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ROAD LIGHTING AS AN ACCIDENT COUNTERMEASURE

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FOREWORD

This report has been prepared by CIE Technical Committee TC 4-02 of Division 4 'Lighting and Signalling for Transport'.

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The members gratefully acknowledge the contribution of P Scott who independently critically assessed, from a statistical point of view, most of the accident studies reported in Part 3.

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VII

Road Lighting as an accident countermeasure**SUMMARY**

Road accidents at night are disproportionately high in numbers and severity compared to day. The major factor contributing to this problem is darkness because of its great influence on the driver's behaviour and ability. At night man's visual capabilities are impaired and visibility is reduced. Thus road lighting is a potential countermeasure.

Sixty-two lighting and accident studies, from 15 countries, have been rigorously analysed. Some 85 per cent of results show lighting to be beneficial, with about one third of these having statistical significance.

These lead to the general conclusion that road lighting on traffic routes will reduce the incidence of night accidents. Depending on the class of road and the accident classification involved, the statistically significant results show reductions of between 13 and 75 per cent.

No definitive relationships can be given between accident reductions and light technical parameters. There are indications that increasing light levels improve safety in a law of diminishing return. A substantial body of evidence shows that when lighting is switched off as an economy measure accidents increase. There is some indication that if the uniformity of lighting is too great the accident benefit associated with a particular light level may be reduced.

Depending on the road and traffic classification, cost benefit studies show the accident savings to more than offset the cost of lighting. In the report, warrants for lighting related to accidents and traffic volume are developed. The findings can assist in the preparation of national standards and in decisions on the implementation of road lighting programmes.

Straßenbeleuchtung als eine Maßnahme gegen Unfälle**ZUSAMMENFASSUNG**

Im Vergleich zu Unfällen am Tage sind die nächtlichen Unfälle im Straßenverkehr überproportional häufig und schwerwiegend. Die Hauptursache hierfür ist die Dunkelheit, wegen ihres großen Einflusses auf das Verhalten und die Fähigkeit des Fahrers. Nachts ist das menschliche Sehvermögen beeinträchtigt und die Sichtbarkeit reduziert. Somit ist die ortsfeste Straßenbeleuchtung eine potentielle Maßnahme gegen Unfälle.

62 Untersuchungen über Beleuchtung und Unfälle aus 15 Ländern wurden genau analysiert. Ungefähr 85 % der Ergebnisse weisen die Beleuchtung als nützlich aus. Ungefähr ein Drittel davon sind statistisch gesichert.

Sie erlauben die generelle Schlußfolgerung, daß die ortsfeste Straßenbeleuchtung auf Verkehrswegen das Auftreten nächtlicher Unfälle vermindert. Je nach Straßenart und verwendeter Unfallklassifizierung liegen die statistisch gesicherten Verringerungen zwischen 13 und 75 %.

Es können keine genauen Beziehungen zwischen Unfallreduzierungen und lichttechnischen Parametern angegeben werden. Es gibt Anzeichen dafür, daß mit steigendem Beleuchtungsniveau die Sicherheit verbessert wird, und die Unfälle abnehmen. Ein wesentlicher Teil des Untersuchungsmaterials zeigt, daß bei Abschaltung der Beleuchtung aus Kostengründen die Unfallzahlen steigen. Es gibt einige Anzeichen, daß bei zu großer Gleichmäßigkeit der Beleuchtung die Unfälle zunehmen.

Abhängig von der Straßen- und Verkehrsklassifikation zeigen die Kosten-Nutzen-Studien, daß die Unfallverminderung die Kosten für die Beleuchtung mehr als ausgleicht. In dem Bericht werden Begründungen für die Beleuchtung in Abhängigkeit von Unfallgeschehen und Verkehrsaufkommen entwickelt. Die Ergebnisse können die Vorbereitung von nationalen Normen und Entscheidungen über die Verwirklichung von Straßenbeleuchtungsprogrammen unterstützen.

VIII

Eclairage routier comme mesure contre des accidents**RESUME**

Le nombre et la gravité des accidents de la route qui se produisent de nuit sont sans rapport avec ce qui se passe de jour. Le principal facteur responsable de ce problème est l'obscurité, qui a une grande influence sur le comportement et les capacités du conducteur. La capacité visuelle humaine est affaiblie pendant la nuit, et la visibilité réduite. L'éclairage routier constitue donc une contre-mesure potentielle.

Soixante-deux études d'éclairage et d'accidents, effectuées dans 15 pays, ont été analysées en détail. Environ 85% des résultats - dont à peu près un tiers sont statistiquement significatifs - montrent que l'éclairage améliore la situation.

Ces études mènent en général à la conclusion que l'éclairage routier des voies de circulation réduit effectivement la fréquence des accidents nocturnes.

Selon la catégorie de route et la classification des accidents, les résultats les plus statistiquement fiables montrent des réductions comprises entre 13 et 75 pourcent.

Il n'est pas possible d'établir une relation définitive entre la diminution des accidents et les paramètres d'éclairagisme. On a cependant quelques indications qui montrent que des niveaux croissants d'éclairage améliorent la sécurité selon une loi non-proportionnelle. Une preuve substantielle en est que, lorsque l'éclairage est coupé pour des raisons d'économie, le nombre d'accidents augmente. On a aussi parfois constaté que si l'éclairage est trop uniforme, la diminution des accidents liée à un niveau particulier d'éclairage est moindre.

Selon la classification de la route et du trafic, les études de coût-bénéfice pourront montrer que les économies liées à la diminution des accidents font plus que compenser le coût de l'éclairage. Le présent rapport traite des relations entre le volume d'accidents et de circulation et l'éclairage. Ces conclusions peuvent aider à élaborer des normes nationales et décider de la mise en place d'un programme d'éclairage routier.

INTRODUCTION

In 1960 the CIE published "Street Lighting and Accidents". This document showed that night accidents on urban traffic routes could be substantially reduced, both in number and severity, by the implementation of good street lighting. However this conclusion was based mainly on one investigation, albeit an extensive and reasonably well conducted one. In addition the document dealt in some detail with accident data and methodology to be used in further studies in order to obtain statistically reliable conclusions.

Since that time a multiplicity of studies have been carried out in many countries, on all types of road construction and under many conditions. The wealth of data now available justifies revision of the original document, so that the data from diverse sources are presented in a single comprehensive and authoritative collection, so that the original conclusion can be further substantiated and expanded and so that accident reduction can be linked to the economic viability of road lighting.

The CIE has published a series of documents on light technical requirements for road lighting viz:

12.2	(1977)	Lighting of Roads for Motorized Traffic
30.2	(1982)	Calculation and Measurement of Luminance and Illuminance in Road Lighting
31	(1976)	Glare and Uniformity in Road Lighting Installations
32	(1977)	Lighting of Road Situations Requiring Special Treatment
33	(1977)	Depreciation and Maintenance of Road Lighting Installations
34	(1977)	Road Lighting Lantern and Installation Data
47	(1979)	Road Lighting for Wet Conditions
61	(1984)	Tunnel entrance lighting: A survey of fundamentals for determining the luminance in the threshold zone
66	(1984)	Road surfaces and lighting (joint technical Report CIE/PIARC)
88	(1990)	Guide for the lighting of road tunnels and underpasses

These documents provide a basis for good road lighting practice.

This document, Road Lighting as an Accident Countermeasure, complements these in that it draws attention to the benefits of road lighting in terms of accident reduction. It is of particular significance to administrators of public roads, who have to critically justify expenditure of public monies and energy.

It is in three self contained parts:

Part One is a statement on the night road situation and on road lighting as a proven, economically viable accident countermeasure. It is meant to be used as a concise briefing for those at the highest level of administration.

Part Two is an analysis of the subject together with a summary of and findings from the lighting and accident studies. It is meant to inform those drafting policy and advising decision makers.

Part Three contains the details and data of each of the individual lighting and accident studies. It is a comprehensive presentation meant for those closely associated with data collection and analysis.

PART ONE

STATEMENT ON THE PROBLEM OF NIGHT ROAD ACCIDENTS AND ON ROAD LIGHTING AS AN ACCIDENT COUNTERMEASURE

Part 1 is a statement on the night accident situation and on road lighting as a proven, economically viable accident countermeasure. It is meant to be used as a concise briefing for those at the highest level of administration.

1.1 ROAD ACCIDENTS AT NIGHT

Road accidents at night are disproportionately high in numbers and severity compared to daytime. The proportion of fatal accidents at night in 13 OECD countries range between 25 and 59 per cent, average value 48,5 per cent. Estimates of vehicle kilometres travelled during the hours of darkness range from 17 to 32 per cent, average value 25 per cent.

1.2 REASONS FOR ELEVATED NIGHT ACCIDENT RATE

Individually factors such as increased alcohol usage, fatigue, over representation of young drivers in night traffic contribute to the problem. However, the major factor is darkness, as is demonstrated in accident studies in which the effect of these other factors has been taken into account.

At night, with its low light levels, man's visual capabilities, such as acuity, distance judgement, speed of seeing, colour discrimination and glare tolerance are impaired. There will also be adverse interactions between impaired vision and other factors, such as inclement weather.

