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The Causation of Bus Driver Accidents

Cresswell and Froggatt

Nuffield Provincial Hospitals Trust

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Bus Driver Accidents

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The Causation of Bus Driver Accidents

The term 'accident proneness' is widely used although few understand its precise meaning. It was coined by psychological research workers in 1926, and since then its concept—that certain individuals are always more likely to sustain an accident than others, even though exposed to equal risk—has seldom been seriously challenged.

The present book, which contains the results of an exhaustive investigation into the road accidents incurred by bus and trolley-bus drivers in Northern Ireland over a period of four years, presents an alternative hypothesis which is considered to be more realistic in the context of road accidents. In this new model of accident causation every driver is assumed subject to 'spells' during which he is more liable to accident. The authors speculate that a 'spell' may be associated with temporary factors, such as domestic worries or ill-health, which can be imagined to lead to impaired efficiency. This model, unlike the theory of accident proneness, also allows for the occurrence of accidents primarily due to other road users. This is important because a driver is not always to blame for every accident in which he is involved.

After subjecting the data to statistical analysis and conducting clinical examinations of certain drivers, the writers conclude that the validity of the concept of accident proneness is more than doubtful.

Two additional findings were (1) that the accident rate tended to increase with the onset of old age, and (2) that the accident rate was high in the first year or so of driving even after training. If either or both of these held for the general population it would constitute a serious problem in accident prevention. Suggestions are made for further research on these and related topics. The book also contains reviews of the relevant literature and an extensive bibliography.

Throughout the book the authors have attempted to conform to a strict scientific discipline. As a result some of their methods require the use of statistical techniques which may not be familiar to all readers. As far as possible only those statistical methods which are commonly used in epidemiology are employed within the main text. Details of the more complex methodology, including some work presented for the first time, are confined to a separate section. Much of the raw data are published (in an Appendix) in order to allow other workers to apply these theories and to compare the findings with their own results.

Price 45s Net

The Causation of Bus Driver Accidents

An Epidemiological Study

The Causation of Bus Driver Accidents

An Epidemiological Study

by

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Preface

The term 'accident proneness' was coined in 1926; since then it has enjoyed wide currency in both medical and lay press. Its basic connotation, i.e. that some individuals are at all times more likely than others to sustain an accident even though exposed to equal risk, has been questioned but seldom seriously challenged. The principal theme of the present work is a comparison between the concept of accident proneness and an alternative hypothesis in terms of their respective abilities to explain the accident experience of bus drivers in Northern Ireland.

Throughout, we have attempted to conform to a rigorous scientific discipline. As a result some of our methods demand the use of statistical techniques which may not be familiar to all readers. As far as practicable only those statistical methods which are commonly applied to epidemiological problems are employed within the main text; the more complex techniques are confined to a separate section between the main text and the Appendix.

This book is divided into five sections. Section 1 deals with the collection of the data and the delineation of the experimental populations. Section 2 is concerned with the formulation and comparison of the hypotheses under test. Section 3 comprises a general exposition of various ideas concerning accident causation, suggestions for further research, a summary, conclusions, and a full bibliography. Section 4 contains information relevant to those theoretical distributions which are currently fashionable in the investigations in the literature concerned with the distribution of multiple events. It also contains the derivation and properties of two further theoretical distributions, one of which is presented for the first time. Work which is not fundamental to the comprehension of the argument but which is likely to be valuable to certain readers, is relegated to the Appendix (Section 5).

As far as possible, in each chapter a review of the literature is presented *before* the results of the present study. We have frequently quoted literature *in extenso*. We have done so because it is abundantly evident that many investigators have misconstrued the content of some basic studies, and we consider it prudent to follow Ruskin's

advice (Sesame and Lilies, 1, §13): 'Be sure that you go to the author to get at *his* meaning, not to find yours'.

This investigation would have been impossible without the co-operation of many persons and organisations. In gratefully acknowledging our indebtedness we recognise that the following are only a few of the many who gave advice and help.

The Nuffield Provincial Hospitals Trust met the entire expense incurred. The managements of the Ulster Transport Authority and Belfast Corporation Transport, and the officials of the Amalgamated Transport and General Workers' Union, the National Union of General and Municipal Workers, and the Ulster Transport and Allied Operatives' Union, welcomed and facilitated the enquiry. Dr. J. R. Nelson, Messrs. H. Montgomery, F. W. Young, H. Wallace, J. C. McClelland, K. Thornton, Miss P. A. Lavery, and many others too numerous to mention, helped to collect data and to organise the interviews. Dr. Peter McEwen, Dr. Beatrice Lynn and Mr. A. E. Barbour helped to plan the clinical investigation and to evaluate some of the results. Professor J. G. Gibson, Dr. D. Russell Davis and Dr. Alastair Heron gave much useful advice on 'measures' of personality. Mr. L. H. C. Tippett advised on the statistical treatment of some of the data, and Mr. R. L. Moore, of the Road Research Laboratory, supplied the Prague data of Křivohlavý. Professor J. Pemberton facilitated the investigation in many ways, and we are particularly indebted to Dr. L. G. Norman for his encouragement. Dr. J. C. Stutt, Industrial Medical Officer to Belfast Corporation, kindly placed the amenities of his department at our disposal, and the high esteem in which he and his staff are held played an important part in obtaining the co-operation of those drivers who attended for interview.

Dr. J. A. Smiley conceived and initiated this study and was the author of some of the ideas on which our concept of accident causation is based. Throughout this enquiry Dr. Smiley was always ready with encouragement and counsel, placing at our disposal the knowledge gained from his wide experience in the field of accident study. He and Professor D. C. Harrison shouldered the burden of reading the drafts, and we are indebted to both for the many constructive suggestions that they offered.

We owe a particular debt to the Nuffield Provincial Hospitals Trust and to The Whitefriars Press Ltd., who in every way facilitated the progress of this work to publication. Finally, we are grateful to the many drivers who, often at considerable inconvenience to themselves, attended for interview; without their co-operation this work would have been incomplete.

We gratefully acknowledge the courtesy of the following for permission to reproduce certain data the provenance of which is given in the text or under the appropriate table.

The Controller of H.M. Stationery Office.
The Medical Research Council.
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The Biometrika Trustees.
Royal Statistical Society.
The American Psychiatric Association.
Dr. Sauli Häkkinen.

We are indebted to Sir Ronald A. Fisher, F.R.S., Cambridge, and Dr. Frank Yates, F.R.S., Rothamsted, also to Messrs. Oliver and Boyd Ltd., Edinburgh, for permission to reprint part of Table No. XXII from their book 'Statistical Tables for Biological, Agricultural and Medical Research'.

Little is known about the causation of accidents. We hope that this contribution to the literature on the subject might stimulate other investigators to try to unravel the tangled skein of accident epidemiology.

W. L. C.
P. F.

March, 1963

Contents

Introduction

During the last hundred years road accidents have increasingly attracted public attention. The reason is not hard to understand. In 1840 nearly 800 persons were killed by 'coaches, carriages, wagons and carts, etc.' in England (Registrar-General, 1846), a crude death rate of 0·05 per 1,000 population. In 1896 the first deaths due to a motor-car were registered (Registrar-General, 1896), in 1902 those due to a motor-cycle (Registrar-General, 1902), and in 1959 over 6,000 persons lost their lives, and over 300,000 persons were injured, on the roads of Great Britain (Monthly Digest of Statistics, 1960), a crude death rate of 0·13 per 1,000 population. But the interest aroused has grown out of all proportion to the comparatively modest increase in the death rate. In the eighteen-sixties although road deaths were of sufficient consequence to be specified by William Farr in his annual 'Letter' to the Registrar-General, 'where [in the streets of London] children, women, old people and even vigorous men are killed weekly by horses and carriages of various kinds' (Registrar-General, 1865), they were not a widely debated topic, but by the nineteen-fifties their every facet inspired scrutiny, and the magnitude and urgency of the problem are recurrent themes in both medical and lay press. Certainly there are adequate grounds for concern. During the period of the present study (1952–1955) motor vehicle accidents, although a relatively infrequent cause of death in adult females, ranked about ninth for major causes of death in males in the 20 to 64 age group, and if the figures are considered from the aspect of 'working years lost', as suggested by Dickinson and Welker (1948) and discussed by Haenszel (1950), they assume an even greater significance (Table i.1). In fact it is in the second and third decades of life that road accidents reap their grimmest harvest; since 1951 in England and Wales, and 1952 in Northern Ireland, they have ranked consistently first in males among the causes of death, (as classified on the Intermediate List (W.H.O., 1955)), and third in females, in the age-group 10 to 30 years.

Accidents were formerly presumed to be fortuitous events or the manifestation of some unpropitious deity: 'Desine fata deum flecti sperare precando' (Virgil). Later, although industrial accidents were considered the inevitable price of mechanisation, and improved

Table i.1 *Six of the Ten Leading Causes of Death in Males Aged Twenty to Sixty-four Years, and which have Approximately Similar Crude Death Rates*

Cause of Death (with International Classification)	*No. of Deaths of Men aged 20–64 (1949–1953)*	*No. of Working Years Lost*
Vascular lesions of C.N.S. (330–334)	29,869	274,355
Pneumonia (490–493)	13,064	150,763
Hypertension (440–447)	12,572	119,415
Chronic Rheumatic Heart Disease (410–416)	10,941	180,470
Suicide (E963, 970–979)	10,149	176,713
Motor Vehicle Accidents (E810–835)	9,471	250,425

Source: Registrar-General's Decennial Supplement 1951, Part II, p. 21. A death in age group 20–24 is counted as 42·5 working years lost, i.e. 65–22·5, and similarly for other age groups.

protection the prime desideratum of prevention, their allocation to human beings at risk was reckoned analogous to the throwing of a six or the dealing of an ace: 'On ne peut donc pas douter que la loi des grands nombres ne convienne aux choses morales qui dépendent de la volonté de l'homme, de ses interêts, de ses lumières et de ses passions, comme à celles de l'ordre physique' (Poisson, 1837). The abnormal industrial conditions of the First World War were associated with an increase in the accident rate in many branches of industry, and suggested to some that the personal factors of impaired efficiency and fatigue, assumed at that time to be purely physical phenomena, could have an adverse effect upon safety. This suggestion together with his experiences on the Committee of the War-time Flying Service (Greenwood, 1927), prompted Greenwood to reappraise the theory of accident distribution. Briefly, his work (Greenwood and Woods, 1919; Greenwood and Yule, 1920) suggested that accidents were not entirely chance events, and he speculated that human characteristics might play a role in their causation. To explain this observation the concept of 'accident proneness' was introduced by the psychologists Farmer and Chambers (1926), and subsequently it has enjoyed wide acceptance. This concept is examined in greater detail later, but broadly it implies that all men are not equally likely to incur an accident even if exposed to identical risk, and that this is because of differences in 'personal factors'. It further infers (Farmer and Chambers, 1939) that the population can be divided into two classes on the basis of whether they are accident prone or not, or at least can be ranked in terms of the degree of accident proneness.

