is at present underway in 5 urban areas in GB with the aim of ascertaining what benefits can be gained from this approach. For further discussions of the approach see Dalby (1979) - Area wide measures in urban road safety - TRRL Supplementary Report 517.

10. TRAFFIC CONFLICTS TECHNIQUES

10.1. INTRODUCTION

Road accidents are relatively rare events; air transport accidents are even more rare. Whenever there is a "near-accident" (or "near-miss") involving aircraft, it is standard practice to study the circumstances surrounding it very carefully, in order to identify the factors involved and identify actions that should be taken to avoid repetition or a collision. Near-accidents have been studied by road safety researchers (and some practitioners) for over 20 years, although the investigation is much less detailed and rigorous than in the aviation industry. In both contexts, however, the study of near-accidents (or traffic conflicts) is seen as contributing to accident reduction.

The first systematic procedure for observing and recording road traffic conflicts was that proposed by Perkins and Harris (1967), who were charged with finding out whether vehicles made by General Motors were involved in more or less "unsafe incidents" than were vehicles made by other manufacturers. They concluded that the task they had been given was futile, but that the technique they had developed might be used to assess accident potential.

Traffic conflicts can be seen as part of the continuum of events that range from "safe" driving through to accident and injury. The concept of the "safety pyramid" is a more useful concept than the "safety continuum", as the former conveys some idea of the relative frequency of the different types of events whilst the latter does not (see Figure 1).

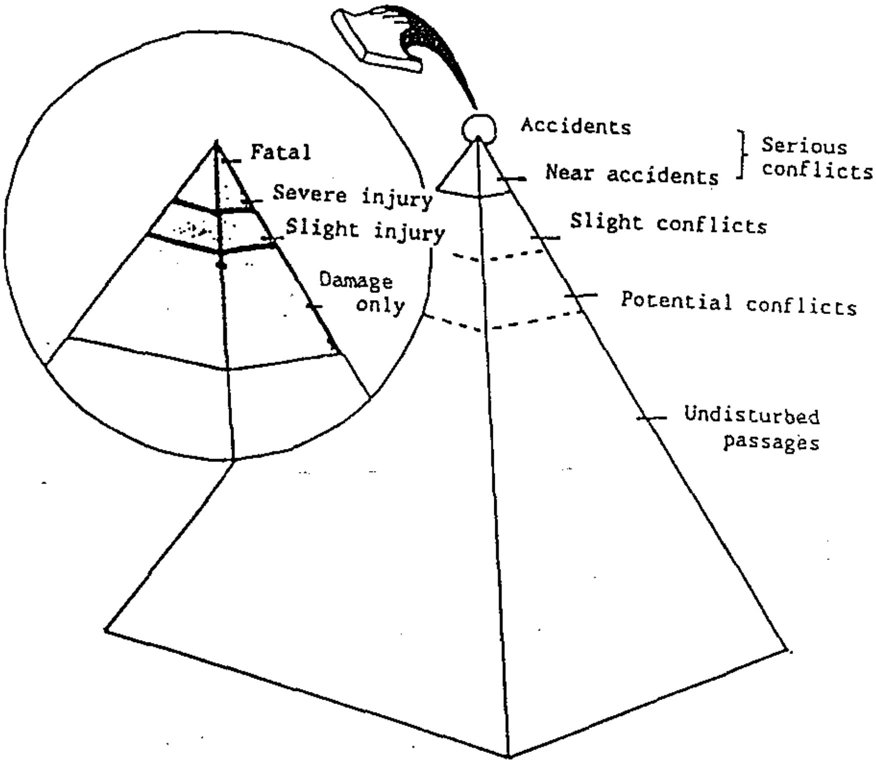


Figure 1. The 'safety' pyramid

The nearer an event is to the accident end of the spectrum, the easier it is to show that the event could well result in an accident but the harder it is to estimate accurately the frequency of such events (due to their relatively low frequency). The further an event is away from the accident end of the spectrum, the harder it is to show that it could well result in an accident, but the easier it is to estimate accurately the frequency of such events (due to their relatively high frequency). The trade-off between statistical reliability and validity is a crucial issue in applying traffic conflicts techniques and assessing their utility, and the definition of a traffic conflict is at the heart of the matter.

10.2. DEFINITION OF A TRAFFIC CONFLICT

In 1967, Perkins and Harris adopted the following definition:

> "a traffic conflict is any potential accident situation; there are two categories of traffic conflicts ... evasive actions of drivers, and traffic violations."

In the subsequent procedure manual (Perkins, 1969), he association of conflict with evasive action was made more explicit, the definition being:

> "a traffic conflict occurs when a driver takes evasive action, brakes or weaves, to avoid a collision."

There has subsequently been a continual debate about how best to define a traffic conflict, taking account of logical, practical, semantic and geographical issues in addition to the trade-off between statistical reliability and validity. In the USA, the 1969 Perkins definition has been retained and widely used, whereas in Europe there has been general agreement that there is a need to superimpose a classification of conflicts according to severity.

Severity grading of conflicts has generally involved the conflict observer exercising judgement, and this has resulted in the criticism of undue subjectivity in the traffic conflicts technique. There have been attempts to develop objective techniques for assessing conflict severity, but these have not progressed beyond research applications (i.e. they have not been adopted in practice).

A major problem has been confusion over whether a conflict is a situation or an event, due to differences over the status given to evasive action. The General Motors procedure basically equates the conflict with the evasive action. Since not all accidents are preceded by an observable evasive action, it is suggested that validity is very doubtful.

It is better to regard the evasive action as a reaction to a conflict situation, and the European procedures have been based on the view that evasive action is the result, not the cause, of a conflict. For example, Older and Spicer (1976) defined a traffic conflict as:

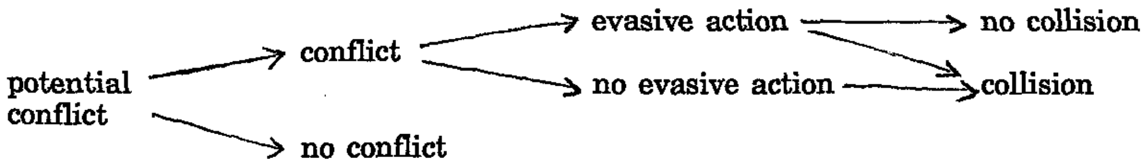
> "a situation involving one or more vehicles where there is an imminent danger of collision if vehicle movements remain unchanged."

There was an international workshop aimed at developing an internationally accepted definition of a conflict, the result being the following definition (Amundsen and Hyden, 1977):

> "a traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged."

It should be noted that this definition rules out conflicts when there is a single vehicle exhibiting undesirable behaviour, such as violating a traffic regulation (e.g. not stopping at a STOP sign) or losing control; such behaviour may well be an indicator of a safety problem that may be susceptible to remedial treatment. It also excludes situations involving parked vehicles.

Nevertheless, it makes the important point that it is not necessary that there be an evasive manoeuvre for a conflict to have occurred. Hence, if we define a potential conflict as situation where if another vehicle were to be in the near vicinity a conflict situation may exist, then the overall process can be represented as follows:



10.3. SOME TRAFFIC CONFLICT PROCEDURES

10.3.1. General Motors Research Laboratory Procedure. The procedure, as described by Perkins (1969) involves observing (from behind) vehicles approaching an intersection, and recording conflict occurrence, as evidenced by

(1) a brake light indication, or

(2) a lane change

by the offended driver, whose right-of-way is threatened or infringed.

The procedure involves classifying conflicts according to the manoeuvres being made by the vehicles involved. For the 10 main conflict types, both

(1) the frequency of particular manoeuvres, and
(2) the frequency of conflicts being associated with those particular manoeuvres,

are recorded. That is, one records both potential and actual conflicts.
For the other 14 conflict types (there are 24 in total), only actual conflicts are recorded.

While one observer observes and records possible and actual conflicts, the other observer of the pair undertakes a "volume count" for the approach under observation, recording the following:

(1) the number of vehicles in the period;

(2) the number of vehicles that obviously braked without the brake lights being activated (conflicts may be factored upwards if it seems that a substantial proportion of vehicles have defective brake lights);

(3) the number of through-vehicles which had to stop, slow down or were able to pass through undelayed;

(4) the number of through and turning vehicles which cross the stop-line without complying with the traffic regulations.

This procedure entails

(1) conflict counts (for an assessment of the safety situation), and
(2) volume counts (for an assessment of the efficiency of operation).

In effect, the procedure recognises that both safety and efficiency should be considered when assessing the overall performance of an intersection.

This procedure provides a little information about many events relating to both safety and efficiency. The procedure is relatively objective and may be used by trained technicians, as conflicts (or evasive manoeuvres) can readily be identified and counted. The definition of a conflict is very arbitrary, taking no account of variations in driving behaviour between drivers, and ignoring the possibility that the best evasive action may be to accelerate.

10.3.2. Transport and Road Research Laboratory Procedures. With the procedure used during the 70's and early 80's, observers generally had one or more specific manoeuvres to monitor, and whenever a conflict occurred, to record:

(1) where and when the conflict occurred and how it arose;
(2) the type and number of vehicles involved;
(3) the evasive behaviour adopted by those involved;
(4) an estimate of the severity of the conflict.

The record generally involved preparing a sketch containing the above information.

The severity grading implied different degrees of unexpectedness of the conflict, as indicated by the suddenness of the evasive manoeuvre. Five severity grades were employed, as follows:

(1) precautionary braking or lane change, minimal risk of collision;
(2) controlled braking or lane change, ample time to avoid collision;
(3) rapid deceleration or lane change, a near-accident;
(4) emergency braking or lane change, a very near or minor accident;
(5) emergency braking or lane change, followed by collision.

Classes 1 and 2 were termed "slight" or "minor" conflicts, while the others were considered "serious" conflicts.

This procedure provided a substantial amount of information about a few events relating to safety only. The procedure was particularly subjective when it came to grading conflict severity, and therefore required greater judgement skills than technicians might possess. The definition of a conflict was situation-based, rather than evasive-action-based, and it was thus possible to have a traffic conflict when the evasive action was unusual (e.g. acceleration).

In 1987, the TRRL (in association with the Institution of Highways and Transportation) proposed a modified traffic conflicts procedure. This procedure is based upon the internationally agreed definition (Section 10.2). The major change is to the part of the procedure relating to grading conflicts according to severity. Whereas the earlier procedure involved exercising judgement with respect to the whole situation, the new procedure requires one to make judgements with respect to four specific matters:

(1) how long in time before the potential accident (or collision) did the evasive action commence (long, moderate, or short);
(2) how severe was the evasive action (light, medium, or heavy);
(3) was the evasive action simple or complex;
(4) how close did the conflicting vehicles get (<1, 1 to 2, or >2 car lengths).

An evasive action is simple if a single action (e.g. braking or change of course) occurs, and complex if more than one action (e.g. braking and change of course) occurs. The proximity of the vehicles when the first is at the collision point is simply judged, with one car length being equivalent to about 15 feet (or 4.5m). To assist judgement of the severity of the evasive action, the following descriptions are given for braking:

(1) light (involving a period of slight controlled braking);
(2) medium (involving more prolonged slight controlled braking or a shorter period of sharper controlled braking in which the front of the vehicle would be seen to dip down);
(3) heavy (involving prolonged sharper, less controlled braking where the front of the vehicle dips abruptly and perhaps some squealing of tyres);
(4) emergency (involving uncontrolled, very heavy, continuous braking, where the wheels may lock up and the vehicle skid out of control).

For change of lane or course, the following behaviour is associated with each severity level:

(1) light (a controlled, slight change of course);
(2) medium (a controlled, complete change of course);

(3) heavy (a less controlled, sudden swerve to change course);
(4) emergency (very heavy, uncontrolled swerving).

The first factor, the time between commencement of evasive action and potential collision, must be judged carefully, taking account of the distance between the vehicles, their direction of travel and their speeds. This factor is probably the most difficult to assess; it, like the severity of the evasive action, cannot be illustrated by way of simple diagrams, whereas the other two factors can. In order to assist with the development of the appropriate judgemental skills, the TRRL and IHT have produced guidelines for the conduct of traffic conflicts studies, part of which is a handbook for trainees and a video tape-based training package.

Depending upon the assessments for each of the four factors, conflicts are put into four severity grades, one for slight conflicts and three for serious conflicts. Given the number of options for each factor, there are 72 (= 3 x 4 x 2 x 3) possible combinations. In fact, some combinations are not feasible, and the conversion of factor levels to conflict grades is done using Table 1 (showing 58 combinations).

The new procedure makes the assessment of conflict severity more involved but less subjective; one must quantify the proximity of vehicles and the time between evasive action commencing and the projected collision occurring (although there is still scope for making the latter factor more quantitative, by specifying time ranges just as distance ranges are specified for the former factor).

The new procedure is more tabular in nature; rather than drawing sketches for each conflict situation, one describes the conflict situation by entering information into a table (see Figure 2). In this way, the new TRRL procedure has become more like the GMRL procedure.

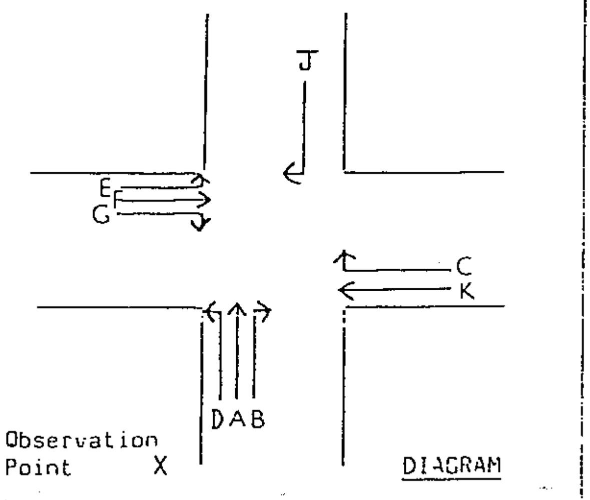
10.3.3. The Modified GMRL Procedure. The original GMRL procedure has been modified (Glauz & Migletz, 1980), who adopted the following definition of a conflict:

> "a traffic event involving two or more road users, in which one performs some atypical or unusual action, such as a change of direction or speed, that places another user in jeopardy of a collision unless an evasive manoeuvre is undertaken."

This definition requires an unusual action instigating a conflict situation, but excludes evasive manoeuvres that are strictly precautionary and violations that do not place another user in jeopardy of a collision.

GRADES	FACTOR A Time to Collision	FACTOR B Severity of Evasive Action	FACTOR C Complexity of Evasive Action	FACTOR D Proximity of Conflicting Vehicles
1.	Long	Light	Simple/Complex	>2 Car Lengths
	Long	Medium	Simple/Complex	>2 Car Lengths
	Long	Light	Simple/Complex	1-2 Car Lengths
	Moderate	Light	Simple/Complex	>2 Car Lengths
	Moderate	Light	Simple	1-2 Car Lengths
	Moderate	Medium	Simple/Complex	>2 Car Lengths
	Short	Medium	Simple/Complex	>2 Car Lengths
2.	Long	Light	Simple/Complex	<1 Car Length
	Long	Medium	Simple/Complex	1-2 Car Lengths
	Long	Heavy	Simple/Complex	>2 Car Lengths
	Moderate	Light	Simple	<1 Car Length
	Moderate	Light	Complex	1-2 Car Lengths
	Moderate	Medium	Simple/Complex	1-2 Car Lengths
	Moderate	Heavy	Simple/Complex	>2 Car Lengths
	Short	Light	Simple/Complex	1-2 Car Lengths
	Short	Light	Simple/Complex	<1 Car Length
	Short	Medium	Simple	1-2 Car Lengths
	Short	Heavy	Simple/Complex	>2 Car Lengths
3.	Long	Medium	Simple/Complex	<1 Car Length
	Long	Heavy	Simple/Complex	1-2 Car Lengths
	Moderate	Light	Complex	<1 Car Length
	Moderate	Medium	Simple/Complex	<1 Car Length
	Moderate	Heavy	Simple/Complex	1-2 Car Lengths
	Moderate	Heavy	Simple/Complex	<1 Car Length
	Short	Medium	Complex	1-2 Car Lengths
	Short	Medium	Simple/Complex	<1 Car Length
	Short	Heavy	Simple/Complex	1-2 Car Lengths
	Short	Emergency	Simple/Complex	>2 Car Lengths
	Short	Emergency	Simple/Complex	1-2 Car Lengths
4.	Moderate	Emergency	Simple/Complex	<1 Car Length
	Short	Heavy	Simple/Complex	<1 Car Length
	Short	Emergency	Simple/Complex	<1 Car Length

TABLE 1. Conversion of Factor Levels to Conflict Grades



SITE ....

DAY..

DATE..

OBSERVER..

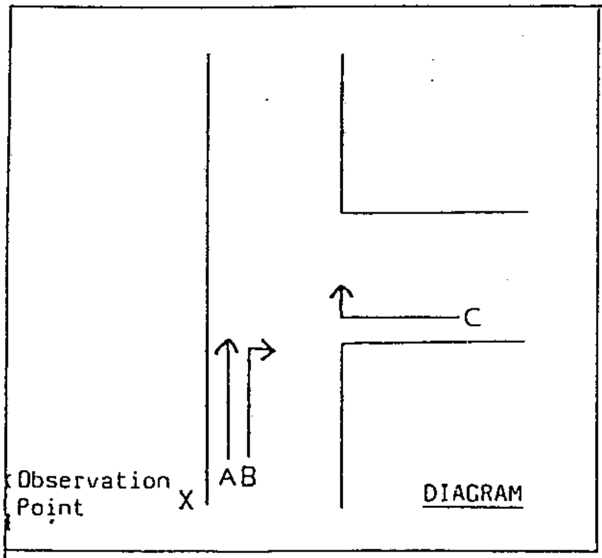
WEATHER..