As a result visibility will be severely reduced at night. Thus, it would be expected that the provision of light through road lighting would be a countermeasure.

1.3 ROAD LIGHTING: A SUCCESSFUL ACCIDENT COUNTERMEASURE

Sixty two lighting and accident studies from 15 countries have been evaluated. Some 85 per cent of results show lighting to be beneficial, with about one third of these having statistical significance. Therefore the overwhelming evidence is that road lighting is successful.

However, the installation of lighting cannot be expected to result in a reduction in accidents if there is a major non-visual problem at any particular site.

The numerical values of the benefits are summarised in Table 1.1. For each road class the first line gives the details of results which have statistical significance and the second line gives details of all results whether significant or not. The results are given only from before and after studies involving the implementation or upgrading of lighting on traffic routes.

Table 1.1 Summary of the benefits of lighting (per cent reduction of night-time accidents)

Road Class	Accident Classification								
	All Accidents			Pedestrian			Casualty		
	Sample	Range	Mean	Sample	Range	Mean	Sample	Range	Mean
Urban									
Continuous	3	21 to 75	43	2	46 to 75	51	6	29 to 48	34
	10	9 to 75	29	4	16 to 57	42	9	16 to 48	29
Pedestrian crossings				1		64			
				8	32 to 74	54			
Rural									
Continuous	2	13 to 75	44				2	38 to 53	45
	4	13 to 75	37				6	13 to 100	44
Junctions	1		44				0		
	2	26 to 44	35				1		9
Freeways									
Continuous	1		57				0		
	3	56 to 58	57				1		62
Interchanges	1		41						

Results from studies surveying roads with and without lighting or those concerned with economies of lighting through reducing or switching out have been excluded, being less robust than the before and after type of study.

The table shows that the average reduction in accidents is at least 30 per cent, since this value is exceeded in each cell for which there are statistically significant results. This conclusion is supported by the non significant results and also by the survey and lighting economy studies not included in the table.

This value can be used for benefit/cost analysis, feasibility studies and the like, if a single, composite value for accident reduction is required. However, if a result of a local study is available that should be used, or alternatively, a figure within the range given in the Table 1.1 can be selected for a particular application.

1.4 THE INFLUENCE OF THE QUALITY OF THE LIGHTING

In most studies the lighting was upgraded from poor or no lighting to good lighting; by good lighting is meant often to that of the national lighting standard at the time. Little can be said definitively about the relationship between accident reduction and individual light technical parameters describing lighting quality.

Accidents decrease as the light provided in an installation increases. However, there is a law of diminishing return and the level of lighting at which there is no further decrease in accidents may be several times higher than is usual in national standards.

As a corollary, with reasonable supporting evidence from lighting economy studies, the reduction or switching out of lighting has an adverse effect on safety.

Another measure of quality is uniformity of luminance: there is some evidence that if uniformity is too great the accident benefit associated with a particular light level may be reduced.

There is no information available on the influence of other quality criteria, such as glare, on accident reduction.

1.5 COSTS AND BENEFITS OF ROAD LIGHTING

Road lighting can be expected to reduce accidents. However to be cost effective the accident savings in monetary terms have to be greater than the capital and running costs of the lighting, taken over the life of the installation.

Lighting on arterial roads, particularly in urban areas, will more than pay for itself in accident savings. This is without considering other benefits, such as reduction of distress caused by death and injury and possible increased traffic service and efficiency, crime prevention possibilities and improved amenity.

However, it is important to consider in the cost-benefit evaluation possible induced accident hazards from the lighting columns. These can be minimised by set back, guardrail or use of frangible, energy absorbing or slip-base columns.

It appears that lighting is justified on urban arterial roads (non freeway) if the night casualty rate exceeds about one per kilometre per year or if the annual daily traffic exceeds about 10,000 vehicles. For freeways and motorways these warrants will be somewhat higher. Exact warrants can be derived from the cost structure pertaining to a particular country and location.

The sensitivity of the conclusions of cost/benefit calculations to the accuracy of the input values should be tested by varying all items, including the accident reduction value chosen by the methods given in 1.3.

1.6 CONCLUSIONS

A general conclusion for the purpose of evaluating road lighting as an accident countermeasure and preparing engineering warrants is that it may reduce night accidents when properly designed, installed and maintained. The most reliable studies show reductions to be between 13 and 75 per cent, depending on the class of traffic route and the accident classification involved.

PART TWO

ANALYSIS OF THE PROBLEM OF NIGHT ROAD ACCIDENTS AND OF ROAD LIGHTING AS AN ACCIDENT COUNTERMEASURE

Part 2 is an analysis of the subject together with a summary of and findings from the lighting and accident studies. It is meant to inform those drafting policy and advising decision makers.

2.1 ROAD ACCIDENTS

Road accidents contribute significantly to the mortality rates of both developed and developing countries. Road accidents are distributed over all age groups and types of road user. Besides death, road accidents are responsible for great numbers of injuries and considerable damage to property. In any country the costs of road accidents are a measurable part of total economic activity within the country and a significant part of total road transport costs [63]. However, the economics of road accidents do not normally take into account suffering and grief resulting from accidents.

2.2 ROAD ACCIDENT COUNTERMEASURES

Road accident countermeasures may be classified in various ways, eg the traditional 3E's; Engineering, Education and Enforcement. Countermeasures are related to the three components of the road transport system, viz:

- the road users
- the vehicles
- the road environment

and to primary (accident prevention) or secondary (trauma reduction and treatment) safety by the formal road safety matrix shown in Fig 2.1. Road lighting is a potential engineering measure operating in the context of road environment/accident prevention.

	Accident Prevention	Trauma Reduction	Trauma Treatment
Human Factors			
Vehicle Factors			
Environmental Factors	Public lighting as a countermeasure		

Fig 2.1: Matrix for road accident and countermeasure evaluation.

Note: Only the cell relating to the consideration of road lighting is indicated.

Countermeasures which can be engineered into the road environment and vehicles require little or no conscious cooperation of the road user for their success, and they are self-enforcing.

As the transportation system is complex, a more sizeable reduction of road accidents may be expected when a number of countermeasures are involved in a safety program. Which measures are used will depend on their relevance to the particular accident situation, their proven effectiveness and the ratio of the benefits accruing to the costs of implementation. It is within this framework that road lighting as an accident countermeasure is examined.

2.3 ROAD ACCIDENTS AT NIGHT

It is difficult from a cursory examination of accident data to isolate the effect and responsibility of darkness alone on road accidents. However the data lead to the incontrovertible conclusion that the accident problem during the hours of darkness is worse than in daylight. A comprehensive survey of road safety at night has been made by the Organisation for Economic Co-operation and Development [64]; much of the data presented in this section is taken from that report.

A disproportionately large number of accidents and resultant casualties occur during the hours of darkness. By disproportionately large is meant large in relation to the exposure of road users in the road transport system, measured by the number of vehicle kilometres or person kilometres travelled in the hours of darkness.

The number of fatalities occurring at night is likely to approach that by day. The proportion of fatal accidents occurring at night in 13 OECD countries range between 25 and 59 per cent, with a median value of 48,5 per cent [64]. However, estimates of vehicle kilometres travelled during the hours of darkness range from 17 to 32 per cent.

Therefore, in general, the casualty accident rate during the hours of darkness will be several times that for the hours of light; at weekends this difference is further accentuated: see Fig 2.2.

Rel.Rate

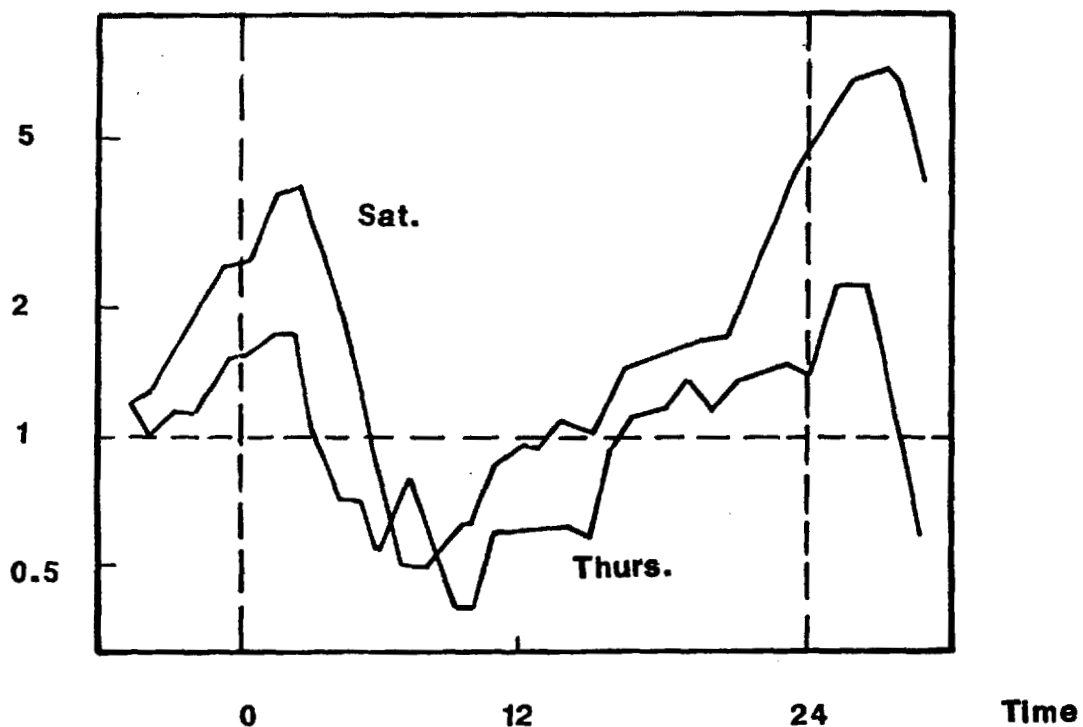


Fig 2.2: Relative accidental rate with time of day, where 1 is the average rate throughout the day (After OECD, ref 64).