Accepting this thesis implies accepting its corollaries, viz. that the accident prone individual can be identified with some certainty, and his removal from the population at risk must reduce the overall accident rate. It is argued later that up to the present this thesis has not been established as valid and its corollaries have never been convincingly demonstrated; but being plausible it readily became accepted. To produce corroborative evidence some investigators were tempted to draw conclusions which their data hardly justified: 'By using the accident records for two four-week periods it was found that the 17 workers who had the highest accident record during the first period had 2·5 times as many accidents as a similar number of workers who had the lowest record during the first period. This finding, when considered with the frequency of personal accidents noted in this group would suggest that the accident tendency is a lifelong characteristic, and it appears to invade all aspects of life. Those who have most accidents at work also have the greatest number away from work' (Wong and Hobbs, 1949).

Nevertheless, on a practical basis a valuable advance in accident prevention would be made if a valid technique could be evolved which would enable individuals, liable to incur an undue number of accidents, to be identified and removed from hazardous occupations. The following table (Table i.2)—due to Adelstein (1952)—shows the accident rate of a group of 104 shunters, and also of the 'remainder', i.e. those who would remain if the 10 men who incurred the most accidents in the first year had been removed from the group over the entire period. This suggests that accident proneness (assuming that it exists) may not be a constant factor, and that inferences should be made with caution from results based on a short period of observation.

Meanwhile more radical views of accident causation were being promulgated. Jones (1933) wrote: 'Probably four-fifths of the terrible death roll on our roads comes about in the same way, by the driver's unconscious interfering with his doing the right thing

Table i.2 *The Effect of Removing the Shunters with the Highest Accident Rate in the First Year (Mean number of accidents per man)*

Population	*Year*		
	1st	*2nd*	*3rd*
Whole Group	0·56	0·36	0·32
Remainder	0·39	0·36	0·33

Re-cast from ADELSTEIN (1952): 'Accident Proneness: A criticism of the concept based upon an analysis of shunters' accidents', *J. R. statist. Soc.* (series A), **115,** 354–410.

in an emergency'; and many psychologists concurred with Adler's (1941) verdict: 'We know from experience that suicidal persons usually have a revengeful attitude toward someone whom they want to punish through their suicide. In these workers we may therefore consider accidents as something like a substitute for suicide.' These, and other, opinions formulated from personal and clinical experience, generally have not exercised the same influence on accident studies as those supported by mathematical theory.

In 1951 Arbous and Kerrich (1951) remarked '. . . it is a very unfortunate but real fact that our knowledge of this concept [accident proneness] has hardly proceeded further, and in some respects has suffered a reverse, from the time when Greenwood, Woods, Yule and Newbold undertook their classic studies in 1919 and 1926'. A further study of the incidence of accidents among a population at risk, and a reappraisal of the concept of accident proneness, therefore seem timely. Briefly, it is proposed to investigate whether the distribution of accidents among a population of drivers equally exposed to the risk of incurring an accident during a specified period of time is such as can only be reasonably ascribed to constant personal differences between drivers, which, for example, exist independently of such variables as age and experience. The essential steps in such a study are the following.

1 The definitions used must be precisely stated.
2 Ascertainment of accidents must be reasonably complete; i.e. the investigator must be satisfied that the great majority of the

accidents incurred were detected and allocated to the appropriate driver.

3 The routes over which the men drove must be grouped in such a way as to ensure that all drivers within each sub-group can be reckoned as being equally exposed to the risk of incurring an accident.

4 The incidence of different 'types' of accident incurred must be examined to see if drivers who sustained an undue number of one type were also likely to incur an excessive number of any other type.

5 Any effect on the accident rate due to the variables of age and experience must be identified, and the population subsequently appropriately restricted to ensure relevant homogeneity.

6 The theoretical distributions most commonly compared with accident frequency distributions should be discussed in detail, because an appreciation of their genesis is fundamental to any critical consideration of hypotheses of accident distribution.

7 If the accepted hypotheses are either inapposite or found wanting in the specific investigation, alternative ones must be formulated and tested using the presented data.

It has been possible in the present instance to formulate two such coherent hypotheses and to derive the associated theoretical distributions. The respective abilities of one of these hypotheses and the generally accepted concept of accident proneness, to explain the data derived in the present study, are evaluated in Chapters 5 to 9.

Ten years ago during the discussion on Adelstein's (1952) paper on accident proneness read to the Royal Statistical Society, van Rest (1952) commented: 'It is now over thirty years since Greenwood and Woods, Yule and Student published their papers which brought in this new idea of the negative binomial. Yet we seem to have made little advance in our knowledge of accident causation. I cannot avoid the conclusion that we need some radically different approach.' It is hoped that the present work makes some contribution towards a new approach to the problem, utilising for this purpose the records of two large Road Transport Authorities, namely the Ulster Transport Authority (U.T.A.) and the Belfast Corporation Transport (B.C.T), which between them comprise the entire public road transport system of Northern Ireland.

Section 1

Chapter 1 Definitions and Data

a The Problem of Definition

Adelstein (1952) wrote: 'The statistical approach [to the study of accident distribution] is to observe a group of persons equal, as far as possible, in all relevant respects and exposed to the same essential conditions for a period of time.' These requirements though rigorous are fundamental; failure to comply with them is a feature of many accident studies and has been too seldom criticised. However, formulating adequate criteria presents formidable problems; these are now discussed.

Exposure to Risk

In the above quotation Adelstein clearly implied that there must be no difference between the accident records of the individuals in a group which could solely be attributed to disparity in exposure to the risk of incurring an accident. Such differences most frequently arise when some drivers travel over more hazardous routes, cover a greater mileage, or spend more hours at the wheel than their group colleagues. Häkkinen (1958) comments: 'Due regard has not often been paid to the homogeneity of the risk and the period of exposure. The accident rates should not form the starting point because clearly accident rate and risk will be correlated.' To achieve such homogeneity is imperative but is in fact one of the most obdurate problems in accident investigation. Some workers simply ignore it, others underestimate the importance of its solution. In order to calculate a convincing 'exposure to risk' index due allowance should be made for possible differences in route hazards, time of day of duty, make of bus, hours at the wheel, weather conditions and other variables, because any of these might affect the driver's risk environment. Some factors, viz. weather conditions, can be ignored when each driver works in the same locale because it is assumed that they affect all drivers equally over the period of study; some, namely hours at the wheel and make of bus, have it is hoped been adequately considered in this investigation; but differences in exposure arising from diverse routes or times of duties present a more fundamental problem. Häkkinen's approach was to calculate the number of accidents per driver year on each route, and, finding that over 85 per cent of the driving was over routes on which the accident rate varied between 1·1 and 1·7 accidents per driver year, he concluded, 'thus the influence of the differences between the lines could not have been very decisive, even if the drivers would have driven mostly on only one line or on lines with equal risks, which, however, was not the case'. Smeed (1960) rightly questioned this assumption. Häkkinen proceeded to calculate a risk index for each driver based on the number of accidents, the 'accident coefficient' of the line (route), and the length of time driven on the line, a method similar in principle to that employed by Whitfield (1954) with colliery workers. To carry this reasoning to its logical conclusion would have involved the application of similar indices calculated for time of day, day of week, and other measurables influencing exposure to the risk of accident.

In the present study drivers' duty rotas were not constant for each driver over the period, e.g. a man may have driven 'early' or 'late' duties during the week and 'spread-over' duties at the week-end, or *vice versa*; he may have driven 'early' one week and 'late' the next; he may have driven different duties on overtime from his normal duties; he may have changed his duties regularly; he may have worked on his day off, etc. He may in fact have varied his environmental exposure in a bewildering number of ways any of which could have affected his actual exposure to risk. Only the basic number of hours of duty per week was uniform. To regularise the data thoroughly for these factors may have been theoretically advisable but in practice impossible. In the Belfast Corporation Transport detailed duty sheets are not available for years previous to the preceding year; precise indices of 'risk' could not therefore be retrospectively computed. What could be done was to estimate the accident rate for each route, pool routes with similar rates, and postulate that the duty changes within each group were so frequent and varied that they precluded any driver from contributing unduly to a route by reason of consistent driving over it. This approach is further validated by the fact that after trams finally became obsolete in February, 1954 (during the period of study), the basic duties of most drivers were altered. The data from the Ulster Transport Authority presented an exactly similar problem but in this instance only populations with approximately equal accident rates were pooled. Route analysis together with detailed comment on method appear in Chapter 2.

The Connotation of 'Accident'

All acceptable definitions of 'accident' must contain the essence of the following: 'In a chain of events each of which is planned or controlled, there occurs an unplanned event which, being the result of some non-adjustive act on the part of the individual (variously caused), may or may not result in injury' (Arbous and Kerrich, 1951). It is at once evident that what one normally ascertains as an accident, viz. personal injury and/or material damage, is in fact the *outcome* of an accident, and if either is used as the criterion the investigation becomes a study of the incidence of injury or damage and not of accident as defined; and that 'near-misses' (so-called), which are not normally ascertainable, are embraced by the definition. Retrospective records relate only to injury or damage, and to overcome this apparently insuperable obstacle two suppositions must be made. The first is, that the outcome of an unplanned event is chance determined; the second, that the probability of ascertaining injury or damage is independent of its severity or extent.