....

VEHICLE 1. is the one whose actions cause the conflict.

VEHICLE 2. is the one that has to take the avoiding action.

TIME OF CON-FLICT	VEHICLE 1. TYPE C = Car B = Bus L = Light Goods H = Heavy Goods M = Motor-cycle	VEHICLE 1. MANOEUVRE	VEHICLE 2. TYPE C = Car B = Bus L = Light Goods H = Heavy Goods M = Motor-cycle	VEHICLE 2. MANOEUVRE	TIME TO COLLISION L = Long M = Moderate S = Short	SEVERITY OF EVASIVE ACTION L = Light M = Medium H = Heavy E = Emergency	TYPE OF ACTION S = Simple C = Complex	PROXIMITY <1 = less than 1 car length 1 - 2 = 1 to 2 car lengths >2 = more than 2 car lengths	COMMENTS	GRADE OF CONFLICT
	C	D	C	A	S	H	C	<1	Veh. 1 did not indicate	4
	C	J	C	A	M	H	C	<1	–	3



SITE ....

DAY..

DATE..

OBSERVER..

WEATHER..

....

VEHICLE 1. is the one whose actions cause the conflict.

VEHICLE 2. is the one that has to take the avoiding action.

TIME OF CON-FLICT	VEHICLE 1. TYPE C = Car B = Bus L = Light Goods H = Heavy Goods M = Motor-cycle	VEHICLE 1. MANOEUVRE	VEHICLE 2. TYPE C = Car B = Bus L = Light Goods H = Heavy Goods M = Motor-cycle	VEHICLE 2. MANOEUVRE	TIME TO COLLISION L = Long M = Moderate S = Short	SEVERITY OF EVASIVE ACTION L = Light M = Medium H = Heavy E = Emergency	TYPE OF ACTION S = Simple C = Complex	PROXIMITY <1 = less than 1 car length 1 - 2 = 1 to 2 car lengths >2 = more than 2 car lengths	COMMENTS	GRADE OF CONFLICT

Fig 2

Whereas the original GMRL procedure involved 24 conflict types (10 main and 14 other types), Glauz and Migletz propose 13 basic conflict types, not all of which are likely to occur frequently in all situations. They thus developed conflict recording forms with different conflict types depending on the number of arms to the intersection and whether it is signalised or not; signalization should reduce the number of conflict types that will occur frequently.

The retained volume counting, albeit with fewer details; only the number of vehicles making each manoeuvre during the observation period is to be recorded. Conflicts which arise when a vehicle in a conflict situation takes evasive action and places another road user in jeopardy of a collision are termed "secondary conflicts", as opposed to "primary conflicts", and Glauz and Migletz recommend distinguishing between them. They also retained the concept of "opportunities" for conflicts (or "potential conflicts"), for those situations where one road user performs an unusual action that would have placed another user in jeopardy of a collision, had another user been nearby.

Glauz and Migletz did introduce the European practice of classifying conflicts according to severity, choosing the definition that a conflict is serious if the time-to-collision (i.e. the time interval from when a conflicted vehicle reacts until a collision or near-miss would have occurred had there been no reaction), is less than 1.5 seconds, as determined subjectively by trained observers. Those conflicts where the time-to-collision is greater than 1.5 seconds are still to be recorded, as ordinary conflicts.

Glauz and Migletz undertook a comprehensive review of research, as well as testing their recommended procedures against the criteria:

(1) reliability (there should be little variation between different observers independently monitoring the same event);

(2) repeatability (the level of variation in repeated observations by the same observer at the same site under nominally identical conditions should not be large);

(3) practicality (reliable, repeatable, safety-related and site-related data should be obtainable in a reasonable time with reasonable resources).

For conflicts to be safety-related, they should be "related statistically to accidents", and to be site-related, they should be "useful in diagnosing problem locations or measuring the effectiveness of site improvements".

They concluded, amongst other things, that:

(1) the traffic conflicts technique is most suitable for diagnosis, improvement evaluation, and confirmation or denial of hazards at suspect locations;

(2) the technique is not suitable for routine identification of hazardous locations;

(3) conflict data should supplement, not replace, accident data;

(4) serious conflicts occur too infrequently to be of use as diagnostic or evaluation measures;

(5) conflicts vary markedly in number from day to day (even under nominally identical conditions), with the amount of data collection needed to obtain

reasonably precise conflict-rate estimates being typically of the order of a few hours to a few days (depending on the type of conflict and the type of intersection).

10.4. PROCEDURES USING SPACE-TIME TRAJECTORIES

A number of researchers, notably Haywood (1972), Hyden (1977) and Allen & Shin (1977), have endeavoured to develop more objective methods for deciding whether a conflict has occurred and the severity of the conflict. The methods developed so far entail:

(1) obtaining space-time trajectories for vehicles (from video recording, say);

(2) making measurements from trajectories, to identify conflicts and their severity.

A number of measurements have been proposed, including:

(1) the time measured to collision (TMTC);
(2) the time to accident (TO);
(3) the proportion of stopping sight distance (PSD);
(4) the gap time (GT);
(5) the post-encroachment time (PET);
(6) the deceleration rate (DR).

These measures are illustrated in Figures 3 and 4.

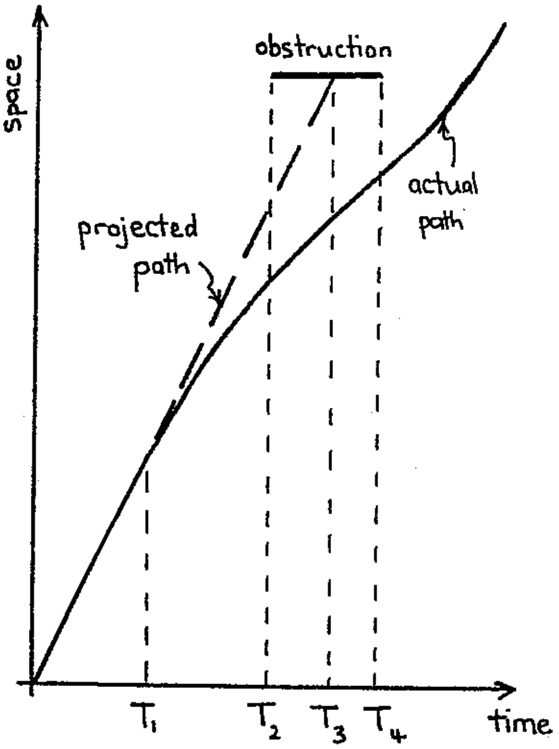


FIGURE 3

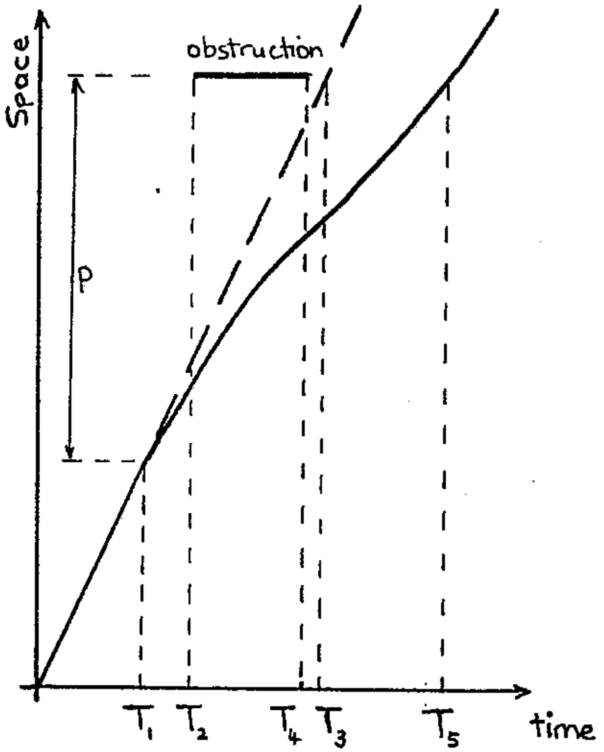


FIGURE 4

Figure 3 shows the case where a collision would have occurred in the absence of evasive action, and Figure 4 shows the case where a collision would not have occurred.

The Times T_1 ... T_5 are defined as follows:

(1) T_1 = time hazard is perceived (evasive action commences some time later, at T_1 + PIEV time);

(2) T_2 = start time of obstruction;

(3) T_3 = projected collision time (or projected time of arrival at location of obstruction if no collision would occur);

(4) T_4 = finish time of obstruction;

(5) T_5 = actual time of arrival at location of obstruction.

The period (T_4 - T_2) is known as the encroachment time.

The measures are defined as follows:

$\text{TMTC} = T_3 - T_2$ $\quad \text{TO} = T_3 - T_1$
$\text{PET} = T_5 - T_4$ $\quad \text{GT} = T_3 - T_4$
PSD = P / (required stopping sight distance)

where P = actual distance to location of obstruction at perception time, T_1 and the required stopping sight distance is based on no change of speed for the PIEV time, followed by deceleration at the appropriate rate for road design. The deceleration rate is obtained from the curvature of the space-time trajectory.

None of the six measures is without some weakness. For instance:

(1) the smaller the value of PET, the greater the apparent severity of the conflict, but it may be that some drivers will be happy with a short PET time while others will decelerate more and ensure a longer PET time;

(2) the deceleration rate (DR) depends upon the degree of caution exhibited by the driver;

(3) different drivers feel differently about what is a comfortable deceleration rate, while the estimation of PSD is based on a single deceleration rate for all drivers;

(4) the TMTC measure seems somewhat irrelevant, as it seems to ignore the fact that the hazard may have been perceived (and evasive action commenced) well before time T_2.

10.5. STUDY DURATION

Like traffic accidents, traffic conflicts are random events, and the daily conflict count at a location is generally subject to considerable variability. The goal of a traffic conflict study is to estimate the underlying true conflict rate (UTCR), using observed daily conflict counts. The best estimate of the UTCR is the arithmetic mean of the observed daily conflict counts, about which a confidence interval can be placed. As for estimation of the underlying true accident rate from observed accident counts, the width of that confidence interval will decrease as the duration of the conflict survey increases.

If daily conflict counts were Poisson distributed, then the charts (Chapter 5) for estimation of the mean of a Poisson process could be used. It has been found, however, that daily conflict counts are generally too variable for them to be well described by a Poisson distribution (for which the variance equals the mean). Instead, it is necessary to use a Negative Binominal distribution (Hauer, 1978), for which the variance is greater than the mean.

Hauer (1978) gives procedures for:

(1) assessing the statistical significance of a change in the conflict rate;

(2) estimating the required study duration, so that a particular reduction in conflict rate will prove statistically significant at a particular confidence level.

He concludes that the accuracy of estimation of the UTCR increases rapidly for durations of about three days or less, but much less rapidly thereafter. Hence, he suggests that there is generally not much to be gained by counting for longer than three days. In addition, a change in conflict rate less than 15% will be difficult to detect and to prove statistically significant, given a three day study.

Hauer refers to three days as being a practical limit upon study duration. It has been shown (Chapter 6) that from a statistical reliability viewpoint, five observations of annual accident counts is optimum, when those counts are governed by a Poisson distribution. Hauer has found that daily conflict counts are more variable than annual accident counts, and it thus seems that from the statistical reliability viewpoint, a conflict study duration of more than five days must be optimum. It seems that concern over the practicality of conflict studies had a large effect on Hauer's conclusion that there is generally little to be gained by counting for longer than three days.

10.6. OBSERVER RELIABILITY

This is one of the most important aspects of the traffic conflicts technique. Observers will not necessarily agree on what constitutes a conflict, and conflict severity. Observer variations may be classified as:

(1) inter-observer variations (between observers);
(2) intra-observer variations (within observers).

These variations arise from a variety of factors, including:

(1) varying levels of alertness;
(2) varying degrees of experience as conflict observers;
(3) varying "attitudes" (e.g. driving "attitude");
(4) observer location, rate of conflict occurrence, etc.

To minimise observer variations and increase observer reliability, it is essential to train observers thoroughly, to ensure a high level of agreement regarding what constitutes a conflict and the severity of a conflict. The guidelines produced by the TRRL and IHT (1987) are aimed at ensuring a high level of observer reliability. The accompanying videotape enables observers under training to view and record the same events independently. A simple pair-wise comparison of observers can be done, as follows:

(1) get two observers, A and B, to observe and record the same conflicts, occurring at a variety of rates (conflicts per unit time);

(2) plot the recorded number of conflicts for one observer against that for the other observer;

(3) derive the least-squares best-fit line;

(4) compare the best-fit line with the ideal relationship (a straight line, slope = 1.0, passing through the origin).

It is desirable that the least-squares best-fit line be close to the ideal relationship, with not too much scatter (coefficient of determination not less than about 0.8).

10.7. VALIDITY OF THE TRAFFIC CONFLICTS TECHNIQUE

The validity of the technique has been a contentious matter ever since it was first proposed. Unfortunately, the concept of validity has not been defined explicitly, and there is clearly a need for such a definition, as a recent dictionary of psychology apparently cites 22 types of validity!

Validation can be defined (Grayson and Hakkert, 1987) as "the process of assessing the extent to which a test or instrument measures what it purports to measure". According to this definition, validity is not an either/or property; it can only be a matter of degree.

The two main approaches to validation are:

(1) external validation, which depends on demonstrating a satisfactory relationship with some external criterion of what is intended to be measured;

(2) internal validation, which is concerned with the concepts and theories underlying the components of the measuring instrument itself.

In the past, the conventional external validation procedure involved testing whether conflicts could predict accidents, by counting conflicts at several locations and comparing those conflict counts with accident counts for the same locations. Unfortunately, the variability of both accident and conflict counts were invariably not taken into account. Recent studies have shown that, in general, conflict counts are at least as good as accident counts for predicting the underlying true accident rate.

It should also be noted that only a small proportion of all accidents are reported and recorded in most countries (see Chapter 7). In addition, there is the problem of bias. Hence, it seems somewhat illogical to condemn the traffic conflicts technique because conflict counts do not agree with accident counts, when the latter are perhaps unreliable. In the UK, researchers have found serious conflicts and accidents to be well correlated, but not minor conflicts. In the UK, the proportion of accidents reported and recorded is lower than in West Germany, where many non-injury accidents are recorded, and where all conflicts have been found to be well correlated with all accidents.

It may well be that traffic conflicts are a more reliable indicator of driver discomfort and perception of road safety than are accident records.

10.8. APPLICATION

The traffic conflicts technique may be used in either an operational or research situation. The operational uses are:

(1) diagnostic (i.e. identifying the nature of a safety problem and appropriate remedial treatment);
(2) evaluative (i.e. assessing the effectiveness of remedial treatment without waiting years for an adequate accident history to evolve);
(3) predictive (i.e. by relating conflict rates to factors such as traffic flow rates, the effect on accidents of changes in those factors might be estimated).

One should analyse accident data prior to designing a traffic conflict survey, as it will help with the selection of conflict types for monitoring; one should monitor the "dominant" movements and perhaps the "minor" movements, but not the "miscellaneous" ones (see Chapter 9). In addition, conflict data should be analysed in much the same way as accident data for a specific site is analysed; one should prepare conflict diagrams and tabular portrayals (or conflict grids) to assist with diagnosis of the problem and the identification of appropriate remedial treatment (see Chapter 9).

It was thought traffic conflict studies could be used to identify hazardous locations, but in order to get reliable results, skilled observers must observe conflicts for several days at each location, and the cost of conflict studies has made such an application unattractive.

In the research situation, traffic conflict studies involve careful observation of actual traffic behaviour, and this provides a sound base for developing new ideas for accident reduction and prevention.

The main advantages of traffic conflict studies are:

(1) conflicts occur much more frequently than accidents, so that a statistically reliable picture is available in a much shorter time than for accident studies and evaluation of remedial treatment can be completed much sooner;

(2) more comprehensive data can be obtained (especially if a video record is made), including information about the development of conflict situations, so that more effective remedial treatments might be identified.

The main limitations of traffic conflict studies are:

(1) the relationship between traffic conflicts and accidents is somewhat uncertain, and it is by no means certain that a reduction in conflicts will be accompanied by a reduction in accidents;

(2) the subjectivity associated with the identification and assessment of severity of conflicts.

Hauer (1978) has suggested that if a site has an average of 50 conflicts per day and 10 accidents per year, then to have a 90% confidence that a 25% reduction is statistically significant, one would require:

(1) conflict counts for 3 days (both before and after treatment);

(2) accident data for 15 years (both before and after treatment).

It is extremely unlikely that other factors would remain constant for 30 years, and while the traffic conflicts technique is not perfect, it may often be the best available method.

Finally, for a hyper-critical opinion on the traffic conflicts technique, see the article by Williams (1981).

11. ROAD ENVIRONMENT FACTORS

11.1. INTRODUCTION

Probably the most comprehensive review of research on the relationship between road safety and road design elements is due to Jorgensen and Associates (1978), who identified over 400 reports and papers. The goals of the study were:

(1) to identify the key geometric characteristics and combinations of characteristics of road and street design that affect accident frequencies and severity;

(2) to quantify the effects of varying the key characteristics and combinations of characteristics on accident frequencies and severity;

(3) to develop a methodology that can be used by engineers in measuring the cost effectiveness of the various levels of each design element.