Accidents at night are generally more severe in their consequences and more likely to produce fatalities and severe personal injuries than by day [65]. Accidents involving multiple vehicles and pedestrians increase in severity. This increased severity is reflected in the greater economic cost of accidents at night [66].

This pattern of increased accident rate and accident severity at night applies not only to urban traffic routes but to the whole hierarchy of roads - rural roads (despite pedestrians being largely absent) and freeways (in spite of superior design).

The distribution of accidents within the road system of a country will reflect the degree of urbanisation within that country and the usage of the road system. In general a larger proportion of accidents will occur in urban areas than in rural areas; in urban areas accidents involving pedestrians may predominate whereas in rural areas single vehicle ones may do so.

Along many roads there is some form of lighting and here the concern in this report is for the beneficial effects of upgrading lighting and disbenefits from the down grading and switching out of lighting. In most countries the majority of urban roads and only a proportion of main rural roads are lit. However, the lighting of rural roads should be considered since a significant proportion of total night fatalities can occur on rural roads [67].

The absolute volume of traffic is in general growing with time. The absolute number of accidents, however, has decreased in most countries since the early seventies. It is not clear whether the proportion of the casualties occurring at night or the night accident rate, relative to the day rate are increasing with time [68]. However, data from five OECD countries suggest there is no marked trend, either increasing or decreasing [64]. What is evident is that the night accident problem is not going to disappear and hence it is still most important to consider road lighting as an accident countermeasure.

2.4 FACTORS INFLUENCING NIGHT ACCIDENTS

It is generally recognised that a single causal factor cannot be assigned to accidents. While the majority of accidents have an element of human error or failing, this is usually found to be in combination with problems of road design and adverse weather conditions. Reduction in visibility, due to darkness, is intuitively a major factor in the increased accident problem at night. However, the non-visual factors will also contribute and one may expect adverse interactions between darkness and these factors. It is to be expected that properly designed, installed and maintained lighting will increase visibility and also combat these other causal interactions to some extent.

2.4.1 Light and vision

Nearly all of the information that the road user needs in order to drive, ride or walk effectively is of a visual nature. At night such information is often less perceptible and consequently the road user will be less efficient than during the day. As the light level falls, visual performance deteriorates; visual acuity, contrast sensitivity, distance judgement, speed of seeing, colour discrimination, and glare tolerance are all impaired [69].

Some visual information consisting of self luminous sources, such as traffic signals, will be made more conspicuous by darkness and easier to see. Other information, the conspicuity of which depends on reflected light, will be more difficult to see, such as the extent of the visual field and details in it that aid the driver in making subtle judgements of position, speed and trajectory of his vehicle. Such judgements, therefore, will be more difficult, and take more time to make. In an extreme case an object or a pedestrian will not be seen by a driver at all, or until it is too late to avoid.

Experimental evidence suggests that modest levels of lighting, far lower than daylight, will be satisfactory for effective performance by the road user at night. For some roadway situations, particularly low traffic volume rural roads, retroreflective delineation may be sufficient to provide the driver with the necessary visual information. However, as the road becomes busier and more complex, vehicle headlights cannot provide the degree of information needed. This arises because of the need to limit glare from headlights from the geometry of vehicular lighting systems, and from the location of information required by road users. For higher driving speeds, the reach of dipped beam headlights is insufficient for the detection of objects on or near the road as drivers need more information about what is happening further along the road and off to the sides where headlights do not penetrate. Road lighting can provide the necessary visual conditions to overcome these limitations.

From studies of the visual processes involved in acquiring visual information from the road scene, it has been shown that the visibility of an object is dependent primarily on the light

level and also on lighting uniformity and glare restriction [70]. Methods have been developed in which the visibility of standard objects within an installation can be computed and the visibility performance potential of a lighting installation can be assessed [71].

Gallagher [72] reported on the reactions of unsuspecting motorists to an object placed on a low volume urban street. He found that the time remaining to collision at the moment the drivers reacted, assuming no changes in vehicle velocity, increased with increasing conspicuity of the object, measured on a Visibility Index (VI). The time to collision increased with increasing road luminance until after a certain level there was no further improvement. The relevance and application of these matters to current practical lighting design is discussed elsewhere [73].

2.4.2 Non-visual factors

Factors other than light level and visibility contribute to the increased night accident rate. These include fatigue, intoxication, changes in road user population, traffic flow and weather conditions. These can adversely interact with darkness.

2.4.2.1 Fatigue

As a result of normal activity patterns, people are usually more fatigued at night than during the day. Whilst fatigue is a complicated matter, being somewhat offset by arousal, alertness and motivation it would be expected that, in addition to being less efficient at night, the driver would be more subject to errors in judgment and even to falling asleep at the wheel. Evidence of this fatigue factor has been given by Solomon [74]. He showed that large trucks and buses do not experience a higher accident-involvement rate at night while passenger cars do. It can be argued that professional truck drivers are, as a group, more rested and physiologically prepared for night shifts than the average driver of a passenger car, who has probably worked his normal daytime occupation.

2.4.2.2 Intoxication

The road user population changes at night, both in the kind of people using the roads and in the purpose associated with travel. The hours of darkness are those of relaxation and pleasure seeking. This is synonymous with the use of intoxicants, particularly of alcohol. It has been reported [75] that 80 per cent of the drivers fatally injured in single vehicle crashes and who have been drinking, sustained their injuries during the hours of darkness. In contrast only 39 per cent of fatally injured drivers without alcohol involvement sustained their injuries during darkness. Other evidence of the alcohol factor can be shown when accident rates are plotted by hours of the day. The accident rates tend to nearly double with the onset of darkness and usually double again during the hours shortly after midnight, see Fig 2.2. Therefore alcohol, as well as darkness, could be a significant causal factor in the elevated night accident situation. One of the effects of alcohol is to impair vision [76] and this could adversely interact with poor visual conditions at night. The major effect of alcohol, however, is the impairment of judgement. This interacts adversely with the fact that at night the proportion of young inexperienced drivers is higher than daytime. [64].

2.4.2.3 Road user population

The younger drivers do more driving at night while older drivers, particularly those 50 or over, do much less driving at night than during the day [74]. Younger drivers have a much higher accident rate than their elders (there is also an increasing trend for those over 65, but the increase is not nearly as sharp as for those in the younger age group). The disproportionate number of younger drivers on the road at night is probably reflected in the higher night accident rate.

2.4.2.4 Speed and behaviour

Motoring offences, principally excessive speed are more apparent at night. There are many factors which have a great influence on drivers behaviour: less frequent police patrols, lower traffic volume, younger drivers, alcohol, etc. Therefore driving speed and the corresponding severity of accidents increase in darkness.

2.4.2.5 Traffic flow

At low traffic volumes accident rates increase over the fairly constant value associated with higher volumes [77,78]. As was discussed in section 2.3, the volume at night is only about one third or less of that encountered during daylight. Therefore, accident rates might be expected to increase at night because of the generally lower volumes observed.

Hartmann and Linde [79], using freeway data, have shown that at night "catching up" or "rear end" collisions increased for low traffic flows and "queue" or "multiple" collisions increased for high flows, over daylight.

2.4.2.6 Seasons and weather

Accident rates at night appear to be higher than expected at the high end of the traffic volume scale as well as under low volume conditions. This may be due to a time of year factor. During the winter the evening peak hour traffic occurs in darkness. Thus, through much of the world, the period of higher night volumes occurs during periods of inclement weather such as rain, fog, ice and snow, tending to increase accident rates. There are also adverse interactions on visibility due to darkness and weather conditions [80]. It can also be shown that the longer light period in the evenings during the summer months is reflected in a somewhat lower accident rate.

2.4.3 Relative effect of darkness and non visual factors on accidents

Several investigators have tried to isolate the effect of darkness on accidents and exclude the other non-visual factors. Johnson and Tamburri showed that accidents increased between 5 and 7pm on freeways if it is dark (Winter compared to Summer) rather than light. They also indicated that illumination counteracted the effect of the darkness to a large degree. Although the time of day was kept constant and there was a control period from 3 to 5pm (daylight in both time periods), this comparison involved data from very different times of the year, and weather conditions were not controlled [52].