To attempt to validate the first supposition two arguments can be used, namely statistical 'proof' and logical argument. The former involves presenting significant correlation coefficients between types of accident, e.g. between major and minor as they may be defined, or between those in different environments, e.g. at work or at home. The inference would then be that individuals exposed to risk were as likely to incur a serious as a trivial injury and that this was true for all environments. By extension of this argument the conclusion can be reached that chance alone decides whether the result of an unplanned event, or 'accident', is injury (or damage) or not. Resort to such dubious reasoning can be conveniently avoided on the very practical ground that, certainly until Adelstein's (1952) paper, no such significant correlation coefficients based on wholly acceptable data had been published. Adelstein's results are discussed in detail in Chapter 3.

The second argument advanced to establish that the outcome of an unplanned event is chance determined, is based either on an analogy with the axiom that, for example, the result of the throw of a die is independent of the height of the stakes, or on reasoning from pre-suppositions. The following extracts are selected for illustration:

'The law of distribution will not in general be affected by the consequences attaching to the results. The number of sixes thrown with a pair of dice in an hundred trials will not be affected by the height of the stakes. Hence if we are warranted in referring the distributions here discussed to the factor of individual susceptibility, we can have no hesitation in thinking that the same principle may apply to the genesis the results of which whether to the individual or the plant may be grave' (Greenwood and Woods, 1919).

'We look on them [minor accidents] rather as some measure—inadequate though we know it to be—of a vague quality which we will examine more closely as we go on and which we will call 'tendency to accident'. Such a tendency leads to certain events: in 99 cases out of a 100, say, the consequences of these events may be of little or no importance, in the hundredth they may be disastrous, hence the seriousness or triviality of the consequences bears in general no relation to the exciting cause' (Newbold, 1926).

'Moreover, from a psychological point of view an accident is merely a failure to act correctly in a given situation, and the relative gravity of the result of such a failure must be regarded as irrelevant, except in so far as fear of (or indifference to) the consequences may influence the action leading to an accident' (Farmer and Chambers, 1926).

'The gravity of an accident depends largely on chance circumstances—for example, the part of the body injured—so that naturally any peculiarities in the distribution would be common to both major and minor accidents' (The Personal Factor in Accidents, 1942).

Even accepting Irwin's (1952) reservation that the point at issue in Greenwood and Woods' (1919) argument is whether the possible consequences of an accident will affect the prior actions of all workers in an equal manner, in accident studies the analogy of the dice is not well chosen. The possible consequence of an accident, or previous accident experience, may affect the prior actions of an operative, and the effect of the danger level will likely vary according to the individual. Since Adelstein's (1952) results are equivocal the conclusion must be drawn that published work has failed to demonstrate convincingly that the outcome of an unplanned event in this context either is, or must necessarily be, chance determined. In this context the first supposition has failed to be justified.

If the second supposition can reasonably be accepted, namely that the probability of ascertaining injury or damage is independent of its severity or extent, then the problem posed by failure to ascertain 'near-misses' can be ignored and an alternative definition of accident adopted in which injury or damage forms the criterion. For this a reliable ascertainment of 'minor' accidents is a desideratum, but this poses a problem fundamental to all accident studies; since reporting injury or damage is often a subjective decision then a confusion may arise between the *tendency to report* and the *tendency to have* accidents. This fact was recognised by the pioneer investigators: 'But the nervous or ultra-careful woman may, for various reasons, report accidents which the average woman would disregard altogether' (Greenwood and Woods, 1919). Its implications to data derived from industrial records are clear although too seldom stressed. For broadly similar reasons police records, and accident claims by private licence holders on insurance companies, two widely used sources of data, may yield unreliable indices of accident experience, a point put succinctly by Johnson and Garwood (1957): 'It is the liability of policies to claims rather than drivers to accidents that has been studied'. But in the present investigation, invalidities associated with this phenomenon or attributable to incorrect allocation of an accident to a driver, would seem negligible because of the rigorous inspection systems in operation and the fact that few accidents to a bus can be visualised which mark neither bus nor victim. Upon relinquishing his bus at the depot each driver was allowed fifteen minutes of paid time to complete a Daily Report and Signing-Off Sheet stating details of its condition; the foreman then examined any bus stated as damaged or in any way unsatisfactory. Every vehicle was routinely examined the following morning by its prospective driver who was allowed fifteen minutes of paid time to perform this duty. If a driver accepted a bus even at duty change in the street, it became his responsibility. All accidents which marked a bus were easily discovered; in fact less than three per cent were unreported, and these were energetically and usually successfully traced to the appropriate driver. Non-reporting carried the severe penalties of disciplinary suspension or dismissal. In this study the second supposition can therefore with reason be accepted.

The Resultant Population

To ensure valid data the population selected comprised exclusively drivers in constant employment over the entire period of study. It is therefore a selected one, and although some of the selection pressures are obvious others are subtle, and the direction and degree of the resultant bias are not always easy to estimate. Apart from self-selection *before* employment and imposed selection *at* pre-employment interview and medical examination, the principal selection pressures fall naturally into five groups.

1 The employer may transfer to 'safer' tasks a driver who incurs more accidents than his fellows, or alternatively he may dismiss him.
2 A driver may leave voluntarily because of the number or severity of the accidents he incurs.
3 Accidents themselves may cause death, disabling injury or periods of incapacity.
4 Common factors may exist (quite apart from the actual accident rate) which make a driver more liable to incur an accident and at the same time more likely to change his employment fairly frequently.
5 A driver may be excluded from driving for a greater or shorter time on purely medical advice, or as a disciplinary measure.

In both organisations from which the present data were obtained all these factors undoubtedly operated, self-selection out of employment being substantial and often after training was completed and a Public Service Vehicle (P.S.V.) licence obtained. Exact figures were not available but the overall 'turn-over' of drivers was at times as high as ten per cent per annum. It would be relevant to the problem of road accidents in general if certain comparisons could be made between drivers who were employed but subsequently discarded for one or other of the above reasons, and those who remained in continuous employment. Adelstein's (1952) data suggested that 'the shorter the period a group is destined to stay at work the higher its initial accident rate'; but in the present investigation the selection and follow-up of an adequate sample of drivers who left employment was impracticable. In any case the selected bus driver population was certainly unrepresentative of the general population driving during that time.

The definitions adopted in the current study are now stated. Accidents include all those reported as occurring when the driver was in charge of the vehicle, but excluding those to passengers or conductor inside the vehicle or in the act of boarding or alighting, and excluding those to a stationary untended bus. The driver populations at risk comprise those men who were in continuous employment throughout the period of the study (1952–1955) and who were not absent owing to certified sickness for more than ten weeks in either two-year sub-period 1952–1953 or 1954–1955. Further necessary restrictions on the populations were imposed for some of the analyses. On occasions data for 1951, 1956 and 1957 are presented. The field under review concerns the incidence of accidents among Ulster Transport Authority (U.T.A.) bus drivers and Belfast Corporation Transport (B.C.T.) bus and trolley-bus (T.B.) drivers.

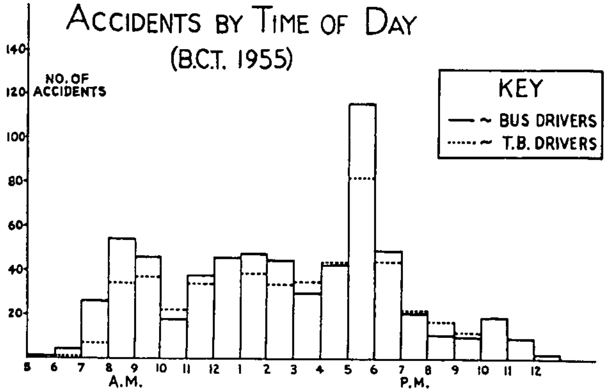
b Secular Influences on the Number of Accidents

Any investigation relating to road accidents should examine the number of accidents occurring at different times of the day, on different days of the week and in different months of the year. But such data must be interpreted with caution because of the wide fluctuation both in traffic conditions and in the number of drivers actually at the wheel. Relevant information for the drivers under review is now presented; it may be of some value to traffic administrators but has limited application to the present problem. B.C.T. vehicles travel only in Belfast County Borough; U.T.A. routes are predominantly rural.

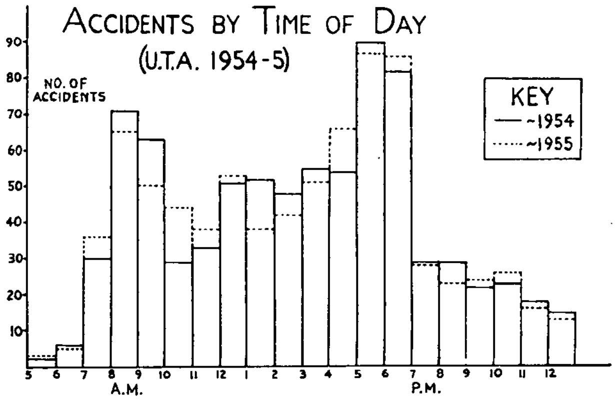
Graphs 1.1 and 1.2 present the number of accidents by time of day.

With the B.C.T. data the effect of the evening rush-hour was striking, and in addition there were clearly defined subsidiary peaks between 8 a.m. and 10 a.m., and between 10 p.m. and 11 p.m. The former would correspond to the morning rush-hour; the latter to the finish of the evening theatre and cinema performances, and the closing of licensed premises. A peak associated with the mid-day period was not conspicuous, possibly because comparatively few industrial and City workers go home for lunch. The U.T.A. data

Graph 1.1



Graph 1.2



produced a not dissimilar picture but with one important difference, viz. the evening peak was less pronounced than for B.C.T. drivers but it spans a longer period of time. On reflection this is not unexpected.

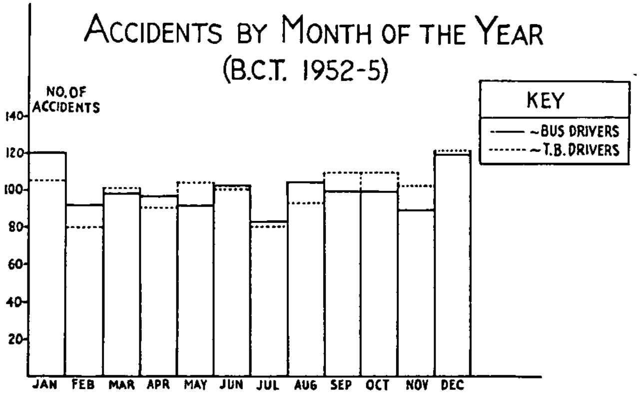
The number of accidents varied according to the day of the week (Table 1.1). Sunday had the fewest number, a fact more pronounced on B.C.T. routes. This disparity between the two Authorities can be traced to the many Sunday excursions run by the U.T.A. during the summer months.