The first and second goals are of particular interest.

They concluded that 50 design features were found to have some type of relationship with road safety, but the measurement of the effects of these design features on safety has not been conclusive and for some features has been contradictory. Those design features are as follows:

(a) travelled way: number of lanes, lane width, cross-slope, surface type, skid resistance, surface visibility;

(b) auxiliary lanes: number of lanes, function, lane width, length of lane, transitions, cross-slope, surface type, skid resistance, surface visibility;

(c) shoulder: width, cross-slope, surface type, surface visibility, curb, drainage inlets/outlets;

(d) median: width, type, barrier presence, barrier openings, glare screen;

(e) roadside: slopes, ditches, accesses, guardrail, fence, other barriers, fixed objects, frontage roads, bicycle paths, embankment height, drainage inlets/outlets;

(f) vertical alignment: grade on tangents, grade on curves, length of grade, vertical curvature (length), vertical clearance, sight distance (vertical and horizontal).

(g) horizontal alignment: degree of curve, length of curve, superelevation, length of tangent, transitions (spirals);

(h) traffic control: lighting, markings (lane and edge), delineators, signs (regulatory, warning, guide), signals, pedestrian crossings;

(i) others (including continuity).

The safety relationship for a particular design feature can vary with the road type (i.e. motorways, multi-lane rural highways, two-lane rural highways, urban arterials) and the proximity of an intersection (with another road or railway) or a bridge. Jorgensen and Associated considered both:

(1) established relationships, based on empirical research;
(2) logical relationships, based on theoretical reasoning and extrapolation of empirical research.

Most relationships appear to fall into the second category.

The Accident Investigation Manual (DTp, 1986) includes a check list for systematic surveys of accident sites, and this recommends noting the features that may have contributed to accidents at the sites (see Table 1). Comparison of the items above with those in Table 1 reveals that there is a considerable degree of overlap, with the DTp list being more extensive (over twice as many items) and more detailed.

11.2. STUDY METHOD

There appear to have been two distinctly different approaches adopted:

(1) mass data studies; these involve obtaining inventories of geometric and other variables (e.g. traffic variables) for a large number of road segments in a large area, and relating accident data to these; cross-tabulation or multiple linear regression is generally used;

(2) accident site studies; these involve identifying accident sites and comparison sites and making a detailed survey of those sites and their environment, in order to identify what factors are present at the accident sites but not the comparison (control) sites.

It may be that the contradictions in the research results (as noted by Jorgensen and Associates) are largely due to the differences in study method. The first approach, whilst being easier to use, may well be less powerful, in that there is much data relating to sites where accidents have not occurred and this may obscure the effect of factors at sites where accidents have occurred.

Many of the studies have suffered from a lack of rigour. For instance, some studies of the effect of shoulder width have not made any allowance for variations in other factors. If the shoulder width varies systematically with any of those other omitted factors, then the apparent effect of shoulder width on accident occurrence may be largely due to the variations in the omitted factors.

Numerical relationships between accident frequencies and the physical characteristics of sites, based on observations over a large sample, may be of limited utility. It has been suggested (IHT/DTp, 1987) that such models "can deal with only a narrow range of physical characteristics ... (and) may not account for the oddities of circumstance which sometimes lie at the root of the problem at a blackspot, where, for example, the road geometry may be unexceptional".

Clearly, any statistical safety relationship cannot be reasonably expected to explain all variations in the occurrence of accidents (many studies report coefficients of determination of about 30-35%, or less); they can merely indicate the general relationship between accident occurrence and geometric features.

There are undoubtedly other methodological problems with several of the studies. For instance, the assumptions underlying multiple linear regression may not be well satisfied; the road design process is aimed at ensuring consistency of geometric standards, so that there will be correlation between geometric characteristics, which are thus not independent and not appropriate explanatory variables. It is also likely that insufficient allowance has been made for temporal variations in accident occurrence. Most studies have preceded the discussion of matters such as regression-to-the-mean (see Chapter 14), and thus estimates of the effect of changes in road geometry (such estimates are often the basis of relationships between accident occurrence and road geometry) may be inaccurate (subject to bias).

In the next sections the effects of a number of selected features will be considered.

11.3. SURFACE CONDITIONS

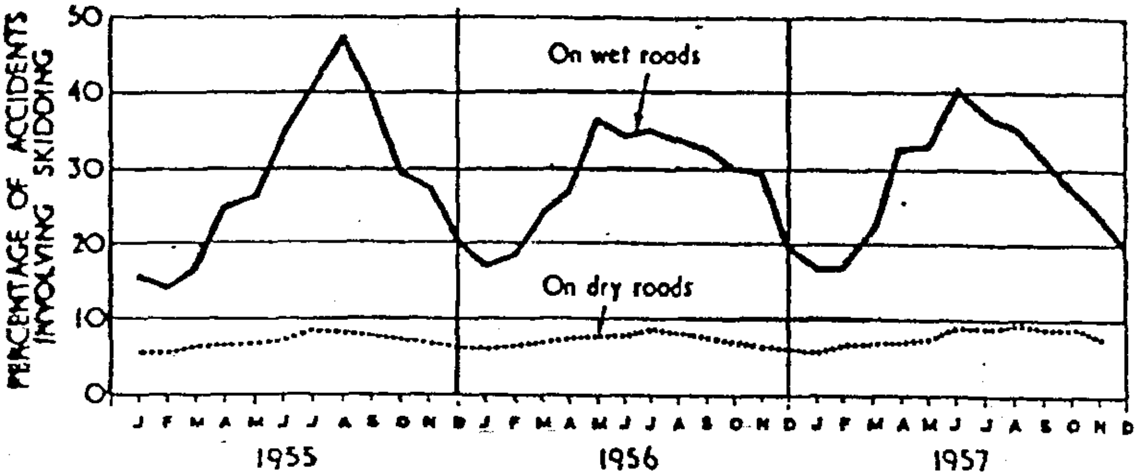
Although there is considerable attention being given to the effects on vehicle operating costs of road roughness, there is as yet no evidence of road roughness affecting accident occurrence. It is likely that a rough road would be attended to before it got to the stage where it became a factor in accident occurrence.

Probably the aspect of surface conditions most relevant to road safety is the skid resistance characteristics of the surface. There is an abundance of evidence that accidents are related to skid resistance. For instance, the percentage of accidents in the UK in 1955-57 involving skidding was:

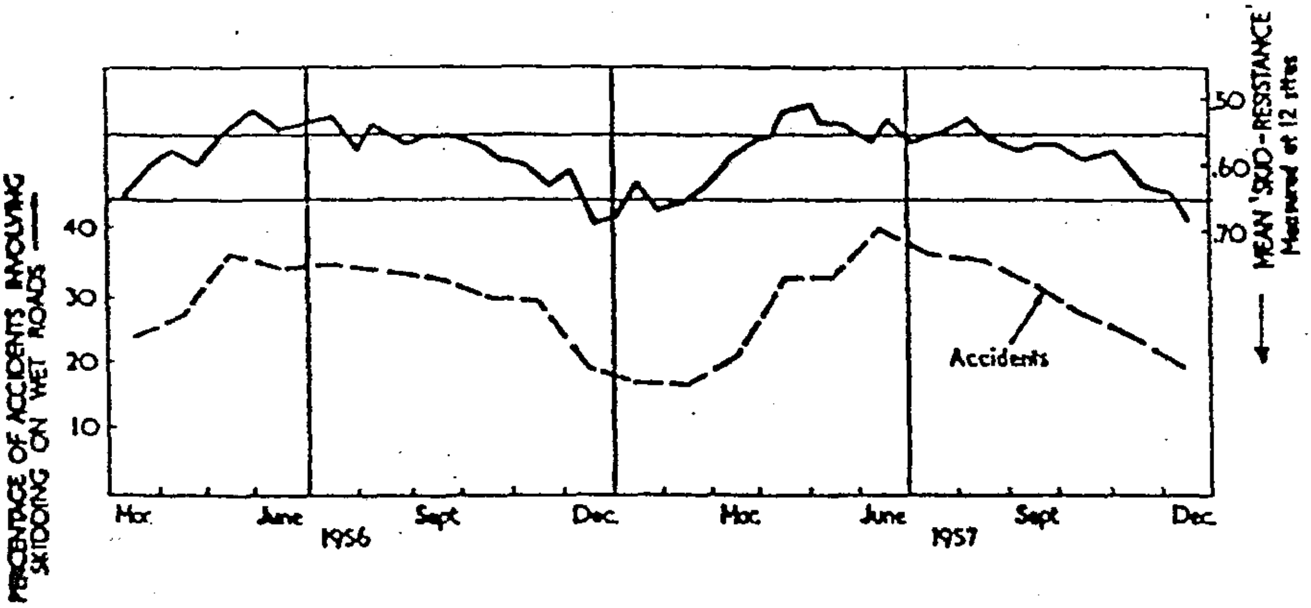
(a) about 7% for accidents on dry roads, with very little variation during the year;

(b) about 28% (on average) for accidents on wet roads, with substantial variation during the year, from about 15% in mid-winter to about 40% in mid-summer.

The percentage of accidents involving skidding is higher in summer than in winter, due to the greater sensitivity of skid resistance to the presence of moisture during dry periods (see Figure 1). In addition, temporal variations in the percentage of accidents on wet roads involving skidding is strongly correlated to temporal variations in wet road skidding resistance (see Figure 2).



. Seasonal variation in skidding accidents: data for personal-injury accidents in Great Britain 1955-57



Seasonal variation in skidding accidents and skidding resistance

Figures 1 and 2:

Obviously, wet road skid resistance is most critical, although very slippery surfaces may be dangerous even in dry weather. Some understanding of the interaction of the tyre and the road is important.

The rubber tread of a tyre grips a clean stone surface mainly by deforming into the fine irregularities of the stone surface. These irregularities range in size from coarse sandpaper texture down to microscopic features, and they are known as the "microtexture" of the road surface. The extremes of microtexture are termed "harsh" and "polished".

The effect of trafficking is to reduce the harshness of the microtexture, or to polish the stone, and varying types of stones have varying resistance to polishing.

The presence of moisture has little effect on skid resistance when vehicles are travelling at low speeds, but as speeds increase, the water must be squeezed away from the surface by the tyre before it can grip. The water can drain away through the channels in the tyre tread and the coarse pattern of inter-connected depressions in the road surface (i.e. the "macrotexture"). As vehicle speeds increase the water must be removed more quickly, and if the drainage is inadequate, the area of tyre grip is diminished, and skid resistance is decreased.

The extremes of macrotexture are commonly termed "rough" and "smooth" (or "fine"). Aquaplaning, in which the tyre does not develop full grip over any area because of the inadequate drainage of water, is more likely at high speeds, with bald tyres and a fine macrotexture.

The effect of speed, macrotexture, microtexture and tyre condition on the coefficient of skid resistance is shown in Table 2. It can be seen that:

(1) with a coarse macrotexture, tyre condition has virtually no effect;

(2) with a fine macrotexture, a treaded tyre is much better than a bald tyre;

(3) skid resistances are similar at low speeds but dissimilar at high speeds, for the same microtexture.

Temporal variations in skid resistance can be categorised as follows:

(1) long term - the trafficking effect dominates;
(2) medium term (seasonal) - the trafficking and weather effects dominate alternately;
(3) short term - the weather effect dominates.

While trafficking gives polishing, harsh weather leads to restoration of microtexture. In summer, trafficking is greater (and weathering is less) than in winter.

Micro-texture	Macro-texture	Tyre Condition	Skid Resistance Coefficient 20 km/h	100 km/h
harsh	coarse	treaded or bald	0.7	0.45
harsh	fine	treaded	0.65	0.28
harsh	fine	bald	0.65	0.15
polished	coarse	treaded or bald	0.33	0.20
polished	fine	treaded	0.45	0.15
polished	fine	bald	0.43	0.05

Table 2: Typical Values of Skid Resistance

The reduction in skid resistance at the start of rain after a prolonged dry period can be substantial (perhaps as much as 50%); this fact appears to be generally not well known by road users, who may thus be taken by surprise and may thus be involved in an accident or near-miss. The long-term and seasonal variations are less dramatic and are thus probably less likely to surprise regular users.

Although skidding accidents may be attributed to other factors (e.g. excessive speed), it may well be more cost-effective and practicable to enhance skid resistance than to endeavour to attack the other factors (e.g. reduce vehicle speeds). For instance, the provision of a special high skid resistance surface on the approaches to intersections and pedestrian crossings (areas where rapid deceleration may well be necessary to avoid a collision) has proved very cost-effective in London.

11.4. ROAD LIGHTING

The roles of road lighting are:

(1) to reveal the presence of people/vehicles/objects on or beside the road;

(2) to delineate the edge of the carriageway ahead of the driver.

Numerous studies have compared two levels of lighting (usually "lit" versus "unlit") and concluded that improved road lighting is associated with a reduction in night-time accident frequency (see Table 3). Some studies have considered the effect of variations of lighting quality over a range (Box, 1971 and 1972), with average luminance being the measure of lighting quality.

	Accident Severity		
Daylight	Fatal	Serious	Slight
Before (B)	16	224	1008
After (A)	17	244	1164
Ration A/B	1.06	1.09	1.16
Darkness			
Before (B)	28	123	354
After (A)	15	90	298
Ration A/B	0.54	0.73	0.84

Note: Improvement in accidents in dark, despite deterioration in daytime accidents.

Table 3: Injury Accidents Before and After 64 Lighting Improvements

There are, in fact, several measures of lighting quality:

(1) lighting quantity, as measured by luminance or illuminance;
(2) uniformity of lighting;
(3) glare.

Luminance is a measure of the quantity of light coming from a source (units of candela/m) while illuminance is a measure of the quantity of light falling upon an object (units of lux). Clearly, the ability of drivers to see the road ahead at night depends more upon the luminance than the illuminance, as the characteristics of the road surface can affect the amount of light which, having been projected onto the road by street lights, finds its way to the eyes of the driver.

A study of the effect of lighting quality on accident frequency has been undertaken by Scott (1980), who used the following measures of lighting quality:

(1) $\bar{L}$ = average road surface luminance (cd/m^2)
(2) L_S = luminance of the surroundings (cd/m^2)
(3) U_O = overall uniformity
(4) E_H = horizontal surface illuminance, along vehicle axis (lux)
(5) E_V = vertical surface illuminance, perpendicular to vehicle axis (lux)
(6) TI = threshold increment disability glare
(7) G = discomfort glare control mark.

In addition, Scott considered the effect of lack of homogeneity in $\bar{L}$, by considering the standard deviation of individual values of $\bar{L}$ expressed as a percentage of the average over the site (i.e. the coefficient of variation).

Obviously, night time accident frequencies will vary between sites for reasons other than variations in road lighting quality (e.g. differences in traffic flow, road geometry, roadside development). Hence, Scott used the ratio of night time accidents to day time accidents as the indicator of the effect of different levels of lighting quality. Random variations in the extraneous factors (i.e. traffic flow, etc.) will increase the variation in the accident ratio, but the effect will be random. Hence, although this would make it more difficult to detect any relationship between lighting quality and accident occurrence at night, there would not be any bias.

It should be noted that studies of the role of skid resistance in accident occurrence have often involved a similar approach, namely use of the ratio of wet road to dry road accidents.

The raw data comprised accident data for 89 road sections, along with measurements of the lighting quality indicators at as many sections as possible. All 8 were able to be measured at only 41 sites, while $\bar{L}$ was measure at all, with $\bar{L}$, L_S and U_O being measured at 75 sites. All such measurements were done for dry roads only, and it is known that values for wet roads will be very different. It might be thought that in some areas, the proportion of hours with a dry road by night might be different to the proportion of hours with a dry road by day, due to the slower drying of roads at night.

A check for variation in the ratio

$$\frac{\text{(night accidents, wet road) / (day accidents, wet road)}}{\text{(night accidents, dry road) / (day accidents, dry road)}}$$

for different areas did not provide evidence of any variation in the ratio (dry hours by night) / (dry hours by day)

Using generalised linear modelling, relationships between the accident ratio and lighting quality were sought. It was found that:

(1) the strongest relationship is:

$$\text{accident ratio (night/day)} = 0.66 \exp(-0.42\ L)$$

which indicates a 35% lower ratio for an increase of 1 cd/m^2 in $\bar{L}$;

(2) L_S, E_H and E_V are also related to the accident ratio, but not as strongly or consistently as $\bar{L}$;

(3) since $\bar{L}$, L_S, E_H and E_V are strongly inter-related, $\bar{L}$ is preferred;

(4) U_0 is a useful explanatory variable when used in conjunction with either $\bar{L}$ or L_S, but the data exhibited very little variation in U_0 values, and this may explain why it did not feature strongly;

(5) both glare measures (TI and G), and the homogeneity of site luminance, seemed to be very weakly related to the accident ratio, if at all.

11.5. CROSS-SECTION CHARACTERISTICS

Of the cross-section characteristics generally believed to affect accident occurrence, the most important are those relating to:

(1) shoulder design;
(2) median design;
(3) lane design.