Cameron [81] showed that the accident rate at pedestrian crossings at a particular time of the day is higher if it is dark at the time than if it is daylight. Again the comparison involves data from different times of the year.

The most successful studies of this type have been made in Great Britain. Tanner and Harris [12] examined accidents occurring during the periods immediately before and after the change to and from British Summer Time (BST). This allows the effect of darkness to be evaluated with minimal interference from other factors, because for one or two weeks on either side of the change date there is little variation in weather or traffic patterns. Most hours of the day were either light or dark, but because of the change to or from BST one hour went from being in light to being dark or the reverse. By taking ratios of accidents in the periods immediately before and after the time change in March or October, it was found that, whereas no change occurred in the hours unaffected by the change from light to darkness, it appears that darkness increased the ratio to about 1,5 for all casualty accidents, both in urban and rural areas, and to about 2,5 and 4,5 for pedestrian accidents, in urban and rural areas respectively, see Fig 2.3.

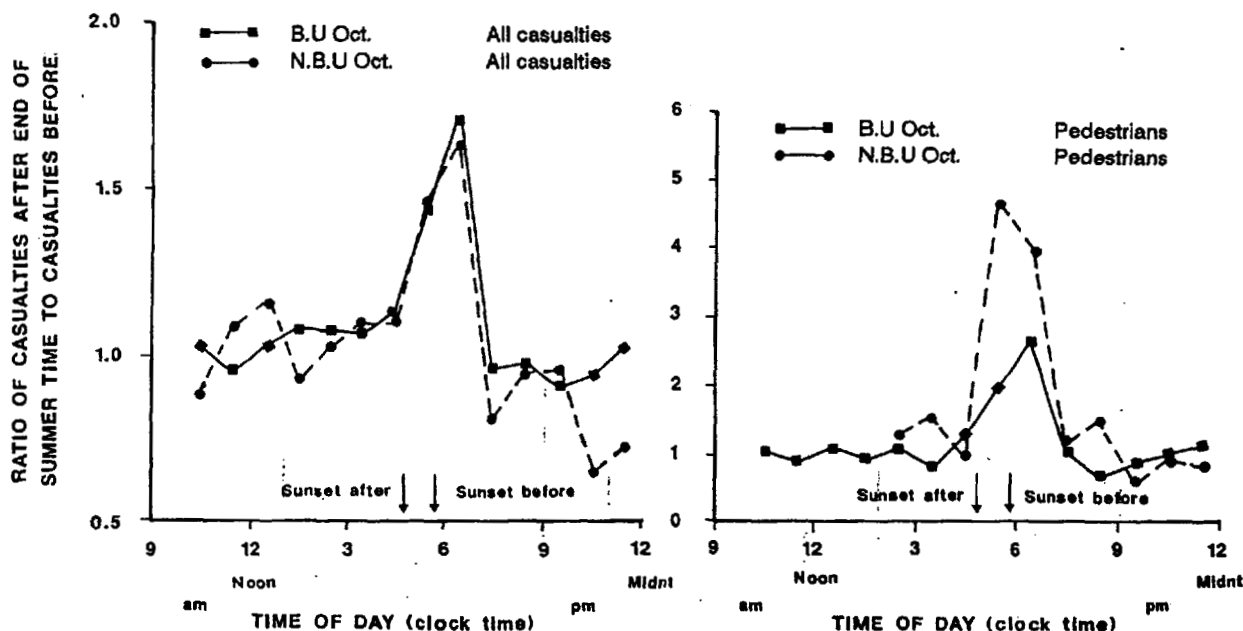


Fig 2.3: Effect of darkness alone on accidents, as shown by changes to and from British Summer Time (After Tanner & Harris, ref 12).

Note: BU is for built-up (urban) areas and NBU is for non built-up (rural) areas. Data for October.

In more recent studies by Green [82] and Broughton [83], the earlier results were confirmed. Green used only accidents occurring on rural roads with speed limits of 50 miles per hour or higher, so that road lighting would not confound the results. For rural roads, the effect of the time change was approximately a 50 per cent increase of injury accidents during dark periods, with fatal and the more serious injury category increasing approximately 100 per cent in the dark environment.

Broughton studied the effect of light on casualty rates in specific half-hour periods during the winter of 1982/3 and 1983/4: these periods change from full daylight to darkness and back to daylight through the winter. It was found that the number of pedestrians killed or seriously injured was on average 80 per cent greater in darkness than in daylight; pedestrian casualties of all severities were about 50 per cent greater in darkness. These increases were less for other road users: about 50 per cent for fatal and serious casualties and 20-30 per cent for casualties of all severities.

It can be concluded with confidence that darkness alone brings about a significant increase in accidents but there are also some non-visual factors involved in elevating the night accident rate.

2.5 COLLISIONS WITH UTILITY POLES

Collisions between vehicles running off the road and utility poles (poles carrying overhead electricity reticulation and/or road lighting luminaires) represent an accident problem of some magnitude [84, 85]. From extensive data on collisions it was deduced that collisions with such poles were implicated in 7.5 per cent of all road crash fatalities on the total road network [85]. A study in the Netherlands [86], based on accident figures for the years between 1968 and 1971, concluded that of all fatalities about 3 per cent in urban areas and about 2 per cent in rural areas result from collisions with lighting columns alone. Another study [87] suggests that on rural roads a row of lighting columns results in a collision risk twice as high as that for all other road-side obstacles together. A further study suggests that twice as many collisions with lighting columns occur at night as during the day.

Thus the installation of road lighting on dedicated lighting columns can introduce a potential safety hazard, both by day and night. The potential safety improvement afforded by the illumination alone can therefore be overestimated. In none of the lighting and accident studies reported in this document, was any attempt made to allow for this factor, if relevant.

It has been shown that collisions with utility poles are not random events but can be predicted from a knowledge of the environmental parameters [84, 88]. These include the road geometry, traffic speed and pole location; for example, it was found that the relative risk of collision falls as the lateral offset of the pole increases, to a minimum for an offset of 3m or greater [88].

The severity of pole collisions can be reduced considerably by the use of frangible lighting columns [84]. These include breakaway and slip base lightweight columns and energy absorbing columns. The benefit/cost ratio accruing from using such columns can be great and can be larger than from other accident countermeasures such as road alignment and anti-skid surface treatments at hazardous sites involving lighting columns. In some instances crash barriers may be effectively used with conventional columns in place of frangible columns.

2.6 ROAD LIGHTING AS AN ACCIDENT COUNTERMEASURE

The details and data of 62 road lighting and accident studies are given in Part 3. In that part the studies are commented upon for reliability and their conclusions are critically re-examined. The conclusions drawn in Part 3 for some studies are different from those of the authors, both in respect to reliability and to the effect of lighting (some authors have overstated and others have understated the effect of lighting).

Later, in section 2.6.2, a summary of these studies and of the effect of road lighting on night accidents is given.

Most studies concern the overall effect of lighting traffic routes, often by the replacement of poor lighting with good lighting: by good lighting is often meant to the national standard in operation at the time. There are very few data relating accident reductions to specific light technical parameters, such as light level, uniformity or glare control.

In addition to the accident reduction data associated with the implementation of lighting, other data are available on changes in accidents associated with the switching out of lighting as an economy measure. However, precise quantitative inferences on the role of lighting as an accident countermeasure are difficult to draw from these studies. Switch-outs are made in a piecemeal fashion and other factors such as overall reduction in road usage and the imposing of a national speed limit have uncertain effects.

The studies pertain only to arterial roads (traffic routes) and have been grouped into three broad classifications, urban arterial roads (non-freeway), rural arterial roads (non-freeway) and freeway/motorways. Beyond this it is not possible to be very specific about the interaction of lighting and accidents with traffic flow, road construction (number of lanes, divided carriageway, frontage land use), weather, etc. Within each grouping there is a great variation of these parameters. Some studies refer to elements of the road such as pedestrian crossings and intersections and these are summarised as separate subgroups. Only one study considers separately the effect of lighting in dry and wet conditions. Where lighting has been implemented for the first time, no allowance has been made for possible effects of lighting columns on both day and night accidents, although methods for doing this are available [89].

Wherever possible the study summary refers to casualty accidents since these are likely to be most accurately reported and have the greatest economic costs. Some studies use all accidents, including property damage accidents, because of the need for sufficient accident data to make analysis meaningful. These studies complement those based on casualty accident data and, of course, the total economic cost of property damage only accidents will not be inconsiderable. There is little specific data on the effect of lighting on accidents by type of road user movement.

It will be seen that there is a generally beneficial effect of lighting as an accident countermeasure. However a few studies indicate a nil or an adverse effect. A number of studies concern data consolidated from multiple sites (which individually would have insufficient data for statistical analysis) and the conclusions that lighting is beneficial refer to the group of sites as a whole. Within the group there may be considerable variation from site to site; for example in the two studies in which such detail was given [11, 90] there was no change or an apparent increase in accidents in 22 and 26 per cent of sites, respectively, after the upgrading of lighting. Thus in arriving at any general value for accident reduction, it should be realised that this will apply to the road network taken as a whole but that within the network there will be variation from site to site.