Table 1.1 *Accidents by the Day of the Week (U.T.A. Bus Drivers and B.C.T. Trolley-Bus Drivers, 1955)*

Day	*U.T.A. Bus Drivers*	*B.C.T. Trolley-Bus Drivers*
Sunday	63	24
Monday	116	93
Tuesday	119	83
Wednesday	127	75
Thursday	138	82
Friday	129	104
Saturday	133	85
Total	825	546

The following graph (Graph 1.3) shows how the number of accidents among B.C.T. drivers varied between months. For easy reading the original figures have been reconstituted on a new basis so that

Graph 1.3



the average monthly number of accidents over the period equals 100. Whereas too much should not be read into these figures the peak occurs in December to January, and a trough is well defined in July. It is tempting to explain the winter peak by winter weather, and the July trough, unshared by August, by the exodus of the 'July holiday'.

Chapter 2 The Variation in the Accident Rate according to the Route

a Analysis of the Data

The first logical step is to ascertain whether the chance of a driver having an accident varied significantly according to the route over which he was driving. Since the frequency of the service varied between routes it seemed reasonable to assess the hazard of each route through the relevant number of accidents discounted by the annual mileage covered. Rotas, as termed by the U.T.A., were grouped into Areas and Sub-Areas to obtain stability; in the B.C.T. a certain, but small, amount of pooling of bus routes was performed but was strictly confined to routes the bulk of whose mileage was over the same roads.

In this chapter the term 'accident rate' denotes the number of accidents per million miles driven. Elsewhere in this study, unless stated otherwise, it has its more usual meaning, viz. the mean annual number of accidents per man.

Data from U.T.A. Bus Drivers

Some 31 million miles were covered each year by U.T.A. bus drivers. The rotas over which they drove were grouped into 18 Areas and Sub-Areas, and the accident rate for each during 1954 and 1955 was calculated. These rates are displayed in Table 2.1.

After being transformed to the square-root the accident rates were subjected to an analysis of variance to ascertain if the chance of a driver incurring an accident varied significantly between Areas. The rationale of transformation of the variate in the present instance is discussed later in the chapter; the result of the present analysis is given in the Appendix (Tables A.1–A.3).

The variance ratio is 5·75 which is very highly significant on the 0·1 per cent level; the conclusion was drawn that the accident rate varied according to the route. On omitting in succession Areas with extremes of accident rate the final analysis suggested that all Areas

Table 2.1 *Accident Rate for U.T.A. Areas (1954–1955)*

Area	*Accident Rate*
Ballymena Area—Ballymena	13·0
—Rest of Ballymena Area	16·1
Ballynahinch Area	21·7
Coleraine Area	30·8
Derry Area—All Derry City	51·0
—Rest of County Derry	25·0
Downpatrick Area	28·6
Dungannon Area	25·6
Lisburn Area—Lisburn	20·3
—Rest of Lisburn Area	20·0
Newry Area	39·6
Newtownards Area—Bangor	22·6
—Newtownards	18·5
—Rest of Newtownards Area	22·0
Portadown Area—Portadown	38·9
—Lurgan and Rest of Area	33·7
Smithfield No. 1 Area	26·2
Smithfield No. 2 Area	23·5
Average over all U.T.A. Areas	26·1

could be adjudged to have similar accident rates with the exceptions of the following five, viz. Ballymena, Rest of Ballymena Area, Derry, Newry, and Portadown (Appendix, Tables A.4–A.6).

On some U.T.A. rotas only double-decker buses were driven. To decide whether the accident rate on these was to be reckoned different from the rate on similar single-decker rotas, the accident rate was calculated for comparable Areas over which both single- and double-

Table 2.2 *Accident Rate for Double- and Single-Decker Buses (1954–1955)*

Rota Group	*Double-Deckers*	*Single-Deckers*
Portadown	26·2	32·1
Ballymoney	44·1	50·3
Portrush	24·7	33·9
Coleraine	26·8	40·0
Ballyclare	26·7	19·5
Average	28·0	31·9

decker buses operated (Table 2.2). The fact that the first rota group belonged to the Portadown Area, the second, third and fourth to the Coleraine Area, and the fifth to the Smithfield No. 2 Area, could be important by virtue of the preceding analysis. Analysis of variance (Appendix, Table A.8) on the transformed variate yielded a variance ratio between 'bus types' of 2·55 which is not significant.

The results in this section indicate that, broadly speaking, U.T.A. drivers were exposed to equal risk of incurring an accident irrespective of the Area over which they drove (except in the case of the five previously noted exceptions), and the level of accident risk was unrelated to whether single- or double-decker buses were driven. But certain points concerning individual rota groups deserve attention, e.g. when Derry City Sub-Area is separated into Urban Derry City and Rest of Derry City the former had an appreciably higher accident rate. This was in contrast to Smithfield No. 1 and 2 Areas; a proportion of their mileage lay in Belfast yet their accident rates were unremarkable. In the sequel the exceptional Areas, viz. Ballymena, Rest of Ballymena, Derry City, Newry, and Portadown, are allocated to one of three groups; Derry City by itself, Ballymena and Rest of Ballymena together (subsequently termed 'Ballymena'), and Newry and Portadown (subsequently termed 'Newry').

Data from B.C.T. Bus Drivers

Collectively, B.C.T. bus drivers covered over nine million miles each year. The routes over which they drove were grouped into 17 Areas, and the accident rate for each Area during 1954 and 1955 was calculated and analysed as described above for U.T.A. data. Relevant information is displayed in Table 2.3 and in the Appendix (Tables A.9–A.11).

The variance ratio is 1·81 which is not significant; consequently the chance of a driver incurring an accident was reckoned to be independent of the route over which he drove. Only Downview was served by single-decker buses exclusively. Its accident rate is unremarkable, a fact which supports the conclusions drawn from Table A.8. The Area with the worst accident rate comprises routes over which buses conveyed personnel to and from the aircraft and ship-building works. These specific journeys were confined to peak periods, a fact sufficient in itself to account for the observed accident rate. It is important to emphasise that any driver was liable to duty over this route.

Table 2.3 *Accident Rate for B.C.T. Bus Areas (1954–1955)*

Area	*Accident Rate*
Aircraft, Queen's Road and R.N.A.S. . .	94·1
Ardoyne and Springfield	48·8
Ballygomartin	59·4
Balmoral and Lisburn Road . . .	59·0
Cavehill	32·6
Cherryvalley	71·8
Crumlin	58·4
Donegall Road	53·5
Downview	58·8
Gas Works	54·4
L.M.S., Duncrue St. and C.C. Boats . .	62·1
Oldpark and Carr's Glen	53·9
Ormeau	47·6
Ravenhill	58·7
Shankill	50·5
Stranmillis and Malone	32·6
Sydenham and Stormont	74·5
Average over all B.C.T. Bus Areas . .	56·5

Data from B.C.T. Trolley-Bus Drivers

B.C.T. trolley-bus drivers covered over eight million miles per year. The routes over which they drove were grouped into 10 Areas;

Table 2.4 *Accident Rate for B.C.T. Trolley-Bus Areas (1954–1955)*

Area	*Accident Rate*
Bloomfield	59·6
Carr's Glen	64·4
Castlereagh	85·0
Cregagh	68·2
Dundonald	55·3
Glengormley	42·5
Greencastle	45·0
Falls	64·3
Ormeau	46·3
Stormont	64·7
Average over all B.C.T. Trolley-Bus Areas .	57·9

the accident rate for each Area during 1954 and 1955 was calculated and analyses performed as above. Relevant information appears in Table 2.4 and the Appendix (Tables A.12–A.14).

The variance ratio is 2·66 which is not significant; the chance of a driver incurring an accident was again reckoned to be independent of the route over which he drove. Also, it can be construed from Tables 2.3 and 2.4 that bus and trolley-bus drivers faced approximately equal hazards on the roads of Belfast, and that, *ceteris paribus*, both classes were exposed to around twice the risk faced by U.T.A. drivers.

b Transformation of the Variate in the Analysis of Variance

In this and Chapter 4, analysis of variance using a transformed variate is employed as a fundamental technique. If its application is dubious in this context the results must be evaluated accordingly. Consequently, the importance of the validity of this approach justifies a discussion of its rationale.

In experimental circumstances where the larger the value of the variable obtained the more likely is it to be unstable under repeated sampling, it is advisable to transform the variate before analysing the variance. In such instances, of which the data presented in this chapter represent an example, the sampling distribution is usually highly skewed without upper bound; consequently a logarithmic transformation (rather than, say, the inverse sine) would seem appropriate. In Chapter 4 where a rare event is the subject of enquiry and the magnitude of the variable comparatively small, the square-root transformation is preferable: 'In applying analysis of variance to data of Poisson type it is advantageous to use the square-root of the variate as a transformed variate, for the latter has a variance which is almost independent of the mean' (Irwin, 1943). In practice both logarithmic and square-root transformations were applied to the data in this chapter, with an identical end-result. For the sake of consistency the square-root transformation is used as the subject of the present analyses both in this and in Chapter 4.