11.5.1. Shoulder Design. Road shoulders have several functions:

(1) providing lateral support to the trafficked pavement;
(2) allowing construction-related edge effects to be located away from the trafficked pavement;
(3) drainage of water away from trafficked pavement;
(4) ensuring good lateral clearances to obstacles alongside road;
(5) providing recovery area for errant vehicles;
(6) allowing stopped/disabled vehicles to stand clear of traffic lanes (or allowing moving vehicles to pass vehicles stopped in traffic lanes);
(7) allowing slow vehicles to move over so that faster vehicles can pass.

These functions are all related to safety, either directly or indirectly. For instance, provision of a recovery area has a direct effect, while avoiding construction-related edge effects within traffic lanes may well lead to easier control of vehicles and thus improved safety. In addition, some of them affect the structural integrity of the pavement, while others affect the capacity of the roadway.

Shoulder design entails two important decisions:

(1) the shoulder width;
(2) whether the shoulder is sealed or not.

Both matters have been the subject of considerable research to ascertain the likely effect on road safety, some of the more notable studies being those by Armour (1983), Raff (1953) and Jorgensen and Associates (1978).

Methodological problems (e.g. inadequate control, or lack of allowance for systematic variation of extraneous variables) have lead to the results of some studies being statistically unreliable and contradictory results being obtained. Nevertheless, it seems that there is general agreement that:

(1) a narrow shoulder (about 1 m) is adequate for the structural function;
(2) an increase in shoulder width up to about 2.5 m is beneficial;
(3) an increase in shoulder width above about 2.5 m may not be beneficial, especially if the shoulder is sealed and traffic flows are either very low or high, as the shoulder may then be used as an extra traffic lane;
(4) the sealing of shoulders is beneficial in providing a better recovery area (i.e. increasing the likelihood of recovery).

Unfortunately, the research results do not permit reliable identification of an optimum shoulder width, as the effect of changes in shoulder width seems to depend upon the road alignment in the vicinity and the traffic characteristics. In addition, the number and width of traffic lanes seems to influence the effect of changes in shoulder width.

11.5.2. Median Design. The purpose of a median is to separate vehicles travelling at high speeds in opposite directions. The separation can be effected by either:

(1) having a wide median which is contoured in such a way that it assists drivers to regain control and avoid crossing into the opposing carriageway;

(2) having a physical barrier (e.g. concrete New Jersey barrier, W-section barrier) which deflects vehicles back into their own carriageway.

The greater the width of the median (without barrier), the greater the probability that the driver will recover control and not transgress into the opposing carriageway. The greater the opposing traffic flow, the greater the probability that a vehicle that does transgress into the opposing carriageway will collide with an opposing vehicle. Hence, the decision regarding the form of separation (space or physical barrier) depends upon:

(1) the traffic flow; the greater the flow rate, the greater is the need for a physical barrier;

(2) the economics of providing a wide median; the higher the cost of land for a wider road reserve (to accommodate a wide median), the more likely is a physical barrier to be the better option.

Some countries (including the USA and NZ) have adopted a warrant for physical barriers, as illustrated in Figure 3. For a given design two-way traffic flow, a certain width of median is considered necessary, and if this cannot be provided, then a barrier should be used. It is worth noting that for traffic flow less than some threshold, a physical barrier is considered optional even where the desirable spatial separation cannot be provided.

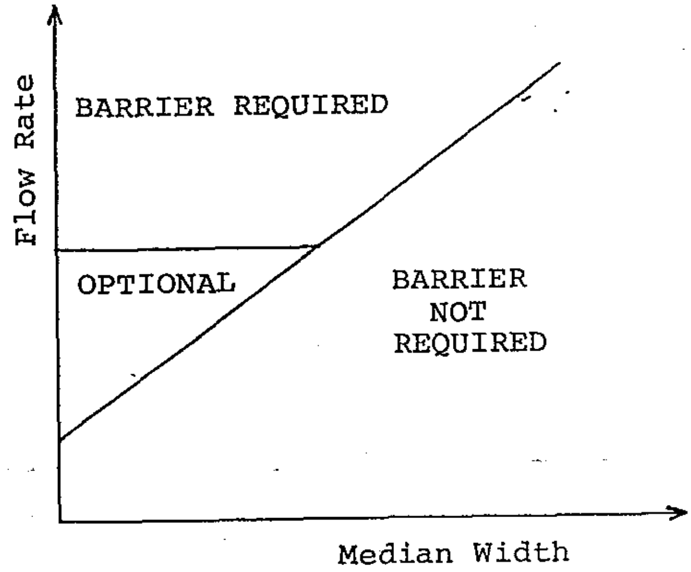


Figure 3:

It may be that a motorway (say) is constructed with a wide median, which is quite adequate for the traffic flows at that time, or for the foreseeable future. Such medians may form an important part of the landscaping of the roadway. Traffic flows may increase more than expected, and the form of warrant shown in Figure 3 can be used to identify the traffic flow level which, when attained, should trigger consideration of construction of a physical barrier.

If physical barriers are under consideration, it should be remembered that they will, if properly designed and implemented, virtually eliminate collisions between opposing vehicles, but can be expected to increase the frequency of collisions between vehicles travelling in the same direction; vehicles which would have recovered in the median area will be deflected back into the path of vehicles travelling in the same direction. Head-on collisions are almost invariably more serious and costly than same-direction collisions, and one can tolerate a greater increase in same-direction accidents than the decrease in opposing-direction accidents, and still get a nett benefit in terms of accident costs.

One study of the effect of installing a safety barrier on the M1 motorway gave the results shown in the Appendix (TRRL, 1974), and a more recent study of the likely effect of safety barriers on all-purpose dual-carriageway roads in the UK (Johnson, 1980) has indicated that:

(1) the number of fatalities is likely to be reduced by 15%;
(2) the number of serious and slight injuries is likely to be little changed;
(3) the number of non-injury accidents is likely to increase by 14%.

These results do suggest an overall reduction in accident costs.

11.5.3. Lane Design. The major decision to be made is lane width, variations in which are known to affect lane capacity, and the number of lanes, which then determines road capacity. Now a number of studies have included lane width as an explanatory variable, and some have used pavement width instead. Jorgensen and Associates (1978) concluded, after a comprehensive review of the literature, that:

(1) pavement width has a relatively small effect (less than shoulder width);

(2) the accident rate decreases as the lane width increases up to about 3.35 m, remaining fairly constant thereafter.

Since pavement width is often related to the alignment characteristics (it is common practice to widen pavements at curves), it may appear that an increase in pavement width is associated with an increase in accident rates, whereas the increase in accident rates is more likely to be due to the curvature itself (see McBean, 1982). Raff (1953) concluded that wide pavements and shoulders were beneficial at curves, but not on tangents, providing justification for the practice of pavement widening at curves.

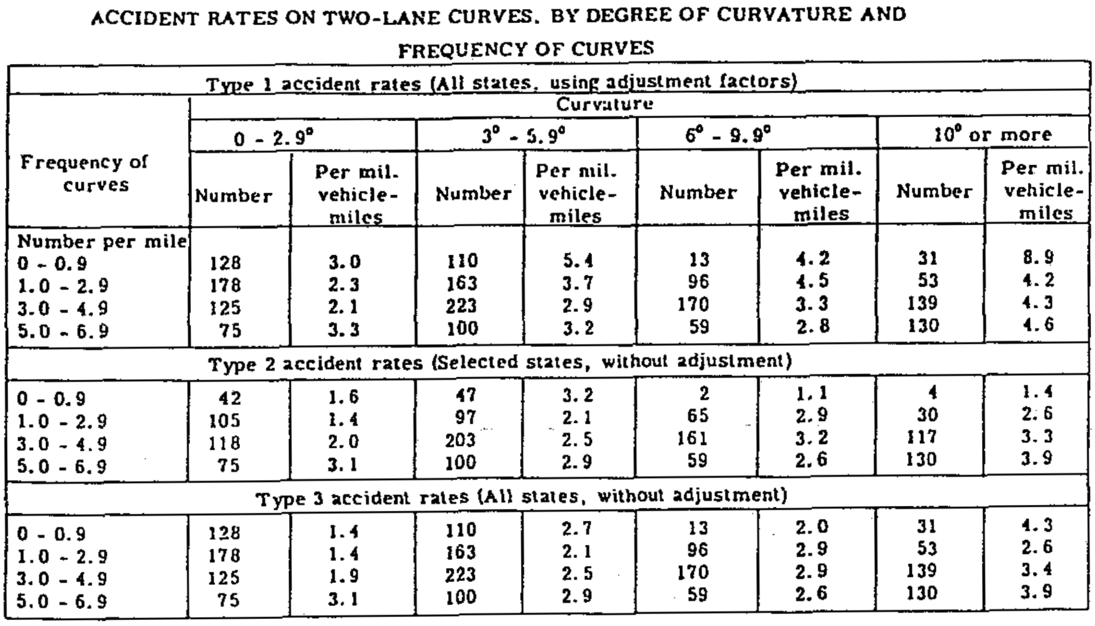
11.6. ALIGNMENT CHARACTERISTICS

The aspects of road alignment generally considered to affect accident occurrence are:

(1) horizontal curvature (curve radius, deviation angle and curve length);
(2) vertical curvature (change of grade and curve length);
(3) tangent length;
(4) gradient;
(5) sight distance;
(6) coordination of horizontal and vertical alignments;
(7) general geometric standard.

One of the earliest studies (Raff, 1953) included consideration of the degree of curvature (this is the central angle subtended by an arc of unit length, and it is inversely proportional to the radius of curvature) of particular horizontal curves and the frequency of curves (curves per length of road). Raff's results (see Table 4) indicated that

(1) accident rates generally increase as radius decreases;
(2) the accident rates generally decrease as frequency increases (using adjusted data, for all states), but this trend is not evident when the data is not adjusted.



ACCIDENT RATES ON TWO-LANE CURVES. BY DEGREE OF CURVATURE AND FREQUENCY OF CURVES

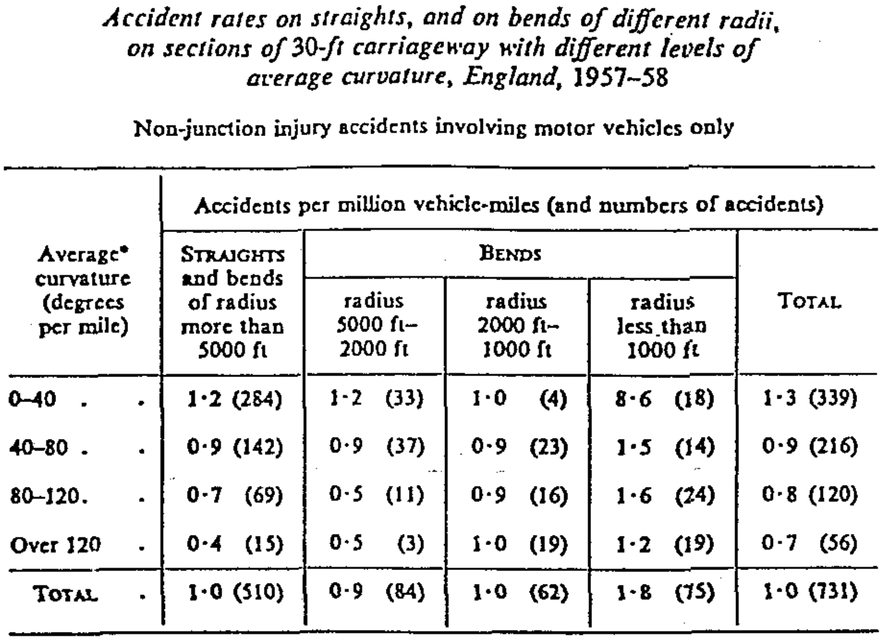
Type 1 accident rates (All states, using adjustment factors)								
Frequency of curves	Curvature							
	0 - 2.9°		3° - 5.9°		6° - 9.9°		10° or more	
	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles	Number	Per mil. vehicle-miles
Number per mile								
0 - 0.9	128	3.0	110	5.4	13	4.2	31	8.9
1.0 - 2.9	178	2.3	163	3.7	96	4.5	53	4.2
3.0 - 4.9	125	2.1	223	2.9	170	3.3	139	4.3
5.0 - 6.9	75	3.3	100	3.2	59	2.8	130	4.6
Type 2 accident rates (Selected states, without adjustment)								
0 - 0.9	42	1.6	47	3.2	2	1.1	4	1.4
1.0 - 2.9	105	1.4	97	2.1	65	2.9	30	2.6
3.0 - 4.9	118	2.0	203	2.5	161	3.2	117	3.3
5.0 - 6.9	75	3.1	100	2.9	59	2.6	130	3.9
Type 3 accident rates (All states, without adjustment)								
0 - 0.9	128	1.4	110	2.7	13	2.0	31	4.3
1.0 - 2.9	178	1.4	163	2.1	96	2.9	53	2.6
3.0 - 4.9	125	1.9	223	2.5	170	2.9	139	3.4
5.0 - 6.9	75	3.1	100	2.9	59	2.6	130	3.9

Table 4 (Raff, 1953)

Table 4:

Studies of accident rates per veh-mile in the UK (Charlesworth and Coburn, 1957; RRL, 1963) showed there was a distinct tendency for accidents to cluster on bends, particularly very sharp curves, and that accident rates decreased as the average curvature (degrees per unit distance) increased. The study by McBean (1982) has revealed that the accident rate seems to increase markedly as the radius decreases below about 500 m.

The results of Table 5 also suggest that roads with very long tangents (or straights) tend to have a higher accident rate than those that do not.



Accident rates on straights, and on bends of different radii, on sections of 30-ft carriageway with different levels of average curvature, England, 1957–58

Non-junction injury accidents involving motor vehicles only

Average* curvature (degrees per mile)	Accidents per million vehicle-miles (and numbers of accidents)				
	STRAIGHTS and bends of radius more than 5000 ft	BENDS			TOTAL
		radius 5000 ft–2000 ft	radius 2000 ft–1000 ft	radius less than 1000 ft	
0–40 . .	1·2 (284)	1·2 (33)	1·0 (4)	8·6 (18)	1·3 (339)
40–80 . .	0·9 (142)	0·9 (37)	0·9 (23)	1·5 (14)	0·9 (216)
80–120. .	0·7 (69)	0·5 (11)	0·9 (16)	1·6 (24)	0·8 (120)
Over 120 .	0·4 (15)	0·5 (3)	1·0 (19)	1·2 (19)	0·7 (56)
TOTAL .	1·0 (510)	0·9 (84)	1·0 (62)	1·8 (75)	1·0 (731)

Table 5:

Whereas most studies have employed the "mass data" approach (section 12.2), some studies (Wright and Robertson, 1976; McBean, 1982) have adopted the alternative approach of studying accident sites and comparison sites (matched for traffic flow characteristics). Unfortunately, this approach is not well suited to identifying the effect of the overall standard of road alignment. They have revealed that a combination of curvature and downhill gradient was much more likely at accident sites than at the comparison sites. Downhill gradient is conducive to higher speed, and is not conducive to rapid deceleration. Gradient on its own does not appear to have a substantial effect on accident occurrence.

Some studies have included consideration of the effect of sight distance (McBean, 1982) but sight distance is generally affected by the road alignment; the presence of horizontal curves generally implies obstructions to visibility, and visibility is governed by the length and change of grade of summit vertical curves. Hence, it has not been possible to establish a conclusive, direct relationship between sight distance and accident occurrence.

Poor coordination of the horizontal and vertical alignments may very well have an effect on accident occurrence, as may poor coordination of the longitudinal alignment with the cross-section characteristics; a narrowing of the road just beyond a horizontal and/or vertical curve with limited sight distance may well lead to accidents. Unfortunately, it is difficult to quantify coordination, and it is thus difficult to incorporate in studies of accident occurrence and road geometry. This may be the reason that no studies have indicated it as an important factor.

A number of studies have indicated that the effect of a geometric feature depends upon its context. Hence, an isolated sharp curve amongst long tangents and flat curves may well be associated with an accident cluster, but the same curve geometry, located amongst a number of similar curves may not be associated with an accident cluster. In addition, the first in a series of curves may have more accidents than similar or more severe curves within the group. Inconsistency in the standard may lead to drivers being taken by surprise, because their expectations are not realised.

11.7. INTERSECTION CONTROL AND LAYOUT

Research into the relationship between accident and traffic flows at intersections (e.g. Tanner, 1953) has revealed relationships (see Chapter 5 of the course notes) that indicate:

(1) where vehicles are crossing a major road by way of two T-intersections, it is preferable that the off-set (or stagger) be to the right;

(2) where it is possible to reduce the number of minor road access points to a major road, this is expected to lead to fewer accidents.

This latter result is consistent with the suggestion of various researchers (McBean, 1982) that the degree of access control affects accident occurrence.
If the locations of access points have already been decided, then it is a matter of firstly choosing the most appropriate form of control:

(1) no designated priority
(2) priority intersection (GIVE WAY or STOP)
(3) priority intersection, with channelisation
(4) roundabout
(5) signal control
(6) grade-separated

It is then necessary to decide upon the detailed layout of each intersection.

One of the factors in the choice of form of control is safety. Where there is restricted intervisibility, then the minor road traffic may be controlled by GIVE WAY or STOP signs (the choice depends upon the extent of the restriction on visibility). Channelisation is a useful technique for

(1) separating potential conflict points
(2) reducing potential conflict areas
(3) controlling the relative speeds of conflicting vehicles
(4) clearly identifying the path to be followed

Hence, channelisation can be very beneficial.