2.6.1 Methodology

Some of the previous remarks indicate the difficulties inherent in accident studies in general and in road lighting studies in particular. In many areas of research on the effect of conditions on performance, such as is carried out in developing agricultural and medical products, the researcher has total control over the experimental conditions and the variables involved. Usually these are laboratory experiments. Classical experimental design and data analysis can be used, yielding valid and unequivocal conclusions. Consideration of the limitation and restrictions of statistical studies is given in Appendix B.

However, the accident researcher has little or no control over the environment or traffic variables, data being collected as it occurs. In such conditions as prevail in field studies it is difficult to separate and compute the effects of all the factors which might influence accident occurrence, which are often complex and interacting. In order to make conclusions as valid as possible, the researcher must endeavour to make data collection and analysis as rigorous as possible.

The studies carried out may be classified into two main types:

- (i) "surveys" of current lighting and accident rates, by which correlation is sought between the accident risk with the lighting quality (in particular with the absence or presence of lighting).
- (ii) "before and after" studies of changes in lighting, by which it is sought to show that a change in accident frequency is coincident with the change in lighting.

Methods of analysis also vary somewhat. Some investigators have done no more than calculate accident rates for various groups of roads and periods of time. Often the differences between the accident rates in different groups are compared with some estimate of the random variation of accident rates, derived either from observed variations in the data themselves or from theory based on reasonable assumptions about the sort of distribution that accident frequencies follow. Resulting from this, statements about the statistical significance of apparent differences are made. Many apparently large differences in accident frequency have turned out to be insignificant in the statistical sense (indistinguishable from random variation). This is not surprising as the accident sample sizes used in some studies have been so small that even quite large real effects of lighting would be unlikely to be detected.

Survey studies have the advantage in comparison to before and after studies that - in principle at least - a selective type of investigation can be made. When all relevant data are collected (apart from lighting and accident data, also the traffic, the traffic composition and details of the infrastructure, etc.) the relationship between lighting and accidents may be found with all other variables as parameters. In practice, however, this is usually not possible.

The necessary range of data is not generally available since lit roads may be only those with large traffic volumes and multiple lanes, compared to unlit roads. Where multiple parameters are investigated, traffic volume will dominate the other parameters and any effect of the lighting will not be readily apparent.

A limited sort of survey method is sometimes made by selecting one type of road with one type of traffic [10]. The result is, of course, only applicable for those circumstances and cannot be generalised. Sometimes the surveys are very rudimentary: the data from whole city areas are just put together and compared simply with some average value for lit or unlit roads. These studies have only limited value.

Before and after studies are easier to carry out and should, in principle, yield unequivocal results. The results can be complicated by the long time intervals of the before and after periods which must be several years each to allow the growth of sufficient accident data and to compensate for random fluctuations in travel and weather. Such long periods, however, are influenced by changes in general trends, eg. in car ownership, legislation and economy, etc. To a certain extent these trends can be compensated for by establishing a control.

In many of the studies daytime accidents are used as a control or comparison. It is assumed that the various influencing factors will affect both day and night accidents proportionately equally, with lighting being the only additional factor at night. Some studies give traffic volumes against which to offset general accident changes in the study period. Very few studies use other sites, in which the status of the lighting remains the same, as an additional control.

In order to put all studies on the same basis the r statistic has been used in the CIE critical reexamination of the studies, viz:

$$r = \frac{cb}{da}$$

where

a is the number of night accidents before
 b is the number of day accidents before
 c is the number of night accidents after
 d is the number of day accidents after.

The statistical significance of any change is tested using the Chi square test, with the 5 per cent level indicating that the result did not happen by chance. However, the fact that the results did not happen by chance does not necessarily substantiate a causal relationship between reduction of accidents and provision of road lighting. Other factors may contribute to any accident reduction.

However, the studies in this report, which are mainly of the before and after type, do yield largely consistent results. Not on the basis of the merit and the reliability of *all* the individual studies - a number of the studies do show the methodological problems discussed above - but rather because they present an *overall* picture of road lighting as an accident countermeasure.

These results, taken with the reasons given in 2.4.1 for expecting lighting to be an effective accident countermeasure, would suggest that a causal relationship exists between lighting and accident reduction.

2.6.2 Summaries of accident studies

In this section summaries of the accident studies detailed in Part 3 are given. They are grouped under three road classifications: urban arterial (non-freeway), rural arterial (non-freeway) and freeway/motorway. All the information contained in Part 3 has been consolidated so that the scope and results of the studies are presented. If additional information on a study, including comment on its reliability, is required reference should be made to the relevant summary in Part 3.

Each summary is in the following format:

- (i) Scope of studies: to show the number, global distribution and type of studies.
- (ii) Tabulation of results: to show the findings of each study, classified by its type.

Based on the discussions in sections 2.6 and 2.6.1 the following presentation has been used. For studies of the survey type or involving the downgrading of lighting a general effect of lighting on accidents is given, i.e. reduction, increase, no effect or no conclusion possible. For the before and after type study the percentage change in accidents is given. Where the CIE conclusions are quantitatively different a second value is given in brackets. Where a change is statistically significant (5 per cent level) it is followed by an 'S'. The accidents include the classification "all accidents", which covers accidents so designated or where no specific designation has been used; "casualty" includes designations of "fatal and injury", "personal injury", etc.

- (iii) Findings: to show the major findings in the form of short but comprehensive statements. Ranges and means involve the CIE results for individual studies.

2.6.2.1 Urban arterial roads (non freeway) Installation or upgrading of lighting

- (i) Scope of studies

Number of studies: 20

Number of participating countries: 8

Type of study: 6 survey
 14 before/after; 1 individual site,
 13 aggregated sites.



(ii) Tabulation of results

Survey Studies

Study	All Accidents	Pedestrian Only
1	Reduction	Reduction, S
3	Reduction, S	
5	No effect	
10		
13	Reduction	
19	Reduction	

Note: All except study number 13 deal with the effect of increasing light levels on accidents.

Before and After Studies (per cent change in accidents)

Study	All Accidents	Pedestrian Only	Fatality	Casualty	Property
2a	-21			-34S	-10
2b	+40S			-55S	+27
4	-21S	-57S		-29S	
6	-22 (-33S)				
7	(-28)				
8				-33S	
9a				-16	
9b				-17	
11		-46S	-49	-30S	
12				-29S	
15	-9	-16		+33	
16	(-75S)				
17	-16			-48S	+6
18	-32				
20	-10 (-19)	-37 (-48)		-15 (-26)	
21	-34				

(iii) Findings

* Of a total of 21 studies, 20 show lighting to be beneficial, whilst 4 show no or adverse effects.

* For the classification 'All accidents':

10 studies gave reductions; Range -9 per cent to -75 per cent, Mean -29 per cent

3 had statistical significance; Range -21 per cent to -75 per cent, Mean -43 per cent

1 study (also significant) gave an increase; +40 per cent

The ten before and after studies showing reductions are strongly supported by 4 out of 5 relevant survey studies.

** For the classification 'Pedestrian only':*

4 studies gave reductions; Range -16 per cent to -57 per cent, Mean -42 per cent
2 had statistical significance; Range -46 per cent to -57 per cent, Mean -51 per cent

The four before and after studies are strongly supported by the one survey study.

** For the classification 'Casualty':*

9 studies gave reductions; Range -16 per cent to -48 per cent, Mean -29 per cent
6 had statistical significance; Range -29 per cent to -48 per cent, Mean -34 per cent
2 Studies gave increases; Range +33 per cent and +55 per cent

2.6.2.2 Urban arterial roads (non freeway)
Reduced or switching out of lighting

(i) Scope of Studies

Number of studies: 7

Number of participating countries: 6

Type of study: 7 before and after; 2 individual sites,
5 aggregated sites

(ii) Tabulation of results

Study	All Accidents	Pedestrian Only	Fatality	Casualty	Property
22	Increase	Increase		Increase	
23				Increase (S)	
24					
25				Increase	
26				Increase	
27a	Increase			Increase	
27b	No effect			No effect	
28	Increase			Increase	Increase

(iii) Findings

** Six out of seven studies show sustained adverse effects, mostly large, when lighting is reduced.*

2.6.2.3 Pedestrian crossings Installation of lighting

(i) Scope of Studies

Number of studies: 6

Number of participating countries: 5

Type of study: 1 survey;
5 before and after; all aggregated sites.

(ii) Tabulation of results

Survey Studies

Study	Pedestrian Only
31	Reduction

Before and After Studies (per cent change in accidents)

Study	Pedestrian Only
29a	(-74)
29b	(-60)
30a	(-32)
30b	(-59)
32	(-34)
33a	(-46)
33b	(-64S)
34	(-63)

(iii) Findings

*** All studies show lighting to be beneficial**

*** For the classification 'Pedestrian Only':**

5 studies gave reductions; Range -32 per cent to -74 per cent, Mean -54 per cent

1 study had statistical significance: -64 per cent

The before and after studies are strongly supported by the survey study.