In general, transformations are used in order to satisfy the relevant criteria for a valid analysis of variance. These are, that within each grouping, e.g. an age-group, the variation about the mean is normal, and that the variance is identical in each grouping. Further, the numbers should be sufficiently large to afford a reasonable basis for estimating the individual means required, and should, strictly, be equal, so that each mean can be estimated with the same precision (with the associated variances equal). In the present study the groupings were selected so as to ensure, as far as possible, that approximately equal numbers of men (in Chapter 4) or miles (in the present chapter) contributed to the means, but by the very nature of the data exact equality was impossible. (Unfortunately there appears no easy solution to the problem of heterogeneous residual variance). But in fact to demand strict adherence to this condition is pedantic; practising statisticians do not accept exactly equal denominators as an overriding desideratum for the applicability of the analysis of variance. For example Tippett (1952b, p. 140) states categorically that the time factor he used to divide the observed number of breaks in order to estimate the warp breakage rate, varied for each cell in a complicated experiment. Also, some among the other conditions need not necessarily be perfectly fulfilled to allow conclusions to be drawn from the analysis (e.g. Cochran, 1947; Eisenhart, 1947). Cochran and Cox (1950), for example, suggest that where the theoretical assumptions do not strictly hold there is a possible loss (or gain) in sensitivity, so that a test ostensibly made at the 5 per cent level may really be at, say, the 8 per cent level. Thus, they recommended that the use of the 5 per cent level is too inflexible and hardly justifiable. This fact must be borne in mind when assessing the interpretation of the results of analyses of variance in the present work. Tippett (1952b, p. 125) puts this point exactly: 'The most important assumption is probably the homogeneity of the residual variations. The examination of this is easy when the data are in the single-factor form, but it becomes progressively more difficult as the form becomes more complex; these forms are usually analysed without much consideration being given to the validity of the assumptions. This is a weakness of our practice, but, if the possibility of error is borne in mind and obvious gross departures from the assumptions are not ignored, we are not likely to go seriously wrong'. Finally, in the practical field, J. O. Irwin (1941) used the square-root transformation in broadly similar circumstances to the present, when examining Farmer and Chambers' (1939) well-known London Transport data.

c Discussion

It is axiomatic that the accident rate for a particular Area can be high because of having an undue number of 'bad' drivers associated with it. This objection has been to some extent overcome in the present study by making Areas reasonably large so that the individual driver's contribution to the Area mean is comparatively trivial, but the basic difficulty remains that drivers and Areas are of necessity associated. If the investigators had untrammelled control over their subjects, then 'families' of drivers, i.e. those initially associated with a particular Area by virtue of being attached to depots which provide the vehicles and drivers required to serve routes or rotas within the Area, could conceivably be randomly rotated over Areas to furnish the basis for a planned experiment, e.g. along the lines of a Latin Square. Such a design would enable possible errors due to differences between Areas, and between 'families' of drivers, to be eliminated from the means thus allowing unbiassed estimates to be obtained, and also from the residual variance making it minimal. However, Public Transport drivers cannot be treated like varieties of barley or beams of yarn, and so an alternative procedure was of necessity adopted. When the results of the analysis so demanded, the available Areas were aggregated into groupings within which all drivers were considered as exposed to the same risk of incurring an accident. It should be noted that this procedure does not exclude a driver from consideration, because every driver in the selected population is allocated to one or other group. However, within the Belfast groupings the accident rates varied considerably (see Tables 2.3 and 2.4) suggesting a true heterogeneity to accident risk between some routes, but the data were insufficient to establish this as fact. Clearly, if such a heterogeneity did in fact exist and the drivers sampled the routes in an uneven fashion, this combination could in itself explain the inability of the Poisson (or 'Pure Chance') Distribution to reproduce the statistics of the observed frequency distributions of accidents over the populations ultimately chosen (Chapter 9). Drivers in Belfast can be allocated to any route or duty rota, and pertinent records relating to the period of study were not uniformly available. If they had been, then recourse to an 'exposure to risk' index—as calculated by Häkkinen (1958) with similar data, and Whitfield (1954) with accident data from colliery workers—would have had much to commend it, although such a technique is not impeccable. For the reasons given here and in Chapter 1(a), it seems reasonably certain that, so far as can be ascertained, all drivers within each grouping selected were indeed equally exposed to the risk of incurring an accident.

The first essential in a proper investigation of the incidence of accidents among members of a population at risk has now been fulfilled.

Chapter 3 Accidents of Different Types, with Special Reference to Belfast Corporation Transport Bus and Trolley-Bus Drivers during 1951–1955

Until Adelstein's (1952) paper appeared it was generally conceded that individuals who incur an undue number of accidents of one type are more likely than their fellows to incur a greater number of any other type. The validity of this proposition is an essential desideratum if the concept of 'accident proneness' is to be accepted *in toto*: 'Accident proneness . . . is relatively stable, in the sense that persons with a larger number of accidents than their fellows in one observational period tend to have more accidents in subsequent periods . . . *and also that persons tending to sustain a number of one kind of accident tend also to sustain a number of other types*' (Chambers and Yule, 1941) (Our italics). The evidence adduced in its support is the significance of the correlation coefficients obtained (e.g. Farmer and Chambers, 1926, 1939; Brown and Ghiselli, 1948) between types of accident, usually 'major' and 'minor' as arbitrarily defined, and argument by analogy which, as discussed in Chapter 1(a), is of dubious application. Adelstein's (1952) conclusions were based on rigorous data and were contrary to those from the above studies: he states explicitly: 'This finding is at variance with those of Farmer and Chambers . . . In the light of this finding it is suggested that this idea should be reviewed'. Although the author of one of the best disquisitions on accident proneness ever published, Adelstein bases this conclusion on comparatively flimsy evidence. Having arbitrarily defined a 'major' injury as one associated with at least seven days' absence from work, Adelstein calculated the correlation coefficient (r) between these and 'minor' injuries for 304 men over five years as 0·1023. He stated that this was not significant. Re-calculation by the present writers gives $r = 0{\cdot}1011$ which, if a 't' test is used, means that $0{\cdot}10 > P > 0{\cdot}05$, and considering the nature of the data a less dogmatic interpretation might have been preferable. Since that time seemingly only Häkkinen's (1958) study supplies relevant data.

Häkkinen calculated correlation coefficients for two separate dichotomies, namely 'minor' and 'major' accidents (where the latter were defined as accidents causing more than £3 damage), and 'collisions' with 'all other types'. In none of his 'total groups' of drivers was the coefficient significant at the level chosen, although for the most part it was positive. In his 'experimental groups', which were less homogeneous with respect to accidents than the 'total groups', some of the correlations may well have been significant. Häkkinen interpreted these results with circumspection and clearly considered them equivocal, although he did state: 'That the correlations are low can be explained by the fact that certain individuals continually incur primarily certain kinds of accidents which is an indication of their proneness to special kinds of casualties'. This conclusion is not wholly supported by Adelstein. In this context Adelstein (1952) had compared observed 'pairs' of accidents of the same type incurred by each member of his population of railway shunters, with an 'expected' number, using a technique described by Archibald and Whitfield (1947). χ^2 was 18·51 (D.F. = 6; $P < 0{\cdot}005$), and Adelstein concluded: 'we have no clear evidence that either learning to avoid accidents takes place, or, on the contrary, that there is a tendency to repeat the same kind of accident'. This may be so, but of the six groupings the 'all other categories' supplied 15·13 of the total χ^2 value, the remaining five supplying only 3·40. Adelstein acknowledged this fact; his stated conclusion should therefore be accepted with reservation.

If the hypothesis be made that chance alone determines the result of an unplanned event, then little benefit can derive from categorising accidents on the criterion of 'type' of outcome. It was previously argued that the unqualified acceptance of this hypothesis might be unwise; consequently it is necessary to group accidents by type to ascertain if in fact those drivers who incurred an undue number of one type can be considered as also having incurred an undue number of any other. If this is not established then the pooling of accidents irrespective of type for the purpose of subsequent analysis is not logically permissible. This pragmatic approach is warranted even though it is conceded that little insight into causation can result, in the present instance, from categorisation of accidents by outcome.

Results

The aspect of the outcome can be classified on the following criteria–which are not mutually exclusive.

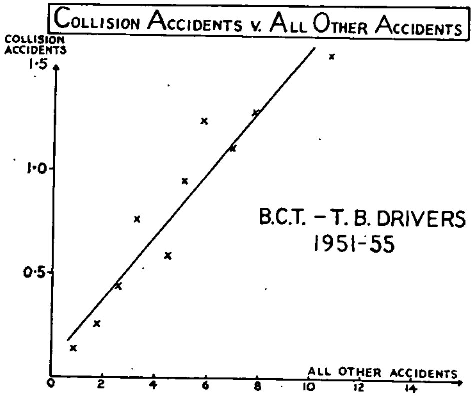
1 The injury to the driver.

2 The injury to the victim.
3 The damage to property.
4 The type of accident, e.g. whether another bus was involved or not.

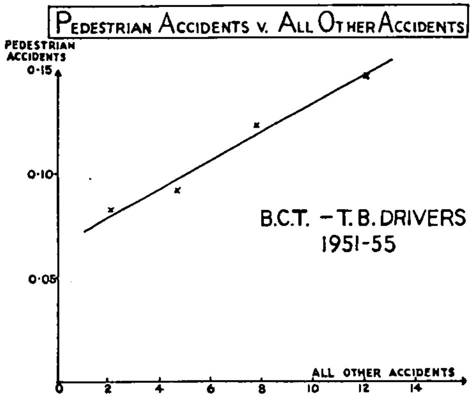
In the first two examples severity may be measured according to the site of injury, the extent of permanent disability incurred, duration of absence from work, or the amount of compensation paid. A combination of compensation to the victim and the cost of rectifying any material damage would seem to be a reasonable theoretical criterion on which to measure severity in the present case, but there were few accidents involving either the driver or victim in personal injury, and complete and accurate ascertainment of the cost of material damage was impossible. Criterion number 4 was therefore used.

Of the accidents appearing on the B.C.T. record sheets, two, and only two, distinct 'types' were identified, namely those involving another bus, trolley-bus or tram (subsequently termed Collision Accidents), and those involving pedestrians. It would have been of value to identify other types but this was impossible; consequently all the remaining accidents were grouped into one class. Tables 3.1 and 3.2 display respectively the relevant data from the B.C.T.