At X-intersections, the number of crossing conflict-points is 16, much larger than the 6 at a pair of T-intersections, which also involve a smaller number of merge/diverge conflicts (12 versus 16). Hence, on the basis that it is beneficial to:

(1) reduce the number of conflict points
(2) reduce the severity of potential conflicts

then a pair of T-intersections is preferable to one X-intersection, except when

(1) the off-set is very small
(2) traffic signals or a roundabout are envisaged.

It is important that the major flow be given priority over the minor flow, otherwise long delays may well be experienced by major flow vehicles, with the consequence being increased driver frustration and perhaps reduced safety. Traffic signals are advantageous in some circumstances, as they

(1) can reduce the frequency of crossing collisions, although same-direction collisions may well increase;

(2) can ensure a more equitable distribution of delay, thereby reducing driver frustration.

Roundabouts are very useful, as they separate potential conflict points and, if well designed, ensure that collisions are not severe due to the low speed of approaching and circulating vehicles.

The choice of the form of control must take account of capacity and delay, as excessive delay can lead to a deterioration in driver behaviour and road safety, no matter how well the detailed design of intersection layout is done. Having chosen an appropriate form of control, it is then necessary to get the detailed design right, as this can also affect accident occurrence.

At present, little is known with confidence about the effect of the details of intersection layout on accident occurrence. Two studies that have shed some light on the effects, as they relate to rural T-junctions and 4-arm roundabouts, are those by Pickering et al (1986), and Maycock and Hall (1984).

Their results, along with recommendations in "Roads and Traffic in Urban Areas" (IHT/DTp, 1987) provide some guidance on the effects of various aspects of detailed design.

11.8. LAND USE

Each type of land use has its own characteristic vehicle access requirements. For instance, industrial/manufacturing/commercial premises all have a need for heavy goods vehicle access for deliveries and collections. The presence of such land uses will affect the composition of traffic in their vicinity, and it may be that the more diverse the mixture, the more likely that there will be interactions of a nature not conducive to road safety.

A more important aspect is the frequency of vehicles entering and leaving the premises; as this increases, the side-friction increases and traffic flow along the frontage road is subjected to more frequent perturbations. Where the premises have not been properly designed for heavy goods vehicle access, the traffic flow may be disrupted while the vehicle manoeuvres into or out of the premises. Each entry or exit movement can be considered a potential conflict, with each perturbation or disruption indicating a conflict, from which a collision may ensue.

It is not just the movement of heavy goods vehicles to or from premises that may lead to accidents. Where there is roadside parking, the movement of cars into and out of the parking spaces can disrupt the traffic flow. Where there is a large off-street (or on-site) car park, the entry/exit points are effectively major-minor intersections. A large proportion of accidents occur at recognised intersections, and it is likely that what are commonly considered non-intersection accidents are associated with vehicles entering/leaving the traffic flow at these unrecognised intersections.

In commercial/shopping areas, there may be substantial pedestrian movements across the frontage road, and pedestrians emerging from behind parked vehicles may not be readily seen by the drivers of vehicles on that road. This, in conjunction with the parking/unparking of vehicles at the roadside, and double-parking of goods vehicles making deliveries to (or collections from) the shops, makes for a complex situation, which is not conducive to road safety.

McGuigan (1982) studied non-junction accidents, and sought to explain (with some success) variations in accident rate in terms of variations in:

(1) road type (whether single or dual-carriageway)
(2) land use on each side of the road.

The land use was categorised as either shopping, commercial, industrial, residential, open (recreational), rural or other. He found that there is strong statistical evidence that accident rates vary according to the land use alongside the road, with shopping development being associated with high accident rates, and rural land use being associated with low accident rates. Chapman (1978) has also shown that accident rates vary according to the land use, and Silcock and Worsey (1982) found that they got improved relationships between accidents and traffic variables after stratifying data according to other variables, including land use.

11.9. CONCLUSION

The discussion above of road environment factors and the nature of their effect on accident occurrence is not exhaustive; a number of factors (e.g. delineation) have not been discussed. It should be clear that there is a considerable range of factors, and the nature of their effect may be very complex. Inter-relationships exist between the factors as a direct consequence of the process of road design, and this leads to serious methodological problems for researchers trying to identify the separate effects of the factors.

Finally, it should be noted that there are in existence a number of sets of guidelines indicating the likely effect of changes to road environment factors (e.g. DTp, 1986). Some give confidence limits for the expected effects, reflecting the uncertainty that exists. Those that do not should be viewed with caution.

12. PEDESTRIAN SAFETY

12.1. ACCIDENTS

Published national figures

It is possible to obtain from publications such as Road Accidents Great Britain (RAGB) quite a lot of information concerning pedestrian casualties. Figures 1 and 2 show a number of breakdowns of Stats 19 data which are in RAGB.

Special investigations

A number of special/one-off studies have been carried out which go into much more detail than the published national statistics. These typically concentrate on one group of pedestrians, in particular children and to a lesser extent the elderly. This is because these groups tend to be overrepresented among pedestrian casualties.

A study of child pedestrian accidents in Hampshire which worked with the cooperation of the Hampshire Constabulary (Grayson,1975) obtained some important additional variables to add to those collected normally through Stats 19. The additional variables recorded included journey purpose, distance from home, accompaniment and the child's view of the cause of the accident. Results showed that most children were knocked down within a quarter of a mile of their home, though this does vary with age, with more older children being knocked down further from home. Very few were not familiar with the street in which the accident occurred. More than one third of pre-school children were found to be playing in the street when knocked down. Many more boys were playing in the streets than girls at the time of their accident and less than half of the children said they were alone. Only 40% said they had stopped at the kerb, while as many as 80% were reported to have been running across the road.

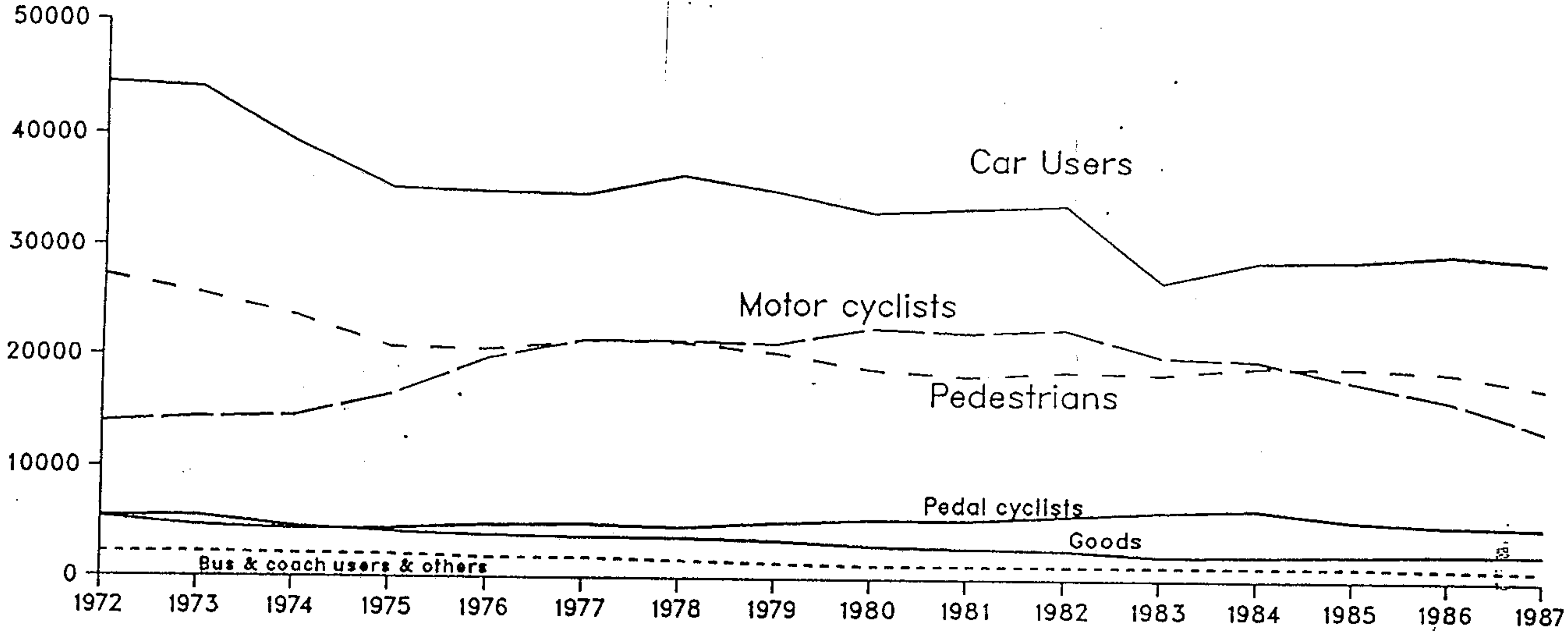
A similar study by Tight (1987) showed that of a sample of 670 accidents involving child pedestrians, nearly 60% of the children were described by the attending police officers as having run into the road. In only 8% of the cases was there any indication from the description that the driver of the vehicle which hit the child might have been at fault, and that these were generally only when the driver had obviously done something wrong, such as driving through a red light, along the pavement etc.

There are a number of other readily available facts about pedestrian accidents, some of which are described below:

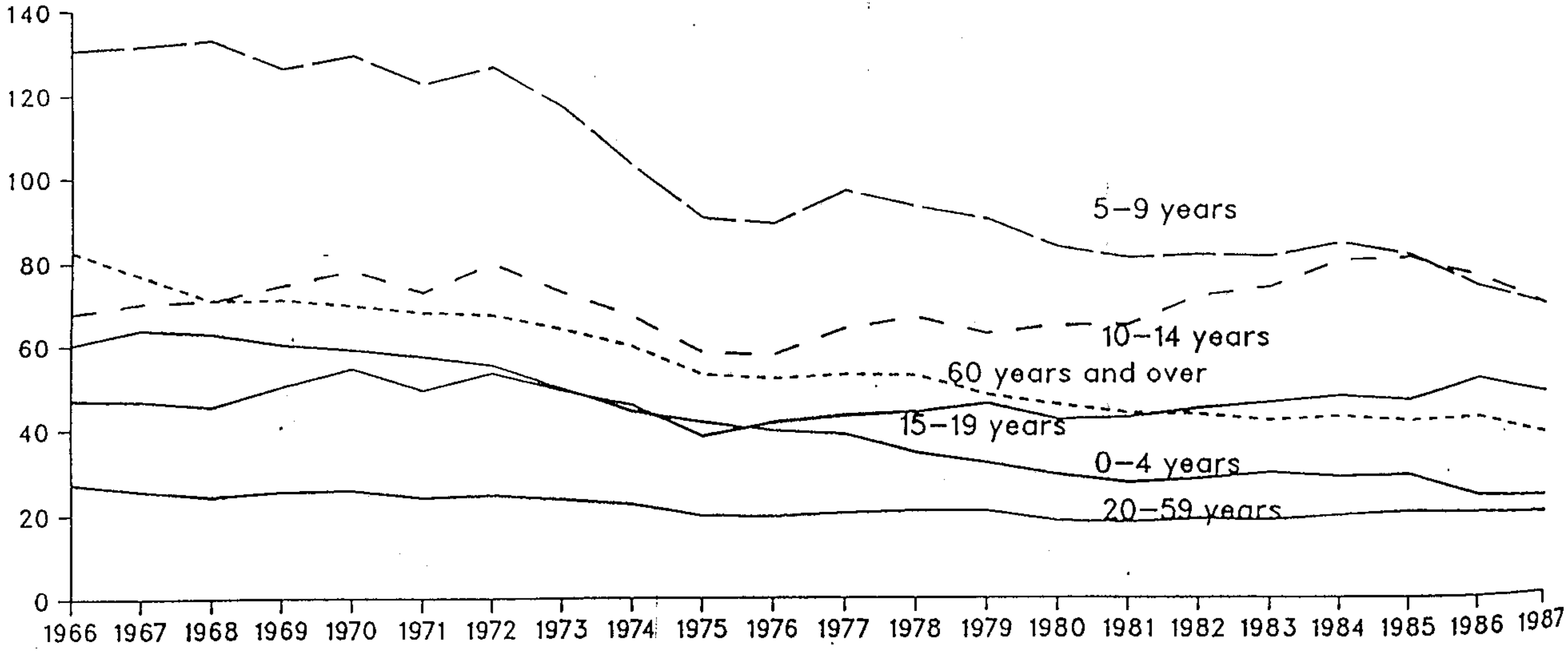
In 1982 the number of 5-9 year old boys killed or injured was almost twice that of girls. Until the age of 60 years, male pedestrian casualties exceed females; after 60, there is a rapid increase in the number of female casualties, although the casualty rates per capita in every age group are usually higher for males than for females. Exposure does not explain these differences entirely.

It is possible to identify three peaks of accidents to child pedestrians throughout the day. These are in the morning between 8 and 9am, at lunchtime and in the early afternoon between 3 and 6pm. The latter of these periods contains by far the highest number of accidents.

1. Fatal and serious casualties by type of road user: 1972–1987



2. Pedestrians killed or seriously injured per100,000 population: 1966–1987



Over 70% all pedestrian casualties occur during daylight (the figures for children are about 85% in daylight), though when these figures are related to pedestrian activity and exposure, the chances of a pedestrian being injured during darkness are shown to be three times higher than in daylight (Lynam,1983).

Irrespective of age or degree of severity, the pedestrian accident problem is overwhelmingly an urban one. The majority of pedestrian fatalities (almost 80%) and of all casualties (almost 95%) occur in built up areas. There are more accidents to child pedestrians in built up areas than to adults. Above the age of 20 years, just under two-thirds in each age group are injured on A and B roads. Below the age of 20, the proportion killed or injured on A and B roads is lower, and is only a quarter for the age group 0-4. By the time children reach the 10-14 age group, over half their accidents are on A and B roads. These figures are probably indicative of the types of roads used by the different age groups.

About 26% of child pedestrian accidents occur on the journeys to and from school. About 13% of child pedestrian accidents are to pre-school age children.

About 40% of child pedestrian accidents occur at T-junctions and a further 40% occur not within 20 metres of a junction. Very few occur at any of the other types of junctions.

In 1986 30.3% of child pedestrians (aged 0-14 years) were masked by a parked or stationary vehicle when they had their accident, while only 12.8% of adults (aged 15+) were.

12.2. EXPOSURE

It is clear from the accident statistics described above that some sectors of the population show a disproportionately high frequency of pedestrian casualties per capita. One reason may be that these groups are overrepresented in the pedestrian population and are therefore more exposed to the risk of becoming a pedestrian casualty, by being present in a potential accident situation with a greater frequency than other sectors of the population.

There are many ways of looking at the extent to which pedestrians are exposed to risk, and many different definitions. With any given level of exposure, pedestrians' risk levels are affected by their behaviour, and different groups at the same crossing location may exhibit different behaviour stemming from different perceptions of the hazard of a certain action. Identifying the pedestrian groups who are at risk, and the reasons why they are at risk, may lead to the development of appropriate countermeasures. Exposure is used as a control parameter; once that is factored out of the distribution of accidents, one may then look at the risk from different locations (and develop traffic management solutions) and at the risk to different groups at the same locations (and try to re-educate pedestrians to safer behaviour).

Tight (1987) examining child pedestrians risk of an accident using a number of different measures of risk found the following statistically significant conclusions:

1) On the journeys to and from school
   a) Accident risk is higher on the journey home from school in the afternoon than on the journey to school in the morning.
   b) Children in Middle and Junior schools had a higher risk of an accident than children in infants or first schools

(where accompaniment by adults is considerably higher) or children from secondary schools.