2.6.2.4 Rural arterial roads (non freeway) Installation of continuous lighting

(i) Scope of Studies

Number of studies: 7

Number of countries participating: 5

Type of Study: 1 survey

6 before and after; 2 individual sites,
4 aggregate sites.

(ii) Tabulation of results

Survey Studies

Study	All Accidents
35	Reduction

Before and After Studies (per cent change in accidents)

Study	All Accidents	Pedestrian Only	Fatality	Casualty	Property
36a	(-25)			(-40)	(-22)
36b				(-13)	(-24)
37	-75S			(-100)	
38			(-75S)	-38S	
39a				+48	
39b				-53S	
40					
41	(13S)		(-53)	(-19)	(-14)

* All 7 studies show lighting to be beneficial, whilst one shows also an adverse effect

* For the classification 'All Accidents':

4 studies gave reductions; Range -13 per cent to -75 per cent, Mean -37 per cent

2 had statistical significance: Range -13 per cent to -75 per cent, Mean -44 per cent

The beneficial findings of the 4 before and after studies are strongly supported by the one survey study.

** For the classification 'Casualty':*

6 studies gave reductions; Range -13 per cent to -100 per cent, Mean -44 per cent

2 studies had statistical significance: Range -38 per cent to -53 per cent, Mean -45 per cent

1 study gave an increase: +48 per cent

2.6.2.5 Rural arterial roads (non freeway)
Lighting of junctions only

(i) Scope of Studies

Number of studies: 4

Number of countries participating: 3

Type of Study: 2 survey

2 before and after; both with aggregate sites.

(ii) Tabulation of results

Survey Studies

Study	All Accidents	Casualty
43		Reduction (S)
45	Reduction	

Before and After Studies (per cent change in accidents)

Study	All Accidents	Pedestrian Only	Fatality	Casualty	Property
42a				+114	-47
42b	-25 (-26)			-45 (-9)	-22 (-36)
44	-52S (44S)				

(iii) Findings

** All four studies show lighting to be beneficial, whilst one also shows an adverse effect*

** For the classification 'All Accidents':*

2 studies gave reductions; Range -26 per cent to -44 per cent, Mean 35 per cent

1 had statistical significance: -44 per cent

The before and after studies are strongly supported by the one survey study.

* For the classification 'Casualty':

1 study gave a reduction: -9 per cent

1 study gave an increase: +114 per cent

The beneficial finding of the one before and after study is very strongly supported by the one survey study.

2.6.2.6 Freeways and motorways Installation of continuous lighting

(i) Scope of studies

Number of studies: 9

Number of participating countries: 5

Type of Study: 6 survey

3 before and after; all single sites

(ii) Tabulation of results

Survey Studies

Study	All Accidents	Casualty
47	Inconclusive	Reduction
49	Reduction	
50	Reduction	
52	Inconclusive	
53	Inconclusive	
54	Inconclusive	

Before and After Studies (per cent change in accidents)

Study	All Accidents	Pedestrian Only	Fatality	Casualty	Property
46	-57S				
48	-56				
51	-58			-62	

(iii) Findings

* Of a total of 9 studies, 5 show lighting to be beneficial, whilst 4 are inconclusive

* For the classification 'All accidents':

3 studies gave reductions; Range -56 per cent to -58 per cent, Mean -57 per cent

1 had statistical significance: -57 per cent

The three before and after type giving reductions are strongly supported by 2 out of 5 relevant survey studies, the others being inconclusive.



2.6.2.7 Freeways and motorways Reduced or switching out of lighting

(i) Scope of Studies

Number of studies: 4

Number of participating countries: 2

Type of Study: 4 before and after; 2 individual sites,
2 aggregate sites.

(ii) Tabulation of results

Before and After Studies

Study	All Accidents	Pedestrian Only	Fatality	Casualty	Property
55	Increase		Increase	Increase	
56	Increase S				
57	No effect				
58	Increase				

(iii) Summary of Findings

* Three out of four studies show adverse effects (mostly large, with two showing statistical significance) when lighting is reduced.

2.6.2.8 Freeways and motorways Lighting of interchanges only

(i) Scope of Studies

Number of studies: 3

Number of countries participating: 1

Type of Study: 2 survey
1 before and after; with aggregate sites.

(ii) Tabulation of results

Survey Studies

Study	All Accidents
60	Decrease S
62	Decrease S

Before and After Studies

Study	All Accidents	Pedestrian Only	Fatality	Casualty	Property
61	-46 S				

(iii) Findings

* All three studies show lighting to be beneficial.

* For the classification 'All accidents':

1 study gave a reduction: -41 per cent

It has statistical significance

This before and after study is strongly supported by the two survey studies.

2.6.3 Studies on tunnels

Accident literature concerning tunnel lighting improvement is extremely limited. No literature appears to exist from which the benefits of lighting can be assessed. The main problems are the very small number of accidents associated with tunnels in general (they are a small proportion of the total road mileage) and variation in the visibility and geometric/traffic conditions from one tunnel to the next that makes pooling of data difficult, if not impossible. Another problem is that of determining the zone in front of the tunnel where the visual problems are such that the accident should be associated with the lighting of the tunnel entrance.

The one study [62] available suggests that day-time accidents could be reduced by regular maintenance of the tunnel lighting.

2.6.4 Accident reduction and light technical parameters

The discussion of studies so far has been concerned with the general effect of lighting on accidents. The light technical parameters operative in reducing accidents and the nature of the relationship of these parameters with accident rate will be addressed next. This information is needed as an aid in determining working limits to the parameters in national standards and for designing cost effective road lighting installations.

2.6.4.1 The significant light technical parameters

The most comprehensive study on the association of light technical parameters with accident rate is reported by Scott [10]. This study was confined to two-way urban major roads with a 48 km/h speed limit, in dry condition. Most of the installations had luminaires with semi-cut-off light distributions. In all, about 100 lit sites were measured, a mobile laboratory equipped with a television camera and video-recorder being used for this purpose.

The light technical parameters measured were average road surface luminance (L_m), horizontal illuminance on the road along the vehicle axis (E_H), illuminance on vertical plane perpendicular to vehicle axis (E_V), longitudinal road luminance uniformity (U_l), overall road luminance uniformity (U_o), luminance of surrounds (L_s), threshold increment (T_i per cent), and discomfort glare control mark (G). The range of values measured for these parameters is shown in Table 2.1. The accident measure used was the ratio of personal injury accidents in the dark to those in the day. Variations in traffic flow rates are assumed to be random and not related to lighting levels.

Table 2.1 Range of light technical parameters in Scott study (After ref 10)

Lighting Variable	Number of sites	Range of X for 90 % of sites
$L_m / \text{cd m}^{-2}$	89	0,66 to 12,63
E_h / lux	61	0,44 to 20,0
E_v / lux	56	3,7 to 11,7
$L_s / \text{cd m}^{-2}$	75	0,30 to 1,15
U_o	75	0,33 to 0,71
U_l	81	0,22 to 0,66
$T_l \%$	58	6 to 26
G	64	2,7 to 4,7

By using a method of statistical analysis analogous to analysis of variance and regression analysis, but weighting sites according to their respective accident totals, the following results were arrived at:

- i) L_m is strongly related to accident ratio, as it improved the fit to the accident data of almost every model to which it was added.
- ii) L_s , E_h and E_v were also related to accident ratio, though not as strongly or consistently as L_m . They were also related to each other and to L_m .
- iii) U_o is a useful explanatory variable only when used in conjunction with either of the luminance measures L_m or L_s . The coefficient of U_o was positive indicating that the accident ratio increased with increasing uniformity.
- iv) Neither T_l nor G nor U_l were related to accident ratio.
- v) The standard deviation of the luminance of the points measured on a site was not related to accident ratio.

In a study undertaken by Janoff et al [91], a number of light technical parameters (as well as demographic and socioeconomic variables) were related to the number of night accidents per 10 000 night-time vehicles. The parameters were:

- (1) Mean horizontal illuminance (HFC 50)
- (2) 15th per centile horizontal illuminance (HFC 15)
- (3) Mean road luminance (L TRAP)
- (4) Mean visibility index (VI 50)
- (5) 15th per centile visibility index (VI 15)
- (6) Mean dynamic visibility index (DVI 50)
- (7) 15th per centile dynamic visibility index (DVI 15)
- (8) Weighted dynamic visibility index (WDVI)

The visibility index was computed from the physical contrast of a test object on the road, the relative contrast sensitivity of drivers and the disability glare factor of the lighting installation. The object used was a cylinder capped by a hemisphere, the total height being about 1,6 m, diameter 18 cm, and reflectance 18 per cent.

It was found that the most important independent variables, as regards correlation with accidents, were VI 15 and HFC 15. However, this latter correlation was rejected by the authors because the accident total rose with HFC 15, a result thought by them to be counter-intuitive.