Graph 3.1



Graph 3.2



trolley-bus and bus driver populations at risk over the period 1951–1955. Using the data Graphs 3.1 and 3.2 were drawn, for the sole purpose of illustration, respectively relating (for the average driver) Collision to All Other Accidents and Pedestrian to All Other Accidents. For trolley-bus drivers the correlation coefficients (r) between total Collision Accidents and total All Other Accidents (rows 3 and 4, Table 3.1), and between total Pedestrian Accidents and total All Other Accidents (rows 5 and 6, Table 3.1), were calculated (Appendix, Tables A.15–A.17) as 0·927 ($P < 0{\cdot}001$) and 0·358 ($0{\cdot}20 > P > 0{\cdot}10$) respectively; for bus drivers the former was 0·813 ($P < 0{\cdot}001$), but the latter was not calculated because of the extremely small number of Pedestrian Accidents. In addition, the correlation coefficients between the numbers of Collision and of All Other Accidents sustained by individual drivers were calculated as 0.183 (for trolley-bus drivers), and 0.320 (for bus drivers), which were highly significant and very highly significant respectively.

Only the correlation coefficient Pedestrian Accidents *v.* All Other Accidents for trolley-bus drivers failed to achieve the conventional ($P \leqq 0{\cdot}05$) level of significance. This could be due to the paucity of Pedestrian Accidents, only twenty-five in number, and consequently the sampling errors involved in their distribution over the selected population could have been large enough nearly to swamp any trend that existed. Possibly significance could have been established if a longer period of observation had been initially taken, but this must be speculation. The conclusions drawn are, that subsequent pooling of accidents is logically permissible, and that it can now be argued with some justification that drivers likely to incur one particular type of accident when in charge of a bus or trolley-bus were also likely to incur any other. The first conclusion is of immediate practical consequence; the importance of the second is discussed in Chapters 6 and 10.

Table 3.1 *Types of Accidents—B.C.T. Trolley-Bus Drivers over the Period 1951–1955*

No. of Accidents per Man	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	. .	*21*
No. of Men	7	7	23	18	38	41	19	21	18	18	7	13	4	3	1	4	.	2
Total Collision Accidents	0	1	6	8	29	24	18	26	20	23	10	22	5	6	4	2	.	3
Total of All Other Accidents	0	6	40	46	123	181	96	121	124	139	60	121	43	33	10	58	.	39
Total Pedestrian Accidents	0	0	3	1 (fatal)	3 (one fatal)	5 (one fatal)	1	4 (one fatal)	2	1	0	2 (one fatal)	1	1	1	0	.	0
Total of All Other Accidents	0	7	43	53	149	200	113	143	142	161	70	141	47	38	13	60	.	42

Table 3.2 *Types of Accidents—B.C.T. Bus Drivers over the Period 1951–1955*

No. of Accidents per Man	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
No. of Men	8	22	25	33	32	24	8	12	8	3	3	3	1	0	0	1
Total Collision Accidents	0	0	6	13	13	22	10	22	11	9	5	6	1	0	0	7
Total of All Other Accidents	0	22	44	86	115	98	38	62	53	18	25	27	11	0	0	8
Total Pedestrian Accidents	0	0	0	1 (fatal)	0	1	0	0	0	0	1	0	1	0	0	0

Chapter 4 Age and Experience

a Introduction and Literature

Experience cannot increase independently of age, nor age independently of experience if the latter is considered in its widest connotation. Also, to express experience as the time spent at a particular job in a particular organisation denies the influence of previous or outside pursuits. In fact to measure experience in terms of time at all is expedient but not wholly satisfactory.

In the present study, experience was measured from the first year of driving a bus or trolley-bus in the Authority concerned; there seemed no reasonable alternative method.

The Literature

Many investigators have studied the effect of increasing age or experience on accident rates both in industry and among road users. King and Speakman (1953) review much of the work. Briefly, as regards experience, in industry the commonest finding is that the accident rate was highest in the first week of employment but then rapidly fell, this decline sometimes continuing for many years (Chaney and Hanna, 1918; Gates, 1920; Fisher, 1932; Humke, 1936), although Shiorbree (1933) and Tiffin (1942) have presented dissentient data. With road vehicle data, the accident rate was highest in the first year of driving, and this effect of inexperience either died out in the second or third year (Ghiselli and Brown, 1947; Moffie and Alexander, 1953), or persisted for a longer period (e.g. Slocombe and Bingham, 1927). As regards age, available industrial data suggest that the accident rate is highest in the 16 to 20 year age group after which it declines sharply, and then either remains reasonably constant through subsequent age groups (Hewes, 1921), declines steadily until retirement (Mann, 1944), or rises again at age 50 plus (Vernon, Bedford and Warner, 1928; 1931). With road vehicle drivers, youngest licence holders usually had the highest accident rate, those aged 30 to 60 the lowest, and after this age the accident rate often, but not always, increased (DeSilva, 1938; Johnson, 1946; McFarland, Moseley and Fisher, 1954).

Some of these general findings are contradictory largely because of differences between groups. But they are in fact strictly inconsequential; none of the above studies adequately considered one variable while allowing for the other, and the data seldom afforded even an approximate estimation of exposure to risk. More rigorous studies are those of Newbold (1926), Farmer and Chambers (1939), Häkkinen (1958), and Cornwall (1961), all of whom drew their conclusions from more reliable data; their investigations, and the much quoted study of Lauer (1952), are now discussed.

Newbold's total population comprised 6,938 male and 2,024 female 'workers', and they were employed in twenty-two factories. As an accident she took, 'any injury, however slight, which is recorded as treated either in the Ambulance Room or from Ambulance Boxes', and the period for which data were obtained varied from three months to two years. She was characteristically circumspect about the uniform quality of her material: 'Stress must be laid on the fact that no comparison as regards the average number of accidents should be made from one group to another; the conditions are quite different, and such a comparison would lead to no useful result'. She then discussed her technique for handling the data: 'In our present study we have tried to choose periods in which there were no great changes as regards pressure of work.... Some attempt has also been made to separate the two factors of age and experience by using the method of partial correlation. We have only been partly successful in this as our measure of experience is limited to that of the particular occupation at the period of observation and consists of the length of service in that particular factory.... Experience in the same occupation but in other factories is thus left out of account'. The age distribution of her populations varied between groups, but males from 13½ to 75 years, and females from 14 to 70 years, provided the data. The results of the partial correlation technique in which, as far as possible, the author allowed for the reduced exposure to risk through absence, showed: 'There is a tendency for the number of accidents to decrease to some extent with age, and apparently also, though to a less extent with length of service in the factory, but when allowance is made for age, there is no independent association between experience and accidents; while when allowance is made for experience, the association between accidents and age remains....

We must remember, however, that our groups do not contain many absolutely new workers, and it is these, as a rule, who seem to be responsible for the sudden rises in accident-rates with increased trade'.

In discussing these results, she remarked: 'It may be that part of the association between accidents and age is due to selection, i.e. that the younger workers with liability to accident get weeded out, but the fact that the association still remains when length of service is kept constant, suggests that this is not a very important factor'. And again: 'The possibility of a greater willingness to report trivial accidents among the younger workers must be considered.... In our present data, although we cannot hope to have entirely eliminated unreported accidents, we have tried to escape them by careful choice of factories ...' This was a wise precaution; already the Factory Inspectorate, cognisant of the employment problem, had drawn attention to 'the anxiety on the part of elderly men to preserve their employment and full wages, resulting in their concealing trivial injuries until compelled to go off work by sepsis' (Factories, 1923).

Newbold's work is admirable; little critical comment is possible.

Farmer and Chambers (1939) used data obtained from groups of omnibus and trolley-bus drivers (Groups A to D), army drivers under training (Group E), four groups of owner drivers of private cars insured in one of the big insurance companies (Group F.1–4), and more than a dozen groups of drivers of heavy lorries (Group G). The period for which statistics were available varied from five years for Group A, to twelve weeks for Group E. Among the members of Groups F.1 and G, there was a gradual decline in mean accident rate until about age 45 followed by a rise until about age 55 to 60, and ultimately a second fall which continued into the period 60 plus years. In considering this phenomenon the authors remarked: 'A possible explanation of this is that advancing age may come almost imperceptibly upon people, so that they continue to take the same risks as they did in their earlier years. When they are definitely old they realise that this cannot be done and so take fewer risks'. To consider the effect of experience, data from Groups A and B were presented to show the considerable drop in mean accident rate between first and any subsequent year's experience. All drivers had had previous experience of driving heavy vehicles but this was their first year of bus driving in London. The authors concluded: '[these results] suggest that the effects of experience on accidents are of relatively short duration in these groups of bus drivers'. Further data suggested that the decrease in accident rate with experience held also for 'spare drivers', viz. 'conductors who had been trained and had passed a driving test and were employed as full-time drivers during the summer season', and that the percentage of 'novices' in Group F who sustained accidents was higher than that of 'not-novices'. Also, data from the same two groups indicated that the proportion of blameless accidents to all accidents increased with experience. The authors' general conclusions were: 'that beginners tend to have more accidents in their first year of exposure than in subsequent years, increasing experience tending to reduce accident rates, and second, that among experienced drivers continued experience does not appear to affect the accident rate as much as it does in the initial stages'.

Some comments seem justified. The data, on which the authors adduced a specific relationship between age and accidents, are unsatisfactory. Accident claims by private licence holders on insurance companies are an unreliable index of actual accident experience. In another study, using a rather broader connotation of 'claim', Johnson and Garwood (1957) clearly emphasised this point: 'It is the liability of policies to claims rather than drivers to accidents that has been studied'. Also, to be aware of, but to ignore, both the influences of probable disparity in exposure to risk in a group of over two thousand private licence holders aged 16 to 80, and that of the experience component, is unrealistic. Data from Group G (drivers of heavy lorries) supported the general findings and are more reliable on this score, but the members were more highly selected, the age limits narrower, and the ascertainment method unspecified. This last may be important since the drivers were based at different local centres.

The data relating accident rate and experience derive from public transport authorities. The age range, viz. 24 to 37 years, is narrow. The authors stated: 'Our data do not make it possible to differentiate between age and experience in the same way as did Newbold, but they do allow us to show the effect of increasing experience in two groups of new drivers'. Failure to standardise for age is not important to the results as calculated. In general, these authors were less circumspect than Newbold as to the limitations of accident data; nonetheless this work is justly considered fundamental in the field.