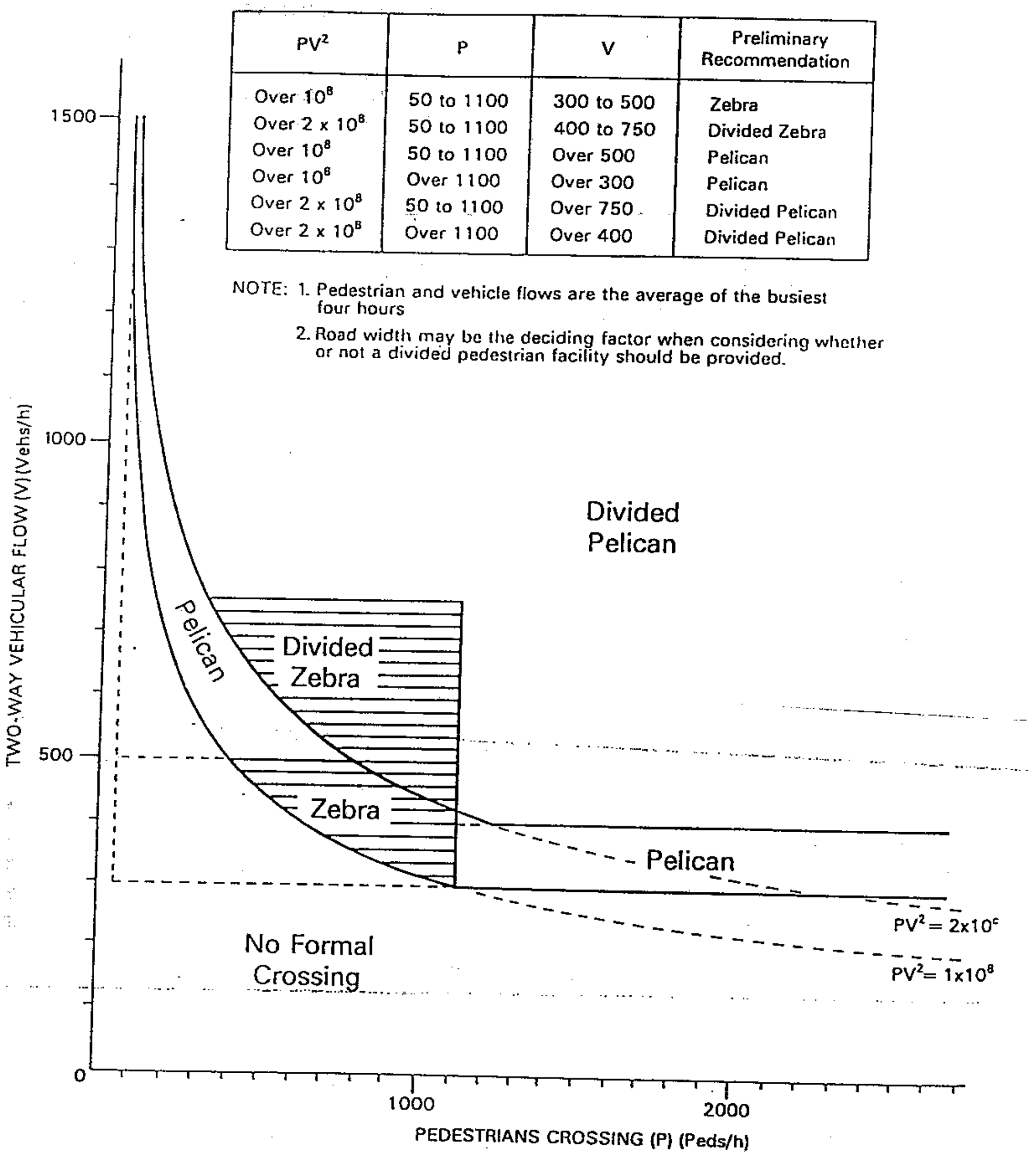
- c) Accident risk is about 10 times as high when crossing main roads, as when crossing other roads.
- d) The risk of an accident is approximately twice as high within 0.5km of schools compared to further away.
- e) Accident risk when crossing a main road not at a crossing facility was about three times as high as when crossing a main road using a crossing facility.
- f) Each child had a very small risk of an accident on a journey to or from school. For the schools surveyed in this study there was on average one accident per 350,000 walk journeys made by children, or per 1.5 million road crossings, or per 270,000km walked, or finally per 4.0 to 5.0 million minutes (7.6 to 9.5 years) spent in the road environment on journeys to and from school.
- g) There was no significant difference in accident risk between boys and girls.

2) Use of the roads for reasons other than going to and from school.
   - a) On school holidays, though not on schooldays (outside of the journeys to and from school), boys were found to have a higher risk of an accident than girls.
   - b) Children's risk of an accident was much higher on main roads compared to other roads.

12.3. PEDESTRIAN BEHAVIOUR

There is a lot of material available on implicit aspects of pedestrian road-user behaviour, much of which is based on observations or eye witness recollection. Some of the most important observations in this field are the differences in crossing behaviour which exist between children and adults. According to Routledge, Repetto-Wright and Howarth (1976) "adults assess the crossing situation as they approach the kerb, while children pay little attention to the crossing situation until they arrive at the kerb, and are therefore less well prepared to take advantage of favourable traffic configurations. Having stopped at the kerb to wait for a gap in the traffic children are slower to start and seldom anticipate when they cross through a chosen gap, while adults take most advantage of gaps in traffic by anticipating their arrival. Children learn to adopt these adult strategies without instruction and indeed contrary to the way in which they have been taught. There appears to be a mismatch between the information they receive from parents, schools and safety programmes and the information they gain from their own experiences and from observation of adult pedestrians".

FIGURE 3



PV^2	P	V	Preliminary Recommendation
Over 10^8	50 to 1100	300 to 500	Zebra
Over 2×10^8	50 to 1100	400 to 750	Divided Zebra
Over 10^8	50 to 1100	Over 500	Pelican
Over 10^8	Over 1100	Over 300	Pelican
Over 2×10^8	50 to 1100	Over 750	Divided Pelican
Over 2×10^8	Over 1100	Over 400	Divided Pelican

NOTE: 1. Pedestrian and vehicle flows are the average of the busiest four hours

2. Road width may be the deciding factor when considering whether or not a divided pedestrian facility should be provided.

Suggested warrants for formal pedestrian crossing facilities

Source: TD4/79 DTp (1979)

According to Shinar (1978) "children represent a particular hazard since they may lack the skills and habits, that are typically acquired at a later age, which enable people to behave safely on the road. Unintrusive observations of children walking to and from school have led to the realization that the child pedestrian, particularly under the age of 10, lives in a different conceptual world than the adult pedestrian. Some of the generalisations that have been repeatedly made concerning child pedestrians are that their perception and ways of thinking is still egocentric; they have only a fragmentary understanding of the rules and structure of the traffic system; their attention level fluctuates and they are easily distracted; and their knowledge of traffic signs is incomplete - and for young children practically nil. In light of all these limitations, Sandels (1975) who pioneered the systematic observations of children in traffic, concluded that it is impossible to fully adapt the small child to the complex traffic environment of the 1970's. Instead, she argues we should design the traffic system with these constraints in mind".

12.4. PREVENTION OF PEDESTRIAN ACCIDENTS

Typically this can be split into one of three main methods, namely road and vehicle engineering, education and enforcement. Some of the main ideas and methods used in each category will be considered here.

12.4.1. Engineering solutions.

At-grade pedestrian crossing facilities
These aim to minimise delay and maximise safety for pedestrians and drivers. Studies have shown that these typically attract over 75% of the pedestrians crossing within 45m of them. There are 5 main types:

Refuges
School crossing patrols
Zebra crossings
Pelican crossings
Pedestrian facilities at signal controlled junctions

Refuges (or traffic islands): These are the most common and generally the least costly type of crossing aid for pedestrians and their installation is not so tightly prescribed as the siting of pelican or zebra crossings. They permit pedestrians to concentrate on crossing one stream of traffic at a time by creating a relatively safe waiting point, usually in the centre of the carriageway. Refuges are often appropriate at sites where pedestrian crossing movements are concentrated but are insufficient in number to justify a more formal crossing.

School crossing patrols: The decision to introduce a patrol will depend largely on site characteristics and the police, the highway authority and the education department will usually be involved.

DTp criteria for the provision of zebra or pelican crossings are a function of the pedestrian and vehicle flows per hour (see figure 3).

Zebra crossings: These can be provided at relatively low cost, but are unsuitable:

a) Where traffic is heavy and fast moving
b) In busy shopping streets and opposite railway stations
c) At special sites such as contra flow bus lanes.

Zebras tend to have high accident rates in their near vicinity. Studies suggest that they should only be used where an accident problem has been defined. If used elsewhere they tend to increase the accident rate. Zebras effectively allow pedestrians to cross at any time (assuming traffic has sufficient time to stop), while pelican crossings mean that there will normally be some delay to pedestrians.

Pelican crossings: These help in areas of high pedestrian flow by providing specific safe pedestrian crossing periods and give direct indication to motorists of pedestrians' legal right of way. Pelican crossings are more appropriate than zebra crossings in the following situations:

a) Where there are significant numbers of elderly and infirm pedestrians.
b) At sites with high approach speeds, where a pelican with vehicle detection should be used.
c) Where pedestrian flow is heavy.
d) At special sites such as contraflow bus lanes.
e) In areas operating under urban traffic control, as pelican crossings can be linked to traffic signals.

In the 1970s many zebras were converted to pelicans as a result of a DOE (1974) report on a sample of conversions which showed an average 60% reduction in accidents. However, some studies subsequent to this have shown no clear safety benefit. At pelicans the delay for pedestrians can be up to 44 seconds, much longer than the threshold of 30 seconds beyond which pedestrians take greater risks to cross the road, although in practice less than 3% of pedestrians experience a delay above 30 seconds at fixed time pelicans. It is generally acknowledged by traffic engineers that, when a section of the public asks for a crossing to be installed they mean a pelican and not a zebra (55% prefer pelicans, only 31% zebras).

Provision for pedestrians at signal controlled junctions: At signalled junctions specific facilities for pedestrians can be incorporated using separate "green man" pedestrian aspects.

Grade-separated crossings (footbridges and subways)
These are "solutions with problems". They are expensive to build, and pedestrians are often reluctant to use them, seeing a trade-off between safety and convenience.

The installation of a grade-separated crossing in preference to one at-grade is appropriate in the following circumstances:

a) where there is a high, fast vehicle flow, which it is advantageous to keep moving, and high pedestrian flow, which is all being delayed.
b) where considerable delay to pedestrians occurs.
c) at sites where pedestrian accident levels necessitate some pedestrian facility being provided.

Impact of road traffic systems: Pedestrian risk may be affected by the technical engineering details of many traffic management measures, including one-way streets, turning movement allowances and prohibitions, parking arrangements, bus lanes, cycle lanes and shared pedestrian/cycle facilities, the maintenance of footpaths and roadways, the design of road furniture, and area wide measures for pedestrian safety.

Other engineering measures include space-sharing and pedestrianisation. The former is a concept developed by the Dutch, in the late 1960's and early 1970's and known as "woonerf". This is an area intended for use by both pedestrians and traffic and incorporating road narrowing, humps,and other obstacles to slow traffic entering the area and discourage through traffic.

Pedestrianisation: this is extremely difficult to justify on a safety cost/benefit basis. Pedestrianisation is largely carried out for environmental purposes and, in commercial centres, tends to be oriented towards increasing retail activity rather than safety.

Vehicle design for pedestrian safety: The types of injuries sustained by pedestrians when struck by vehicles have been shown to be most commonly to the head and legs, followed by the arms, chest and pelvis. Fatalities result mainly from injuries to the head and thorax. Pedestrians are injured by being struck by a vehicle and in many cases also by hitting the road; in a small number of cases the victim may, further, be struck or run over by other vehicles or run over by the striking vehicle.

Because of the severity of injuries caused by vehicle impact and because little can be done to protect the pedestrian who hits the ground, research intensified in the 1970's into how vehicles caused injury to pedestrians and how the designs of specific features could be changed to protect the pedestrian in the event of an accident.

Generally the following is true:

At speeds below 15mph - Generally minor injuries only
15 - 20 mph - Moderate to severe injuries
20-25mph - Serious to fatal injuries
Over 25mph - Predominantly fatal

However, fatalities have been found at speeds below 15mph and minor injuries at speeds above 25mph.

TRRL research has aimed at redesigning the shape of the car to control the trajectory of the pedestrian onto the bonnet. This is partly to avoid the victim being knocked onto the road and run over; also, it is preferable to prevent the pedestrians head from striking the windscreen surround or other sharp and solid parts of the car, and to absorb momentum over as large and flat a surface of both the body and car as possible. University of Birmingham research suggests benefits from modifications to vehicle shape as follows:

From accidents at impact speeds up to 19mph	Reduction in overall number of serious casualties : 1-2%
Up to 25mph (if the measures are totally effective)	6-9% reduction

It also suggested that compliant front ends (the "soft nosed car") could have the following benefits:

From accidents at impact speeds up to 19mph	Reduction in overall number of serious casualties about 10%
Up to 25mph (if the measures are totally effective)	20% reduction

12.4.2. Education and publicity. Education and training measures for pedestrians are mainly aimed at children, although publicity programmes for the elderly are becoming increasingly of interest to practitioners in the field. It is difficult to measure the direct benefits of educational programmes, because of the time scale and other exogenous factors involved. Even projects which have been monitored have not been able to show conclusively that reductions in accidents were solely due to improvements in education, although there has been a time series correlation in the case of the British Green Cross Code scheme and Scandinavian Traffic Clubs.

12.4.3. Enforcement. In Britain pedestrians have precedence on zebra crossings or on a signal controlled crossing when the signal to cross is illuminated. Pedestrians must not proceed when asked to stop by a police officer controlling traffic. They are not allowed to walk on motorways. Other than these specific instances there is no law in this country to prevent pedestrians from crossing roads; indeed the right of access to the Queen's highway is enshrined in common law.

Legislation affecting drivers' behaviour towards pedestrians mainly concerns zebra and pelican crossings and School Crossing Patrols. The Highway Code advises drivers on suitable behaviour towards pedestrians in a wider variety of circumstances and stresses the vulnerability of young, elderly and disabled pedestrians. However, failure to observe a provision of the Highway Code is not in itself a criminal offence.

13. EVALUATION STUDIES

13.1. INTRODUCTION

There is uncertainty regarding the effectiveness of accident countermeasures. Therefore, it is important to undertake post-implementation evaluations of remedial treatments, to ascertain their effect and improve the accuracy of predictions of their effectiveness in subsequent ante-implementation evaluations.

The most direct indicator of the performance of a remedial treatment is the change in accident costs. It may be that the frequency of some accident types will increase while the frequency of others will decrease. An increase in less severe and less costly accidents may well be acceptable if the decrease in more severe and more costly accidents is sufficient to ensure a reduction in total accident costs.

Very often, it is assumed (implicitly or explicitly) that all accidents at an individual site have similar costs, in which case the change in accident frequency is a direct indicator of performance. If such an assumption is not made, however, it is necessary to consider the change in frequency of each accident type separately.

Accidents are relatively rare, especially when dealing with an individual site or section of road, and the small numbers of accidents makes it difficult to show that a statistically significant change has been achieved. The stratification of accidents by accident type aggravates the situation, and it is thus widespread practice to analyse changes in the frequency of accidents in total.

13.2. CHOICE OF PERFORMANCE INDICATOR

A number of less direct indicators of performance are available (e.g. conflicts, speeds). The attraction of these performance indicators is that a large number of observations can be obtained in a short time, as the phenomena are much less rare than accidents. Such indicators are perhaps less <u>relevant</u>; a reduction in conflict frequency or the frequency of high approach speeds may not lead to a reduction in accident frequency.

If accident frequency is chosen as the performance indicator, then in order to get a sufficient number of accidents before and after implementation, to detect a change in accident frequency, a long observation period is likely to be required. The longer the observation period, the greater the probability that some other, unplanned change will occur and make the identification of the effect of the remedial treatment more difficult to estimate.

The extra resources associated with the use of a less direct indicator may be considerable; accident data is collected routinely and at zero extra cost, while special surveys are required for such indicators as conflicts and speeds. Hence, the choice of whether to use a direct or indirect performance indicator entails balancing

(1) a low resource requirement, a long observation period, and obvious relevance, <u>against</u>

(2) a high resource requirement, a short observation period, and doubtful relevance.

It is not always necessary to make a trade-off between relevance, resource requirement and length of the observation period. For instance, where the remedial treatment is expected to affect approach speed, then a standard speed survey will provide information about the distribution of approach speed at some location, and the change in mean approach speed is less relevant than the change in the frequency of high approach speeds. The resource requirement is essentially the same for each indicator. In addition, a change in the frequency of high approach speeds may result in the mean speed being reduced very little, while the 85th percentile speed (say) will be reduced much more and is thus a more sensitive indicator.

The relationship between accident occurrence and approach speed is rather uncertain; a driver familiar with the road may well be able to approach at a high speed and safely negotiate the hazardous feature, while a driver unfamiliar with the road may have more difficulty despite approaching at a lower speed. A more relevant performance indicator than speed at a point is probably the rate (or suddenness) of deceleration, which can be obtained from measurements of each vehicle's speed at several points on the approach. This, of course, would entail greater resources, so it is basically a case of making a trade-off between relevance and resource requirement.

13.3. CHOICE OF OBSERVATION PERIOD

Since the goal is to assess the effect of remedial treatment, the evaluation study should take the form of a before-and-after study. The choice of observation period depends upon several factors:

(1) the before and after periods at the treated site should be identical to those at the control site (a site expected to indicate what would probably have happened at the treated site had it been left untreated);

(2) the period during which work is carried out, and a settling-down period immediately after implementation, should be omitted;

(3) the before and after periods should be long enough to provide a statistically reliable estimate of the underlying true accident rates (before and after), but not so long as to include periods when other, unplanned changes have occurred;

(4) the performance indicator.

The short-term effect of remedial treatment may be quite different from the long-term effect:

(1) there may be driver confusion and accidents (or conflicts) immediately after implementation but an improvement thereafter, so that the long-term effect is better than the short-term effect;

(2) the "newness" of the situation immediately after implementation may evoke a driver response (such as much greater caution) that the driver subsequently considers excessive and reduces, so that the long-term effect is not as good as the short-term effect.

In view of the uncertainty regarding the nature of the novelty effect, one can either:

(1) omit the settling-down period
(2) assess the effect at various times after implementation, in order to identify the nature of the novelty effect.

Given that the novelty effect is short-lived, the observation period is necessarily short, and the statistical reliability of the estimate of the novelty effect is consequently low, if accidents are used as the performance indicator. The only practical way of identifying the novelty effect is to use an indirect indicator, or to treat many sites.

13.4. CHOICE OF CONTROL SITE

The adoption of control sites can be for the following reasons:

(1) to take account of systematic changes in the environment, affecting the underlying true accident rate of the treated site (such changes may be national, e.g. a change in the national speed limit for a class of road, or local, e.g. a change in traffic flows along a route as a consequence of a local traffic management scheme);

(2) to take account of the regression-to-the-mean effect.