A study by Box [92] points in the same direction. He found that after an initial drop in the ratio of night accident rate (per million vehicle miles) to day accident rate (per million vehicle miles) in going from no light to some light (5 lux), there was a rise in this accident rate ratio thereafter with increasing light level. No meaningful relation was found between uniformity of illuminance and accident rate ratio, either by using the average to minimum or the maximum to minimum illuminances. The better accident ratios were associated with the poorer uniformities, but the high correlation between lower illuminance and poor uniformity prevented separate analysis. It was found that the illuminance on a vertical plane facing oncoming traffic

showed a high correlation with horizontal illuminance, as would be expected. Therefore, the lower vertical illuminance averages were also associated with the better accident rate ratios.

2.6.4.2. The form of the relationships

The Scott investigation [10] produced relationships associating the log (dark accidents/day accidents) with each of the four variables L_m , L_s , E_h and E_v . The precise form of the relationships is given in Table 2.2 and Fig 2.4 is a plot of the accident ratio against L_m , the lighting variable showing the strongest association with accident ratio. The scatter of results about the lines of best fit is large, so that the models cannot be used for purposes of precise prediction with any great confidence.

Table 2.2 Relationships between various light technical parameters X and accidents, using the model $\ln(\text{dark accidents/day accidents}) = C + AX$ (After Scott, ref 10)

Lighting Variable X	Constant C		Coefficient A		% change in accident ratio for change of 1 unit in X
	Best Estimate	95 % Confidence Interval	Best Estimate	95 % Confidence Interval	
$L_m / \text{cd m}^{-2}$	-0,42	-0,09 to -0,75	-0,42	-0,13 to -0,17	35
$L_s / \text{cd m}^{-2}$	-0,60	-0,34 to -0,86	-0,39	-0,01 to -0,77	32
E_h / lux	-0,40	-0,12 to -0,68	-0,057	-0,024 to -0,090	6
E_v / lux	-0,24	-0,10 to -0,58	-0,100	-0,048 to -0,152	10

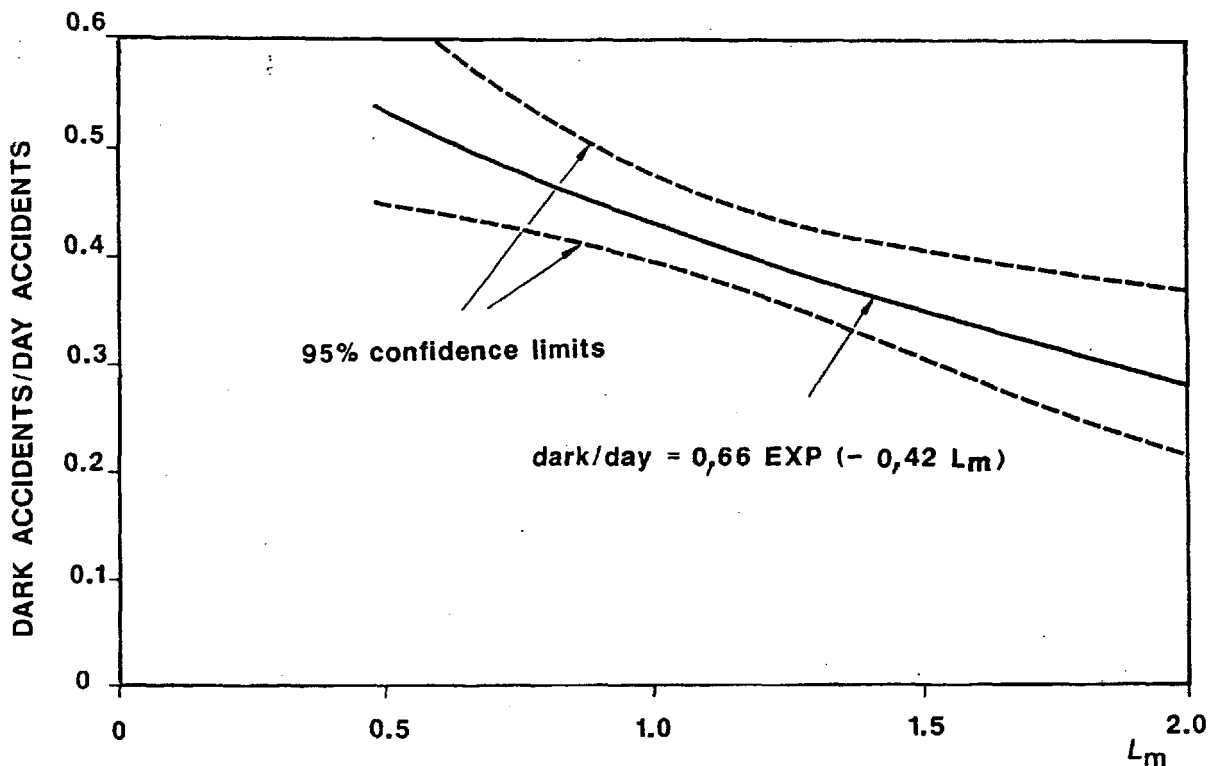


Fig 2.4: Best fitted relationship between dark/day accidents and L_m .

Note: The above applied only to UK urban roads with a traffic speed of 30 mph.

The quantitative decrease of accident ratio with lighting level is supported by the work of Skene [90]. He plotted the ratios of night to day accidents, for both the before and after lighting situations used in a previous study [4], against the amounts of light provided at each site. Owing to lack of on-site measurements, he used the luminaire lower hemisphere flux (LHF) per unit area of carriageway between successive columns (SW) as the criterion of lighting level.

Records allowed light level to be computed before and after the upgrading of each installation. The lighting levels prior to the improvement were in the range 1,1 to 12 lower hemisphere lm.m^{-2} and after 17 to 35 lower hemisphere lm.m^{-2} . He obtained the relationship, shown in Fig 2.5, viz:

$$\text{day accidents/dark accidents} = 1,241 - 0,167 \ln (LHF/SW)$$

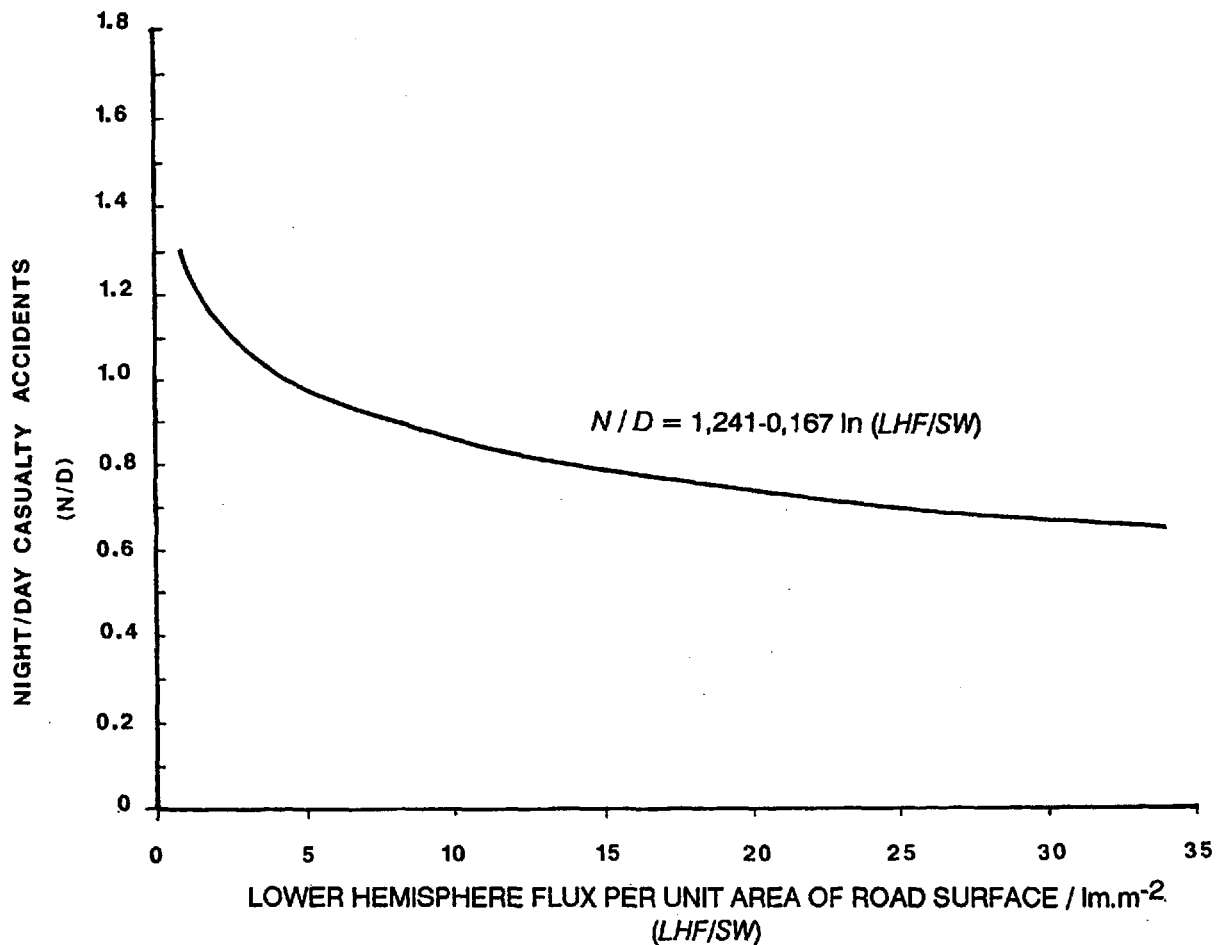


Fig 2.5: Relationship between accidents and road lighting level (After Skene, ref.90).