Häkkinen used his age and experience data in two ways. Using accidents incurred by Helsinki bus and tram drivers observed over a maximum period of eight years, he (Häkkinen, 1951; 1954) was able to show, 'a continuous reduction in the number of accidents during the first four or five years of employment, whereas after this a minimum level is attained. The average frequency of accidents during the first year is nearly three times as high as in the fifth year.... There is a continuous decline in the number of accidents up to the age of 45–48, after which they begin to increase at a gradually increasing rate. Thirty-year-old drivers have, for example, irrespective of driving experience, twice as many accidents as 48-year-old drivers. ... By dividing the whole population into sub-groups according to the length of employment, it has been possible to estimate separately the influence of both these factors. It appears that it is exceedingly difficult for drivers of more advanced age to adapt themselves to new conditions as is evident from the high number of accidents at the beginning of the period of employment' (Häkkinen, 1958).

Fully cognisant of the effect that differences in group age and experience might have on his results, since many of the clinical tests he performed are affected by age, Häkkinen demonstrated that the differences in mean age between the various accident groups were not significant. This result is surprising in view of his earlier findings (Häkkinen, 1951; 1954), and the cause may lie in his adoption of a complex 'accident coefficient' as the criterion, which was defined as 'the total number of accidents as divided by the length of the period of exposure', rather than a simple or transformed accident rate. Smeed (1960) commented: 'Häkkinen calculated the statistical significance of the difference between the mean ages of the various groups of drivers. But this is irrelevant. If all the low-accident group were born on the one day and the high-accident group one week later, the difference in mean age calculated would have been statistically significant but the effect on the analysis nil. If, however, two groups of 4 drivers were taken, one group consisting of 3 drivers aged 30 and one aged 45, while the other group consisted of one driver aged 30 and 3 aged 45, the difference in age—as calculated—would not have been statistically significant, but the effect on the analysis great'. Smeed's criticism must be accepted, but is invalidated in the present study by a 'matching' technique fully described in Chapter 8.

Cornwall's (1961; 1962) data were derived from London Transport Executive drivers, as were Norman's (1960). He presented, for each of four populations or 'grades', tables showing (for the period 1957 to 1959) the number of driver-years, the number of accidents, and the average number of accidents per driver per annum, for certain age groups within the following length of service groups: under 4 years, 4–8 years, 9–13 years, 14 plus years. His four populations were: Central Bus Drivers, Trolley-Bus Drivers, Country Bus Drivers and Single-deck Coach Drivers. Of the average annual number of drivers (18,248) these populations contained, respectively, 69, 16, 11 and 4 per cent. For an 'accident' Cornwall used the same criteria as in the present study, but length of service was measured from entrance to the particular driving grade, which is not strictly analogous to the definition of 'experience' which we employed. Statistics were available for certain drivers between the ages of 65 and 70 years, and during the latter part of the study the periodic medical examination of drivers (Norman, 1958) was in force. Cornwall concluded: 'In all age groups there is a clearly defined tendency for drivers with the longer period of service to have fewer accidents. As might be expected this improvement is particularly noticeable in the early years of service as a driver, but it appears to continue, in general, until drivers pass into the groups with fourteen or more years of service. [Also] there is a marked fall in accident rates up to the age of forty to forty-nine, while for higher age groups the variation with age is much less; improvement in accident rates with increasing experience is more marked than the effect of increasing age and this is more likely to be due to the actual improvement of driving skills than to selective turnover . . . . the replacement by new drivers of carefully selected men who are retained on the job after 65 would probably lead to a deterioration in the overall accident experience and that, except for trolley-bus drivers, operating a vehicle of a different type, differences in the accident experience on different types of service are principally a reflection of the different density of traffic encountered'.

Lauer's (1952) study of accidents among vehicle licence holders in Iowa State is widely quoted as evidence that younger drivers are especially liable to road accidents. To validate the results the author realised that some estimate of risk exposure must be made, and to this end he circulated an inventory, requesting basic information on driving habits, to every two-hundredth licence holder in Iowa State selected on a certain date. Of the 7,692 persons circulated, 1,419 (19 per cent) replied. Using the information obtained, Lauer regularised his data by making a correction for stated mileage driven, and found that those aged 18 to 23 had the worst accident experience. Also, men improved their accident record after about five years' experience.

These two general findings are in accord with those of other workers, but Lauer's methodology seems fallible. Apart from the errors inherent in his ascertainment technique and in the inventorial data generally, it is exceedingly doubtful whether those replying to the questionnaire were representative of the total sample. It is a compliment to Lauer's reputation that so much emphasis has been placed on this investigation.

b Results

In this chapter the term accident rate has its more usual meaning, viz. the mean annual number of accidents per driver. Mileage covered is still of fundamental importance but as previously explained this could not be ascertained for each man. It is assumed for the purposes of the analyses in this chapter that the drivers sampled all driving conditions equally. The arguments advanced in Chapters 2 and 3 indicate that this may not be entirely unwarranted; but in fact since it is the accident rates of different *groups* of drivers that form the units for analysis the assumption does not have to be entirely correct unless self selection out of hazardous routes varied unequally with age and/or experience. As far as could be ascertained this did not occur to any appreciable extent.

Data from the three populations, viz. U.T.A. drivers for 1952–1955, B.C.T. bus drivers over 1952–1955, and B.C.T. trolley-bus drivers over 1951–1955, are presented separately. For their analysis the technique of analysis of variance on the transformed variate, viz. square-root accident rate, as discussed in Chapter 2, is used in preference to partial correlation. Tables of accident rates are included in the text; those showing the analyses, together with additional data and information, appear in the Appendix (Tables A.18–A.38).

U.T.A. bus drivers, 1952–1955

The records of the 547 drivers who commenced driving subsequent to 1940 and not later than 1949, and who were born between 1907 and 1921, were used to determine the influences of age, driving experience and the calendar year upon the accident rate. Groupings were into three-yearly periods for both the year of birth and for the date on which driving in the Authority commenced. The results are shown in Table 4.1.

Table 4.1 *Accident Rate by Age and Experience (U.T.A. Drivers)*

Drive from	*Born in*					*Average*
	1907–1909	*1910–1912*	*1913–1915*	*1916–1918*	*1919–1921*	
1947–1949	0·69	0·64	0·70	0·62	0·68	0·67
1944–1946	0·52	0·56	0·48	0·61	0·63	0·56
1941–1943	0·61	0·52	0·57	0·51	0·50	0·54
Average	0·62	0·57	0·59	0·58	0·62	0·60

The variance ratio (Drives) of 3·71 is significant on the 5 per cent level, so those who commenced to drive in 1947–1949 had a significantly higher accident rate than their colleagues who drove before 1947. The variance ratio (Years) is very highly significant on the 0·1 per cent level, thus the accident rate varied with the calendar year 1952–1955. To establish which years were different Table 4.2 was constructed using the information that the residual variance yielded $\sigma_0 = 0{\cdot}0988$; an average of 15 individual readings had a standard error (S.E.) of $\sigma_0/\sqrt{15}$ and hence the S.E. of the difference of two such averages was $\sigma_0\sqrt{2}/\sqrt{15} = 0{\cdot}0361$. From the table it

Table 4.2 *Differences between Accident Rates relating to certain Significance Levels*

Year	*Average Accident Rate*	*Significant Difference*	*Significance Level*
1952	0·851		
1953	0·764	0·074	5%
1954	0·795	0·101	1%
1955	0·622	0·135	0·1%

may be concluded that compared to 1953 and 1954 the accident rate in 1952 was higher (at the 5 per cent level) and in 1955 lower (at the 0·1 per cent level).

B.C.T. bus drivers, 1952–1955

The records of 159 drivers who were born between 1902 and 1927 were available for analysis. The age and experience groupings selected were rather crude owing to the comparatively small numbers involved. The results are shown in Table 4.3. The variance ratio (Drives) of 12·76 is significant on the 5 per cent level, so those who commenced Corporation driving after 1948 had a higher accident rate than their more experienced colleagues.

Table 4.3 *Accident Rate by Age and Experience (B.C.T. Bus Drivers)*

Drive from	*Born in*			
	1902–1912	*1913–1917*	*1918–1927*	*Average*
1948 on	1·43	1·11	1·04	1·19
Before 1948	0·93	0·73	0·77	0·81
Average	1·18	0·92	0·90	1·00

B.C.T. trolley-bus drivers, 1951–1955

The records of 190 drivers who were born between 1904 and 1928 were used for analysis. Again the age groupings were coarse owing to the small numbers of men involved, and the experience groupings selected were 1946–1947 and 1948–1950 for the year of starting B.C.T. trolley-bus driving. The few drivers who commenced in 1944 and 1945 were omitted in order to adhere as closely as possible to the technical requirements of a valid analysis; data from those starting before 1944 are used in a subsequent analysis. The results are shown in Table 4.4. The variance ratio (Drives) of 5·39 is significant on the 5 per cent level; thus those commencing Corpora-

Table 4.4 *Accident Rate by Age and Experience (B.C.T. Trolley-Bus Drivers)*

Drive from	*Born in*			*Average*
	1904–1912	*1913–1917*	*1918 on*	
1948 on	1·14	1·46	1·36	1·32
1946–1947	0·83	1·25	0·82	0·97
Average	0·99	1·35	1·09	1·14

tion driving during 1948–1950 had a higher accident rate than drivers starting during 1946–1947.

These results from the three populations indicate that, unlike experience, age had no demonstrable effect on the accident rate; but the age range selected is narrow and largely confined to the third, fourth and fifth decades of life. It is now necessary to examine the relationships at the extremes of working life. But there are difficulties. In the largest population, viz. the U.T.A., drivers may drive part-time for two years before becoming permanent, and this part-time spell is related to the season; consequently it was impossible to assess accurately the effect of extreme 'youth' and very little experience. Also, the U.T.A. was founded in 1948 and complete records relating to the previous organisation, viz. the Northern Ireland Road Transport Board, are not uniformly available for the war years; consequently it was not always possible to estimate accurately experience gained before 1948. In the B.C.T., records were available but the numbers of young drivers were too small to allow analysis. However

Table 4.5 *Accident Rate over the years 1952–1955 for U.T.A. Drivers with at least Ten Years' Experience*

Date of Birth	1913–1918	1907–1912	1901–1906	Before 1901
Accident Rate	0·44	0·46	0·48	0·64

Table 4.6 *Accident Rate over the years 1954–1955 for B.C.T. Bus Drivers with at least Five Years' Experience*

Date of Birth	1918–1927	1913–1917	1903–1912
Accident Rate	0·95	0·78	0·90

in both Authorities some information can be presented on the effect of comparative 'old-age', i.e. up to compulsory retirement at age 65, on the accident rate. The previous analyses suggested that the independent influence of experience died out within a few years, and so considering only U.T.A. drivers with more than 10 years' experience, i.e. those who commenced full-time service before 1942, and B.C.T. trolley-bus drivers of at least 7 years' experience, i.e. those who started trolley-bus driving in Belfast before 1944, seemed valid. Data from B.C.T. bus drivers were too slight to merit analysis but did not contradict the general findings. Pertinent data are supplied in Tables 4.5–4.7; further information is in the Appendix (Tables A.31–A.38).