A control site should be similar to the treated site in general characteristics and should be geographically close to it, so that one can be reasonably confident that both will be similarly affected by local variations in factors likely to affect safety (e.g. weather, traffic flows). In addition, the control site should be chosen by the same mechanism that was used to identify the site for treatment, so that if the site for treatment has been identified as a blackspot, then the control site should also be a blackspot. Otherwise, the regression-to-the-mean effect will not be accounted for properly.

Planned experiments, involving pairs of sites identified by the same procedure, with the choice of which one to treat and which one to leave untreated being made at random, have been used successfully to advance knowledge in the physical sciences. The main virtue of such an approach is that inference of cause and effect is straight-forward and sound; the difference in the responses (of the treated and control sites) can be safely ascribed to the treatment, or random variation in accident occurrence. Statistical tests can be employed to estimate the probability of the apparent effect of treatment being due to random variation in accident occurrence.

There is a problem ensuring that the control site remains untreated, if it is also a blackspot. It is not a matter of leaving the control site untreated forever. If treatment of the control is deferred until such time as the effectiveness of the treatment at the other site is proven, the treatment can be applied to the control site with real confidence.

Before discussing the statistical tests which may be used in various circumstances, it is first necessary to discuss three important issues relating to estimation of the effects of treatment (namely, regression-to-the-mean, risk compensation, and accident migration).

13.5. REGRESSION-TO-THE-MEAN, BIAS-BY-SELECTION, AND ACCIDENT MIGRATION

The phenomenon of regression-to-the-mean has been known about for over a hundred years, for in 1877 Sir Francis Galton (a notable meteorologist, biologist and statistician) reported that the off-spring of tall parents are, on average, shorter than their progenitors, while the off-spring of short parents are, on average, taller than their progenitors. The term "regression" was applied to the phenomenon, with regression meaning a tendency to "return toward" (the mean). The phenomenon has been observed in a wide variety of situations.

Regression-to-the-mean has a logical explanation. Considering accident counts for a site, it is known that they fluctuate about some unknown expected value, the underlying true accident rate (UTAR). For any period, the best estimate of the accident count is the UTAR. If the accident count in one period is above (or below) the UTAR, then the accident count in the next period can be expected to be lower (or higher), due to regression downwards (or upwards) towards the mean.

The phenomenon occurs even when there is no intervention, so that a site with a high accident count in one year (due to a fluctuation above the UTAR) should generally, even without treatment, experience a lower accident count in the following year. Regression-to-the-mean in itself is not a problem, but combined with a non-random selection of sites for treatment, it gives rise to a bias in the estimate of the effect of the treatment (hence the term "bias-by-selection").

The regression-to-the-mean effect can result in substantial <u>over-estimation</u> of the effect of remedial treatment, if sites are selected for treatment on the basis that they have a relatively high observed accident rate. A simple illustration of the nature of the problem has been given by Hauer as follows:

> "Consider a group of 100 persons each throwing a fair die (dice) once. Select from the group those who have thrown a six. There might be some 16 such persons. (This is analogous to the arranging of all road sections in the order of increasing number of accidents and selecting the top 16%.) In an effort to cure the 'proneness to throw sixes', each of the selected persons is administered a glass of water and asked to throw the die (dice) again. One can expect that all but two or three persons will have been cured. This 'success' of the water cure is attributable entirely to the process of selection for treatment."

If sites are selected for treatment on the basis that over a short period (one year, say) there were a relatively high number of accidents, then it is likely that many such sites are chosen simply because they experienced a temporal variation well above their underlying true accident rates during that short period. If they were to be left untreated, it is likely that the accident counts in the subsequent period would be lower (i.e. the counts would regress <u>downwards</u> to their means, or their UTAR's). If they were to be treated, then the apparent effect of the treatment includes the regression effect, for which allowance should be made when estimating the true effect of the treatment.

The use of a longer period (five years, say) means that the observed accident rate is very likely to be very close to the UTAR, as illustrated by the narrowing of the confidence interval for the UTAR as the observation period increases (see the charts in Chapter 6 of the course notes). That is, a site would not be likely to be selected for treatment because of a short-term fluctuation well above the UTAR for that site, and the regression-to-the-mean effect is likely to be very small and negligible.

The magnitude of the regression-to-the-mean effect can be assessed using the data in Table 1, which shows accident count data for 82 sites for each of two successive years. There is a clear tendency for sites with an above-average number of accidents in year 1 to experience a reduction year 2, while sites with a below-average number in year 1 tend to experience an increase in year 2. Had those 34 sites with five or more accidents in year 1 been treated between year 1 and year 2, then the effect of the treatment (assuming the treatment has a truly positive effect) would be over-estimated, to the extent of

(74-54) + (18-10) + (56-49) + (14-6) + (54-48) + (45-35)

= 59 accidents in year 2

This over-estimate (of 59 accidents) is about 23% of the total number of accidents at those 34 sites in year 1. If the treatment were truly ineffective, it would nevertheless appear to have caused a 23% reduction in accidents.

In Hauer's example of 100 persons throwing a dice, they are all assumed to be throwing dice with 1, 2, ... 6 spots on the six faces, respectively. That is, it is assumed that had they had many throws, the cumulative average of each and every person's results would tend towards 3.5. In reality, the UTAR can vary substantially between sites, even when they have been grouped together because of their similarity with respect to geometry, traffic flows etc.

EXAMPLE OF REGRESSION-TO-THE-MEAN

Accidents per site in year 1	No. of sites	Aggregate accidents in year 1	Aggregate accidents in year 2	Percentage change
10+	5	74	54	- 27
9	2	18	10	- 44
8	7	56	49	- 12
7	2	14	6	- 57
6	9	54	48	- 11
5	9	45	35	- 22
4	7	28	29	+ 4
3	11	33	44	+ 33
2	15	30	46	+ 53
1	9	9	13	+ 44
0	6	0	7	
	82	361	341	

Table 1:

If the UTAR's are assumed to vary between sites, there is a real chance that sites with high UTAR's will be selected for treatment even when they have a temporal variation below their UTAR's; their accident counts may still be relatively large compared to those for the other sites. If those high UTAR sites are not treated, one would expect their accident counts in the subsequent period to regress upwards towards their UTAR's, and hence if they are treated, one may very well under-estimate the effect of their treatment.

In Hauer's example, the regression can only be downwards, for those people selected for the "glass of water" treatment. The possibility of "reverse regression" (i.e. regression upwards rather than downwards) has been acknowledged by Abbess et al. They assume that:

(1) the UTAR's vary between sites, according to the Gamma distribution;
(2) the annual accident counts for a site vary about the UTAR for the site, according to the Poisson distribution.

Using two sets of actual data, they estimated the regression-to-the-mean effect (i.e. the expected change in observed annual accident rate if no treatment is applied) as being as high as 25% and 15% for the two data sets. The parameters of the Gamma distribution differed between the two data sets, and clearly the magnitude of the regression-to-the-mean effect depends upon precise form of the UTAR distribution.

Hauer and Persaud (1982) make no assumption about the form of the UTAR distribution, merely assuming that the annual accident counts are Poisson distributed about the UTAR for each site. They suggest that for a group of sites, the expected number of accidents during the after period at sites having k or more accidents in the before period, is the number of accidents occurring at sites having (k + 1) or more accidents in the before period. For the data in Table 1, the expected number of accidents in year 2 at sites having five or more accidents in year 1 is 216 (= 74 + 18 + 56 + 14 + 54). The actual number of accidents for such sites in year 2 is 202 (= 54 + 10 + 49 + 6 + 48 + 35), down from 261 (= 74 + 18 + 56 + 14 + 54 + 45) in year 1. The Hauer and Persaud method gives an estimate of the regression-to-the-mean effect equal to 45 accidents in year 2, compared with the actual value of 59. This method, while being simple to apply, gives estimates which may be subject to considerable error.

Hauer (1986) gives a much more sophisticated procedure for estimating the regression-to-the-mean effect. This procedure is more accurate (the standard error of the estimate is less than for the simple procedure), and implies a probability distribution for the UTAR's.

When considering whether to treat any site, anyone of six possible cases may exist:

(1) $k < \alpha < \hat{\alpha}$
(2) $k < \hat{\alpha} < \alpha$
(3) $\hat{\alpha} < k < \alpha$
(4) $\alpha < k < \hat{\alpha}$
(5) $\alpha < \hat{\alpha} < k$
(6) $\hat{\alpha} < \alpha < k$

where:

α = UTAR for the site
$\hat{\alpha}$ = observed accident rate for the site (= c/n)
k = critical accident rate
c = total number of accidents at the site during n years

Ideally, the site should be treated if $\alpha > k$ and should not be treated if $\alpha < k$. In reality, however, α is not known and it is estimated by $\hat{\alpha}$, so that treatment will occur if $\hat{\alpha} > k$ and will not occur if $\hat{\alpha} < k$. The direction of the regression-to-the-mean effect will be upwards if $\hat{\alpha} < \alpha$ and downwards if $\hat{\alpha} > \alpha$. The situation can be summarised, as in Table 2.

Case	Should treatment occur?	Will treatment occur?	Direction of regression
I	Y	Y	down
II	Y	Y	up
III	Y	N	up
IV	N	Y	down
V	N	N	down
VI	N	N	up

Table 2

Consider now the matter of a large number of candidate sites for treatment, and the effect of occurrence of each of the six cases. If cases I, II and IV occur, there will be an effect on the estimate of the effectiveness of the treatment, due to regression-to-the-mean. Now, it is expected that there will be an equal number of cases I and II, and since their regression effects are expected to be equal and opposite, they are expected to have a zero nett effect. Each occurrence of case IV, however, is expected to result in a downwards regression effect, so that there will be a nett downwards regression effect overall within the set of treated sites.

If cases III, V, and VI occur, there will be no effect unless, having not been selected for treatment, the sites are included in the set of control sites. Should this occur, the effects of cases V and VI are expected to cancel, leaving the effect of case III, namely an upward regression effect within the set of control sites. This will give the appearance of "accident migration", a phenomenon claimed to have been observed by Boyle and Wright (1984). A number of subsequent papers (Huddart, 1984; McGuigan, 1985; Maher, 1987) have disputed whether there is a real migration of accidents, with Maher having suggested that there is a statistical explanation, essentially the same as given above.

"Accident migration", it seems, may well be a result of upwards regression amongst control sites, although it has been argued (Boyle and Wright) that it is due to "risk compensation" (discussed below).

It is clear that within the treated sites, there is a nett downwards regression effect, but there is considerable doubt about the magnitude, as it depends upon the variation of the UTAR and the variation of the accident counts about the UTAR, both of which are in doubt.

13.6. RISK COMPENSATION AND ACCIDENT MIGRATION

It is first necessary to discuss what is meant by the term "risk". One meaning is simply "probability"; this is the meaning of risk in Chapter 5 of the course notes, where risk is the conditional probability of an accident occurring given that there is an opportunity for an accident. The use of the term risk meaning probability would generally be considered inappropriate unless the outcome carried with it some undesirable consequence. For instance, one would not generally talk of the risk of getting a "head" when tossing a coin, unless the getting of a "head" would be disadvantageous. Hence, the other common meaning is "expectation". If there are several possible outcomes, the probabilities of which are p , p , etc. and the consequences of which are D , D , etc., then the expectation is the sum over all outcomes of the product of the probabilities and the consequences, i.e.

$$\text{expectation} = \Sigma_i \, p_i \, D_i$$

The probability of death in one game of Russian roulette (one-sixth) is considerably less than the probability of a "head" in one toss of a fair coin (one-half), but many reasonable people would regard Russian roulette as more risky than coin-tossing.
It is also necessary to draw a distinction between "objective risk" (calculated by experts) and "subjective risk" (perceived by road users). The former may be estimated (as a probability) by the ratio of number of accidents to the number of exposures (or accident opportunities). There is considerable evidence that there is a discrepancy between objective and subjective risk. This may well be because objective risk is generally estimated as a simple probability, whereas individual users may be considering both the probabilities and the consequences when estimating risk. Whatever the reason, road users may perceive the risk to be greater or less than the risk calculated by safety experts; very occasionally, the subjective and objective risks may be equal.

Experts may be able to agree on the objective risk, but it must be remembered that each individual road user estimates the subjective risk, and it is virtually certain that there will be some variation in the estimates. That variation can be between drivers, or within drivers; an individual's estimate of the subjective risk may vary with time and the circumstances (including their mental state).

Some road safety programmes are aimed at raising the level of subjective risk, perhaps above the level of objective risk. For instance, drink/driving blitzes are often aimed at increasing the perceived probability of apprehension (and hence the perceived risk or expectation), but should drivers become aware that the real (objective) probability of apprehension is not markedly greater, then the effect will not be long-lasting.

On a particular journey, the level of both objective and subjective risk will vary. Hence, both objective and subjective risk are time-dependent, and the relationship between them may vary with time. It might be argued that when the level of subjective risk drops relative to the level of objective risk, then an accident is more likely to ensue. It does seem that subjective risk can exceed objective risk in certain circumstances, with the situation being reversed in other circumstances.

Observations of traffic behaviour in certain circumstances reveal a tendency for drivers to respond to variations in the level of subjective risk. For instance, during a snow storm traffic generally travels slower, with the melting of the snow and the drying of the road being accompanied by an increase in speed. The adjustment of behaviour in response to varying subjective risk is commonly termed "risk compensation".

It must be remembered that driving style is affected by a complex of factors, of which risk is merely one. In general, the risk (either as probability or expectation) is extremely small; accidents are rare events. Hence, it may well be that the perceived level of risk is a fairly insignificant factor.

It has been suggested by Evans (1985) that as a consequence of driver behaviour adjustment, the actual effect of a safety change can be substantially different from the engineering effect. He proposed a "human behaviour feedback model", giving the following relationship:

(actual effect) = (1 + f) (engineering effect)

Here, the engineering effect is the effect that would actually occur if the feedback parameter f were zero and could be termed the "underlying true effect". It is not the same as the predicted effect, as even with zero feedback (or driver behaviour adjustment), the actual effect can differ from the predicted effect, due to prediction errors. As such errors tend towards zero, the predicted effect will tend towards the engineering effect.

It is necessary to distinguish clearly between the engineering and predicted effects; the discrepancy between the former and the actual effect is due solely to driver behaviour adjustment, while the discrepancy between the latter and the actual effect is due to the combination of prediction error and driver behaviour adjustment. Unfortunately, such a distinction is not always made.

For parameter f equal to minus unity, we have the special case of "risk homeostasis" (Wilde, 1982). The basis of the risk homeostasis hypothesis is that drivers each have a target level of risk, and that any change to the vehicle or road environment aimed at reducing the level of risk will meet with driver behaviour adjustment such that the target level is maintained.

The risk homeostasis hypothesis is very controversial, and is very difficult to prove or disprove conclusively. It implies that each and every safety initiative will have no effect, unless it is successful in changing drivers' propensities for taking risks (i.e. their target levels of risk). Engineering changes to the road environment are thus very unlikely to have any effect. At this stage, it is fair to say that the risk homeostasis hypothesis remains largely untested.

Evans (1985) suggest that the value of parameter f can be:

(1) > 0, in which case the actual effect exceeds the engineering effect;
(2) < 0, in which case risk compensation gives rise to an undermining of safety measures.

It may well be that the value of f depends upon the precise nature of the safety measure. For instance, some safety initiatives are virtually invisible to drivers, and the scope for feedback is thus virtually nil. In such circumstances, the value of parameter f is virtually zero.

Boyle and Wright (1984) seemed to invoke the notion of risk compensation to explain an apparent migration of accidents in a study of the effect of a blackspot treatment programme. They found a tendency for accidents to decrease at treated blackspots but to increase at untreated sites in the immediate vicinity of the treated sites. They argued that treatment of the blackspots reduces the proportion of drivers experiencing near misses at those sites, with a consequent reduction in driver caution and a consequent increase in accidents at untreated sites in the vicinity. In essence, Boyle and Wright were arguing that the treatment of blackspots reduced the perceived risk, with drivers tending to adjust by adopting a more relaxed driving style, leading to more accidents occurring at the nearby sites.

The hypothesis of accident migration implies that much of the benefits of road safety measures will be lost, as accidents saved at one location will simply happen elsewhere. The validity of the hypothesis is in doubt; as suggested by Maher (1987) and in the section on regression-to-the-mean, the apparent migration may simply be a manifestation of upwards regression amongst untreated sites in the vicinity of treated sites.

Risk compensation as a concept is not new; Smeed (1949) stated:

> "There is a body of opinion that holds that the provision of better roads, for example, or the increase in sight lines merely enables the motorist to drive faster, and results in the same number of accidents as previously. I think there will always be a tendency of this sort, but I see no reason why this regressive tendency should always result in exactly the same number of accidents as would have occurred in the absence of active measures for accident reduction. Some measures are likely to cause more accidents and others less, and we should always choose the measures that cause less."

Unfortunately, due to a number of factors, including:

(1) doubt about how risk should be defined, how risk is perceived, and how decisions are made in the presence of risk;

(2) uncertainty in predicting and measuring the effect of accident counter-measures.

there has been very little progress made towards specifying precisely when and where risk compensation may occur, and the extent to which it may occur.

13.7. DISCUSSION

It is not essential that all accident types be considered together. If the treatment is aimed at a specific accident type and if accidents of that type can be observed separately, then the analysis could be confined to such accident types. The other accidents could be analysed separately. The disaggregation by accident type does lead to smaller numbers of accidents, which makes detection of a statistically significant change more difficult (all other things being equal). Disaggregation does avoid dilution of the effect of the treatment, making detection of a statistically significant change less difficult (all other things being equal). Whether it is advantageous to disaggregate or not obviously varies with the circumstances.