According to Marsden et al [93] the Australian results predict a 2,5 per cent reduction in accident ratio for a 10 per cent increase in road lighting in the middle of the range. This agrees well with the figure of 2,1 per cent when the British data are translated into Australian terms. At higher and lower lighting levels, there is a divergence, perhaps as a consequence of the higher accident ratios found in Australia.

The work of Janoff et al [91] and of Box [92] on the other hand indicates that under certain conditions the accident rate increases with increase of light level. Box did not attempt to produce a reason for the relationship between accident data and illuminance. Janoff et al produced a relationship which incorporates non-lighting as well as the lighting variables of HFC 15 and VI 15. They found that if HFC 15 is dropped from the equation the validity of the resulting equation is weaker but still significant. They also found that if VI alone is used then all statistical significance is lost.

A great deal has been learned about visibility and lighting since these studies were completed. The reason that Box and Janoff both found negative correlation between accident reduction and illumination level appears to be related to the way the high illuminance level was obtained. Because relatively few sources were available for roadway lighting, higher illuminance levels were obtained by reducing the spacing between luminaires. This did increase the illumination levels, but it also reduced the visibility by decreasing target contrast. If the light distribution and/or source size had been changed, a quite different result might have been obtained.

2.6.4.3 Pedestrian and non-pedestrian accidents

The only study that permits pedestrian and non-pedestrian accidents to be segregated is that of Scott [10]. The analysis was restricted to the three light technical parameters, L_m , L_s and U_o , because only these were considered likely to be of importance and a large number of sites (75) could be used in the analysis.

No relation between accident ratio and these three parameters was apparent for pedestrian accidents taken alone. Only 30 per cent of the total accidents involved pedestrians so that analysis is less sensitive than for non-pedestrian or total accidents. However, for non-pedestrian accidents, the dark day ratio was fitted very well by a linear model involving L_m and U_o : dark accidents/day accidents = $0,5 \exp (1,49 U_o - 0,75 L_m)$

In this model the accident ratio decreases with L_m but increases with U_o , the positive slope for U_o being statistically significant.

2.6.5 Conclusions from accident studies

(i) Scope of Studies

Total number of studies: 62

Total number of participating countries: 15

Type of study: 18 survey
43 before and after.

(ii) Tabulation of Results

In Table 2.3 the figures in each cell give the number of findings for all accident classifications for all the studies for the stated road class. The figures in brackets indicate the number of these which had statistical significance.

Table 2.3 Summary of the general findings of the lighting and accident studies

Road Class	Effect of Lighting								Total
	Survey				Before/After				
	Ben	Adv	NoE	Incon	Ben	Adv	NoE	Incon	
Urban									
Continuous	5(2)		1		26(11)	4(2)			36(15)
Reduced					11(1)		2		13(1)
Pedestrian crossings	1				8(1)				9(1)
Rural									
Continuous	1				15(5)	1			17(5)
Junctions	2(1)				5(1)	1			8(2)
Freeways									
Continuous	3			4	4(1)				11(1)
Reduced					5(2)		1		6(2)
Interchanges	2(2)				1(1)				3(3)
Tunnels				1					1
Total	14(5)		1	5	75(23)	6(2)	3		104(30)

Notes: Effects of Lighting:

Ben = Beneficial

NoE = No Effect

Adv = Adverse

Incon = No conclusion can be drawn.



Documents

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(iii) Findings

* Out of 104 results 89 indicated lighting to be beneficial in reducing accidents; of these 28 showed statistical significance.

* Only 6 results indicated adverse effects of lighting, with 2 showing statistical significance.

* Of the results indicating a beneficial effect, 84 per cent came from the before and after type study, and of these 31 per cent showed statistical significance.

The results indicating lighting to be beneficial outweigh those indicating an adverse effect by an order of magnitude, for both results showing statistical significance or not. Even if the beneficial results are compared to all other results together they are still in an impressive majority of 6 to 1; the comparison involving only statistically significant results still shows an order of magnitude difference.

It can therefore be expected that good quality lighting will be beneficial when installed over an arterial road network. The numerical value of the benefit to be expected is summarised in Table 2.4. For each road class the first line gives the details of results which have statistical significance and the second line gives details of all results, both only from the before and after studies on implementing or upgrading lighting on traffic routes.

Table 2.4 Summary of the benefits of lighting (per cent change in accidents)

Road Class	Accident Classification								
	All Accidents			Pedestrian			Casualty		
	Sample	Range	Mean	Sample	Range	Mean	Sample	Range	Mean
Urban									
Continuous	3	21 to 75	43	2	46 to 75	51	6	29 to 48	34
	10	9 to 75	29	4	16 to 57	42	9	16 to 48	29
Pedestrian crossings				1		64			
				8	32 to 74	54			
Rural									
Continuous	2	13 to 75	44				2	38 to 53	45
	4	13 to 75	37				6	13 to 100	44
Junctions	1		44				0		
	2	26 to 44	35				1		9
Freeways									
Continuous	1		57				0		
	3	56 to 58	57				1		62
Interchanges	1		43						

The table shows that the average reduction in accidents is at least 30 per cent, since this value is exceeded in each cell for which there are statistically significant results. The non significant results support this conclusion, with of course further support from the survey and lighting reduction studies, not included in the table.

However the ranges of values are somewhat large. Thus a single and conservative value of 30 per cent, being closer to the lower end of the ranges, could be adopted.

If a single composite value is deemed to be inappropriate for the purpose of cost/benefit analyses and feasibility studies then a figure within the range given in Table 2.4 should be selected for a particular application. If local data are available this should be used.

Little can be said definitively about the relationships between accident reduction and the individual light technical parameters. It appears that accidents decrease with increasing light provided in an installation or with increasing average carriageway luminance. There is a diminishing return but the level of lighting at which there is no further reduction in accidents may be several times higher than those used in current national standards.

As a corollary, and with reasonable supporting evidence from lighting studies concerning the switching off of lighting as an economy measure, the reduction or switching out of lighting has an adverse effect on safety.

There is some evidence that if uniformity is too great, the accident benefit associated with a particular light level may be reduced.

2.7 Costs and benefits of road lighting

Although road lighting can be expected to reduce accidents, this does not immediately imply lighting to be a cost effective accident countermeasure. For this to be so the accident savings, in monetary terms, have to be greater than the capital and running costs of the lighting, over the life of the installation.

The principles of cost benefit analysis, their application to road lighting and some results of this are given in detail in Appendix A.

Lighting on arterial roads can more than pay for itself in accident savings. Lighting is justified on urban arterial roads (non-freeway) if the night casualty rate is about one per kilometre per year or if the average annual daily traffic (AADT) exceeds about 10 000 vehicles. For freeways and motorways these warrants would be somewhat higher.

PART THREE

DETAILS AND ANALYSIS OF ROAD LIGHTING AND ACCIDENT STUDIES

Part Three contains the details and data of individual lighting and accident studies. It is a comprehensive presentation meant for those closely associated with data collection and analysis.

3.1 ARTERIAL URBAN ROADS (NON FREEWAY)

INSTALLATION OR UPGRADING OF LIGHTING

(Studies 1-21 inclusive)

SUMMARY OF STUDY NO. 1

Title: Traffic Accident Measures.
Author: J D Thorpe.
Publication: Journal of the Institution of Engineers (Australia) Vol. 35 (i) March 1963.
Site Details: 184 miles of metropolitan streets in Victoria.
Methodology: The standard of lighting on 184 miles of roads was classified in three groups and accident records were examined to see whether the lighting standard affected the night/day accident ratio.
Traffic Details: No details given.
Lighting Details: Lighting standards varied from less than 40 to over 60 lumens per linear foot of street.
Results: Variation of night/day accident ratio with variation in standard of street lighting.

Standard of Lighting	Length of Street (Miles)	Night/Day Accident Ratio (All Accidents)
Good - Central Business District Area (over 60 lumens per linear foot of street)	11,9	0,32
Good - ex CBD area (over 60 lumens per linear foot of street)	55,2	0,57
Fair - 40-60 lumens per linear foot of street	31,5	0,69
Poor - less than 40 lumens per linear foot of street	85,2	0,65

Statistical Test: Because no account was taken for different road and traffic characteristics no attempt was made to determine the statistical significance of the results.

Author's Conclusions: The results appear to validate studies by Tanner (1958) and Turner (1962) but there is no guarantee that the traffic characteristics of all streets are the same. If streets with different lighting standards had different traffic characteristics at night the trend indicated could be misleading.

CIE Comments: Survey method; all accidents used, no matching of road geometry and vehicle flows between lighting groups.