If data on some measured variable (e.g. speed, deceleration) is available, then the analysis can be done in a very similar manner to that shown in sections 14.7.3 and 14.7.5. There are some differences, as follows:

(1) there is no need for the logarithmic transformation, as it is generally assumed that the variable itself is normally distributed;

(2) where there have been several surveys at the same site in the same condition, the results are aggregated by weighting according to sample sizes (rather than the inverse of the standard errors).

It should be noted that the different statistical tests may give different answers in certain circumstances, because those tests involve different assumptions, the validity of which can vary with the circumstances.

14. ECONOMIC EVALUATION

14.1. INTRODUCTION

Having identified hazardous locations and appropriate remedial treatments, it remains to firstly assess whether the treatment is economically sound. The term "appropriate" simply means that the treatment should give a reduction in accidents. Whether that reduction is sufficient to justify implementation depends upon:

(1) the cost of implementation;
(2) the value of the benefits;
(3) whether there are, in economic terms, more attractive investment options and the level of the budget constraint.

The cost of implementation can usually be estimated with considerable accuracy, but there is generally considerable uncertainty regarding the value of the benefits, due to:

(1) uncertainty in the estimate of the accident reduction;
(2) uncertainty regarding the cost of accidents.

Accident reduction uncertainty arises from methodological problems associated with evaluation studies (see Chapter 14 of the course notes) and doubt over whether an accident reduction obtained for one set of circumstances will be obtainable for another; that is, the generalisability of the results of evaluation studies is in doubt. Section 14.7.5 of the course notes shows that the standard error for "general effectiveness" is greater than that for "effectiveness at the treated sites".

14.2. TREATMENT SELECTION PROCEDURES

There may be more than one appropriate treatment for the problem at a hazardous location, and the first task is to choose the best economically. The simplest way is to calculate the first-year-rate-of-return (FYRR), which is simply (first-year benefits minus first-year costs) as a percentage of the total capital cost. The first year benefits may be due to an expected accident reduction, while the first year costs may arise from increases in other operating costs (e.g. delay). In general, one should think in terms of "nett benefits" in each year.

The higher the FYRR, the more attractive is the treatment, so one may choose that treatment with the highest FYRR. In many simple cases, the FYRR is an adequate guide, but where the economic life of the treatment is expected to be short, or the nett benefit is expected to vary markedly from year to year, then the FYRR should not be used. Instead, a discounted cash flow analysis should be undertaken. This involves discounting future benefits and costs for each year, using the appropriate discount factor. The nett present value (NPV) is simply

$$NPV = PVB - PVC$$

where

PVB = present value of benefits
PVC = present value of costs (including the capital cost).

A treatment is economically worthwhile if the NPV is positive.

Alternatively, one may consider the benefit-cost ratio:

BCR = PVB / PVC

and a treatment is economically worthwhile if BCR is greater than unity.

Treatments which are not worthwhile should be rejected. There may be more than one worthwhile treatment for a site, but only one can be implemented (i.e. they are mutually exclusive) and it is necessary to find the most worthwhile. This is done via an incremental analysis, as follows:

(1) arrange the alternatives in order of increasing PVC, so that:

$PVC(i) > PVC(i-1) \quad i = 1, 2, ..., N$

where N = number of alternatives

(2) calculate the incremental nett present value of each alternative relative to the alternative with the next lower PVC (excluding any alternative with an incremental nett present value less than the critical value:

$INPV(i) = NPV(i) - NPV(i-k) \quad i = 2, ..., N$

where k = smallest integer such that $INPV(i-k) > INPV^*$
$INPV^*$ = critical incremental NPV (> 0).

(3) the best alternative is that with the highest PVC and with an incremental NPV greater than the critical value.

As an alternative to the incremental NPV approach, one can use the incremental BCR approach:

(1) as above

(2) calculate the incremental BCR of each alternative, as follows:

$IBCR(i) = IPVB(i) / IPVC(i) \quad 1 = 2, ..., N$

where

$IPVB(i)$ = PVB (i) - PVB (i-k)
$IPVC(i)$ = PVC (i) - PVC (i-k)
k = smallest integer such that IBCR (i-k) > IBCR*
IBCR* = critical incremental BCR (> 1)

(3) the best alternative is that with the highest PVC and with an incremental BCR greater than the critical value.

Having identified the best treatment for each hazardous location, it is then necessary to identify the best programme of remedial works. This can be done by ranking the best treatments for each location according to the ratio NPV/PVC, and selecting from the top of the list until the budget constraint is reached. If there is no such constraint, then there is no need for this step; all the best treatments should be implemented.

If there is a budget constraint, an alternative to ranking best treatments according to the ratio NPV/PVC is to rank them according to the BCR's, and to select from the top of the list until the budget constraint is reached. The last treatment included within the works programme will have a BCR = BCR*, say, and for consistency between this stage and the previous stage (finding the best treatment for each site), the critical (or cut off) incremental BCR (i.e. IBCR*) should equal the critical (or cut off) BCR (i.e. BCR*). Since BCR* is not known when the best treatments are being found, one must assume a value for IBCR* and if it subsequently turns out to be different from BCR*, then IBCR* should be revised and the process repeated, until there is good agreement between the value of IBCR* and BCR*.

If the NPV/PVC ratio is used as the basis of identifying the best programme of work, then the last treatment included will have a value for this ratio, but since this ratio is not the basis of the procedure for identifying the best treatment (this was done on the basis of INPV), it is not so easy to ensure consistency between the two stages. Hence, the use of the benefit-cost ratio is preferable.

If there is a budget constraint, one can rank all worthwhile treatments for all sites according to BCR or NPV/PVC. Again, it is a matter of selecting from the top of the list until the budget constraint is reached, but because there may be several worthwhile treatments for any single site, it will be necessary to "unselect" a treatment should an alternative treatment for the site have both:

(1) a BCR (or NPV/PVC) larger than the critical (or cut off) value;

(2) a IBCR (or INPV), that is larger than the critical (or cut off) value.

14.3. THE COST OF ACCIDENTS

14.3.1. Valuation methods. Two issues arise:

(1) how should accident costs be defined in principle;
(2) how should accident costs be estimated in practice.

Now, the definition depends upon the use to which the accident costs are to be put, that is, upon the objectives of the agency using the accident costs. Four broad classes of objective have been identified (Hills and Jones-Lee, 1982):

(1) national output objectives (e.g. maximisation of gross national product or GNP per capita or growth of GNP);

(2) other macroeconomic objectives (e.g. maximisation of level of employment, minimisation of rate of inflation);

(3) social welfare objectives (e.g. maximising the well-being of individuals comprising society, minimising accident fatalities or injuries);

(4) mixed objectives (i.e. a mixture of objectives from more than one of the above classes).

Hence, "pain, grief and suffering" are relevant, and allowance should be made for them in the definition of accident costs, if one is pursuing a social welfare objective. If one is merely interested in a national output objective, "pain, grief and suffering" is irrelevant and no allowance should be made.

At least six distinctly different methods have been proposed for costing accidents:

(1) gross output method (this involves calculating the discounted present value of the victim's future output, and adding the real resource costs associated with vehicle damage, medical and other costs);

(2) nett output method (this is the same as the gross output method, except that the present value of the victim's future consumption is deducted);

(3) life-insurance method (this involves summing the real resource costs and the amount for which typical individuals are willing to insure their own lives, limbs, etc.);

(4) court-award method (this is the same as the life-insurance method, except that the amount of insurance is replaced with the amount of compensation awarded to victims or their dependents by the courts);

(5) implicit public-sector valuation method (this entails analysis of public sector decisions on investment proposals affecting safety, to identify the implied upper or lower bounds on the cost of an accident);

(6) value of risk-change method (this entails estimating the total amount that all individuals, affected by a proposal that would change their risk of being an accident victim, would be willing to pay to achieve a reduction or avoid an increase).

These six approaches generate substantially different estimates of accident costs; Hills and Jones-Lee (1982) show that the nett output method tends to give the lowest estimates, while the value of risk-change method generally gives the highest estimates. The implicit public-sector valuation method gives extremely variable estimates, depending upon the decisions that are analysed.

The gross output method suggests that the cost of a fatal accident is dependent upon the age of the victim (amongst other things), and reduces to the real resource cost as the victims age approaches the retirement age. The nett output method suggests that if the victim is retired, then the cost may well be negative (i.e. there is a benefit in having such persons killed).

Hills and Jones-Lee consider the relevance of each of the six methods given objectives from each of the four classes, and conclude that:

(1) for a national output objective, the simple gross output method (without any allowance for "pain, grief and suffering" is the most appropriate;

(2) for another macroeconomic objective, none of the six methods is relevant;

(3) for a social welfare objective, the value of risk-change method is most appropriate;

(4) for a mixed objective (i.e. a national output and social welfare objective), both the simple gross output method and the value of risk-change method are fairly relevant.

They also argue that in developed countries, the social welfare class of objective is most appropriate, while for developing countries, the national output class of objective is generally adopted. Since the value of risk-change method gives a much higher estimate of accident cost than the simple gross output method, there is clearly a need to have a smooth transition from one end of the spectrum to the other as a country develops. They suggest this can be done by incorporating an allowance for "pain, grief and suffering", with the allowance being increased as the country develops, so that the estimated cost of an accident approaches the estimate obtained from the value of risk-change method.

The use of the value of risk-change method (also termed the willingness-to-pay method) is the subject of considerable concern; a sudden shift from one method (and a relatively low cost estimate) to another method (and a much higher cost estimate) should lead to a much greater allocation of capital funds for accident reduction and prevention work, with a reduction in the allocation of funds for other forms of roading work (e.g. infrastructure improvement schemes aimed at reducing delay or direct operating costs). A dramatic change in the pattern of expenditure on roading projects, with much more being spent on safety-related projects, seems quite justified, but there is considerable inertia to be overcome. For a discussion of this matter, see Jones-Lee (1977).

14.3.2. Accident Cost Components. The cost of an accident exceeds the cost of an injury or death, as:

(1) there is on average more than one injury or death per accident;

(2) there are real resource costs unrelated to the injury or death (e.g. cost of damage to vehicles and property, administrative costs of accident reporting and accident insurance).

The cost of an accident obviously depends upon the vehicle speed(s); the higher the speed, the greater the probability that an occupant will be injured and the more serious the injury will probably be. In addition, vehicle/property damage will also be greater, on average. Hence, it is common practice to have average accident costs for different situations; in the UK, there are separate average accidents costs for urban roads, rural roads and motorways (see Table 1).

The cost elements (see Table 2) vary in magnitude substantially, according to the type of accident. Clearly where an accident involves a fatality, the lost output component will dominate the other components, because of the cost attached to the loss of life; £161,170 per fatality in June 1984 (see Table 3). It should be noted that each fatal accident involves more than one fatality on average, hence the discrepancy between the per accident figures in Tables 1 and 2, and the per injury figures in Table 3.

Table 1 Average cost of road accident by road type: GB: 1987

(£)

	Built up Roads	Non-Built up Roads	Motorways	All Roads
Fatal	526,630	575,820	683,620	555,130
Serious	18,040	22,820	22,240	19,480
Slight	1,560	2,660	2,910	1,810
All Injury	12,130	30,390	32,990	16,690
Damage only	670	820	960	700
Average cost per injury accident with allowance for damage only	16,410	34,140	37,320	20,850

Table 2 (1984)

AVERAGE COST PER ACCIDENT IN 1984 BY SEVERITY AND ELEMENT OF COST (JUNE 1984 PRICES) £'s

COST ELEMENT TYPE OF ACCIDENT	LOST OUTPUT	MEDICAL & AMBULANCE	POLICE & ADMINISTRATION	DAMAGE TO PROPERTY	TOTAL RESOURCE COSTS	PAIN, GRIEF & SUFFERING	TOTAL
Fatal Accidents	127,700	1,080	300	1,650	130,730	50,310	181,040
Serious Accidents	1,700	1,850	240	1,320	5,110	5,080	10,190
Slight Accidents	20	90	180	940	1,230	110	1,340
All Injury Accidents	3,030	540	190	1,040	4,810	2,340	7,150
Damage Only Accidents	-	-	60	490	550	-	550

Table 3 Average cost per casualty and per accident: GB: 1986 and 1987

(£)

	Cost per casualty		Cost per accident	
	1986	1987	1986	1987
Fatal	467,300	500,000	522,400	555,130
Serious	14,180	15,190	18,180	19,480
Slight	300	310	1,690	1,810
Average all severities	7,700	11,600	15,840	16,690
Damage only	-	-	650	700

Table 4 (1984)

AVERAGE COST PER CASUALTY BY CLASS OF ROAD USER £'s

Pedestrian	6,960
Pedal Cyclist	3,460
Bus and Coach occupants	1,380
Goods vehicle occupants	4,510
Car and taxi occupants	4,000
Motorised two-wheeler riders and passengers	4,810
All motor vehicle users	4,130
Average, all road users	4,620

Table 5 (1984)

TOTAL ACCIDENT COSTS IN 1984 BY SEVERITY AND ELEMENT OF COST (JUNE 1984 PRICES) £'s MILLION

COST ELEMENT TYPE OF ACCIDENT	LOST OUTPUT	MEDICAL & AMBULANCE	POLICE & ADMINISTRATION	DAMAGE TO PROPERTY	PAIN, GRIEF & SUFFERING	TOTAL
Fatal Accidents	656	6	2	8	259	930(35%)
Serious Accidents	106	115	15	82	315	632(24%)
Slight Accidents	4	17	33	174	20	249 (9%)
All Injury Accidents	766	137	49	265	594	1,811(68%)
Damage Only Accidents	-	-	89	750	-	840 (32%)
All Accidents	766(29%)	137(5%)	139 (5%)	1015(38%)	594(23%)	2651(100%)

Table 6 (1984)

TOTAL ACCIDENT COSTS IN 1984 BY SEVERITY AND CLASS OF ROAD (JUNE 1984 PRICES) £'s MILLION

CLASS OF ROAD TYPE OF ACCIDENT	URBAN[1] ROADS	RURAL[2] ROADS	MOTORWAYS	ALL ROADS
Fatal Accidents	480	415	35	930
Serious Accidents	409	211	12	632
Slight Accidents	173	69	7	249
All Injury Accidents	1061	695	55	1,811
Damage only Accidents	666	159	15	840
All Accidents	1,727	854	70	2,651

1 - Urban roads are those roads (other than motorways) with speed limits of 40 mph or less.
2 - Rural roads are those roads (other than motorways) with speed limits over 40 mph.

Note that totals may not equal the sum of their elements due to rounding errors.

The average cost per injury does vary with the class of road user (see Table 4); the cost of a pedestrian injury is (not surprisingly, given the vulnerability of pedestrians) much greater than the average for all classes of road user. It is perhaps a little surprising that pedal cyclists, who are similarly vulnerable, have a below average injury cost.

Tables 5 and 6 show how the estimated total accident cost (£2651 million in 1984) is due to each cost element and each road type; damage to property is the largest single cost element, and urban road accidents account for the lion's share (about 65%) of the total cost. Motorway accidents, despite the attention they receive in the news media, account for only about 2.6% of the total cost.

14.3.3. Accident Cost Estimation. Despite the uncertainty regarding estimates of accident reduction, such estimates are necessary, in order to obtain an estimate of the economic worth of a proposed remedial treatment. Unless it is worthwhile and can compete with other proposals for expenditure of capital, then the remedial treatment should not be undertaken.

Where possible, it is desirable to estimate the effect of the remedial treatment on the occurrence of accidents involving different classes of road user, so that the information in Table 4 can be used. Hence, if the treatment is likely to reduce pedestrian injuries but not injuries to other road users, then the use of an average accident cost will lead to under-estimation of the benefits of the treatment. In some circumstances, use of the average accident cost will lead to over-estimation. Clearly, the disaggregate accident cost data should be used where possible, and it is important that to facilitate this, the effect of the treatment on accident occurrence should, if possible, be done at a disaggregated level.

It is the case that in some countries, the cost of accidents involving vehicles (and other road users) making particular movements has been estimated. Some combinations of manoeuvres involve high relative speeds and hence a greater likelihood of serious injury, and the cost of an accident varies substantially according to the severity. When estimating the effect of a remedial treatment, one should consider which manoeuvres are likely to be most affected and how; in this way, one can get a feel for whether the treatment is likely to reduce serious accidents more than minor accidents (or vice versa). The use of a simple average accident cost and overall accident reduction may give substantial over- (or under-) estimation of the change in accident cost.

14.4. CONCLUSION

One of the goals of economic evaluation is to ensure consistency when comparing alternative opportunities for investment. Hence, it is important that there be consistency in the economic evaluation procedure. Thus, all alternatives should be evaluated in the same manner, using the same basis for accident cost estimation.

Treatments not selected for implementation (either because of a negative NPV or BCR less than unity, or because of a budget constraint) should be re-evaluated at a later date; evaluation results can change over time, as accident rates change and/or capital becomes more freely available.

Finally, it should be noted that the final decision on implementation will generally not be based solely upon the outcome of an economic evaluation; other factors, such as public and/or political pressure, will often influence the matter. This does not, however, justify not doing economic evaluation; it is important that the decision-makers should have information about the economics of proposals under consideration for implementation, so that they know when they are putting non-economic considerations ahead of economic considerations.

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