Table 4.7 *Accident Rate over the years 1951–1955 for B.C.T. Trolley-Bus Drivers of at least Seven Years' Experience*

Date of Birth	1913–1917	1908–1912	1903–1907	1898–1902	1893–1897	Average
Accident Rate	1·30	0·78	1·15	1·15	1·49	1·18

From Table 4.5 the variance ratio (Ages) is significant on the 5 per cent level, and that for Years on the 1 per cent level; therefore drivers born before 1901 had a higher accident rate, more particularly during 1954 and 1955 (Appendix, Table A.31). From Table 4.7 the variance ratio (Ages) achieves the 0·1 per cent level and that for Years the 1 per cent level. The 95 per cent control limits*, for the five-year averages in Table 4.7, are 0·98 and 1·38; the 99 per cent limits are 0·85 and 1·51, and thus drivers born in 1893–1897 had the worst accident record (very nearly exceeding the 99 per cent control limit). Curiously, perhaps, the age-group 1908–1912 had a significantly low accident rate. This taken in conjunction with the observed (non-significant) higher accident experience for those born in 1913–1917 might suggest that these sub-divisions should have been initially grouped together, the numbers of men involved being insufficient to provide accurate estimates.

Alternative Analysis

Quite apart from their immediate relevance the results in this chapter may conceivably have a wider application. It is therefore gratifying that the results of the above analysis are in a sense confirmed by the simplest of exact probability techniques, as follows. Suppose there was no difference in accident rate between the experience groupings within each age group; then the probability of the highest rate falling into any cell, i.e. by chance, would be identical for all cells within each column in Tables 4.1 and 4.3–4.4. But inspection shows that in every column the cell with the highest rate relates to drivers with the least experience; on the above hypothesis the probability of this observation occurring in all eleven columns is: $(1/3)^5 \times (1/2)^6 = 1/15{,}552$, since these are independent trials. Reading across rows it is patent that no corresponding result obtains for the differences between age groups within a row. A similar procedure applied to the data in Tables 4.5 and 4.7 yields (reading across rows) a probability of the combined event of the highest rate being associated with the 'greatest age' cell, (on the null hypothesis), of: $1/4 \times 1/5 = 1/20$.

Both analytical techniques would appear to lead logically to the same conclusions.

The Validity of the Results

U.T.A. and B.C.T. driving conditions are dissimilar. The number of miles each man drives, the average traffic density, the number of

* This term, borrowed from the field of Quality Control, is here used to denote the limits between which 95 per cent of observed means of samples of five individual years should lie, assuming that the distribution of each mean is normal. The meaning of '99 per cent control limits' is clear.

starts and stops per journey, the type of vehicle driven, and the many general environmental factors due to the largely rural/urban distribution of the respective services, differ considerably. The effect of these disparate influences is reflected in the number of accidents per million miles driven, the B.C.T. figure being roughly twice that of the U.T.A. The consistency of the results obtained in the age and experience analyses for drivers of the two Authorities suggests that these results may well reflect true basic findings. All population subgroups, other than representative samples, are 'biassed' in some way; Northern Ireland bus drivers are no exception. Some degree of self discretion or environmental circumstance motivates a man to enter or leave the job, and, in addition, authority imposes selection from the time of application for employment to retirement at whatever age. The fact that the bus driver groups investigated are selected in these ways does not invalidate the results obtained, it merely indicates that these results may not obtain in the general driving population. Selection processes *within* each group could, however, invalidate the results by producing an unknown heterogeneity to risk.

In every sizeable group some members, while ostensibly exposed to the same risk as their fellows, in fact 'self-select' themselves, or get themselves selected, into safer occupations within the group. This is a well-known phenomenon in industry, and affects usually the older and more 'experienced' worker. In the U.T.A. and B.C.T. some selection into certain duties, routes or rotas could influence the results, as could overtime duties or absence from work if inadequately discounted, since even a slight heterogeneity in risk exposure can affect the accident rate. Duty or route selection, although it undoubtedly occurs, cannot be measured but was unlikely to be important—as the results of Chapters 1 and 2 indicate. In point of fact in the upper age groups, where such self-selection can be expected to operate most strongly, the accident rate was higher *not* lower. Opportunities for overtime driving were limited, and as far as could be ascertained no one age or experience group was especially favoured.

Inevitably, absence varied among individuals. In order to assess its importance to the results of the analyses, the total absence other than holidays or rest-days of a sample of B.C.T. drivers was examined. The sample chosen comprised the drivers studied in Chapter 8, and all satisfied the rigid criteria of admission to the experimental populations. This is not a random sample but it does contain drivers with extremes of accident rate. The results (Table 4.8) show that there was an increase in 'exposure' of the older men by virtue of being more at work, but this is negligible being of the order of 1–2 per cent per year. A similar insignificant difference was obtained when the same sample of drivers was dichotomised by the discriminant of 3 years' experience.

Table 4.8 *Total Days' Absence from Work, other than Holidays and Rest-Days*

Absence	*Cases†*		*Controls†*	
	Date of Birth		*Date of Birth*	
	Before 1904	*After 1904*	*Before 1904*	*After 1904*
Total days' absent during 1952–1955	142	1315	227	1056
Number of drivers	7	31	9	29
Average number of days' absence per driver	20·3	42·4	25·2	36·4

† As defined in Chapter 8.

The conclusions drawn from the results of the analyses in this chapter were therefore not invalidated because of marked disparity in absenteeism related to age or experience.

In summary, the results allow the following conclusions.

1 Increasing experience acted as a significant factor in reducing the accident rate among the groups of drivers studied, but as a group property this effect died out within a few years.

2 Age, within the specific ranges considered, had no influence on the accident rate until about age 50–55 years; between this and retirement it was associated as a group property with a significantly increased accident rate. Since it was previously established that increasing experience operated to decrease the accident rate, it seems reasonable to infer that this association can truly be attributed to age.

3 The accident rate varied over the years of study, sometimes significantly.

c Discussion

If the association of accident rate with age is real, to what mechanisms can it be attributed? If it is postulated that anatomical and physiological efficiency alone militated against accidents then the rate should be lowest in young adulthood and subsequently should slowly increase coincidentally with the gradual deterioration in bodily function. This does not happen, nor on reflection would it be expected, since driving a bus is a complex performance and the degree of bodily degeneration, within certain limits, is a poor criterion of a driver's skill. Also, accidents are seldom enacted as single episodes, and avoiding, or extricating oneself from, an accident situation, is probably as important as immediate physical and mental reaction. It can be speculated that the observed increase in the accident rate over about age 50 to 55 years may be due, at least in part, to the ultimate decline in the individual's compensatory mechanisms which had previously nullified any results of physical deterioration, and to the development of more 'rigid' behaviour patterns. This latter can lead to a deterioration in performance when an older driver is 'under pressure' since he takes more time over each item of a task; to an increase in the time required to complete the perception and organisation of a current response so that the time available to deal with an emergency as it arises may be inadequate; and to a tendency to plan ahead or decide a rigid course of action, all of which render the older driver less able to deal with situations requiring a sudden change in procedure. Research into these and associated factors lies mainly in the field of experimental psychology (Welford, 1951; 1956; 1958).

In considering the independent influence of experience investigators are faced with many fundamental problems when trying to disentangle the processes by which complex tasks are learned. Welford (1956) suggested that there may be age-related difficulties in the learning process, a fact which Kay (1955) attributed to a greater difficulty experienced by older persons in discarding irrelevant past experience including inaccurate learning. In the occupational field Shooter *et al* (1956) have shown that older subjects, although they often can learn satisfactorily, take longer to do so than their younger colleagues. Whatever the exact mechanisms involved may be, most investigators agree that performance in a complex task improves with practice up to a certain standard and over a certain time, but that the degree and rate of this improvement may not be independent of age. Welford (1962) has recently summarised much of the pertinent experimental work.

In the present study data relevant to an understanding of the independent influences of age and experience on the accident rate are available and are now presented.

During the period under review trams were becoming obsolete in Belfast. Accordingly, it was possible to examine in some detail the accident experience of a group of former tram drivers over their first two years of driving buses. In all, over 100 tram drivers applied for jobs as bus drivers to be taken up when tramcars were finally disbanded in February, 1954. Of these, 31 were found medically unfit for bus driving, 4 were passed medically but failed to qualify technically, 4 were passed both medically and technically but were excluded on other grounds, and just over 60, of whom 58 stayed for at least two years, took up their new positions. Table 4.9 presents the accident rates of these 58, divided into three age groups, over their first two years of bus driving, and the results for pooled age groups are graphed (Graph 4.1.).

Table 4.9 *Accident Rate of Former B.C.T. Tram Drivers during their First Two Years of Driving Buses*

Date of Birth	*Period*	
	1st Year	*2nd Year*
up to 1904	2·47	1·37
1905–1910	2·29	1·47
1911 onwards	1·95	1·27

In Table 4.9 the decline in the accident rate between the first and second years in each of the three age groups was not significant perhaps because of the small numbers of drivers. However, if the first two and then the second two age groups are combined, the improvement of the accident rate between the two years is significant on the 1 per cent ($t = 2{\cdot}80$) and 5 per cent ($t = 2{\cdot}24$) levels respectively. Also, the figures would appear to suggest that the older men might initially have had the worse accident record, but this could not be demonstrated again possibly because of the small numbers involved. If the difference were real, then *cet. par.* four times as many men would have been necessary to establish the effect at the 5 per cent level. This difference, if in fact real, would appear curious in that the older men who, as a group, had a longer experience of tram driving might be expected to have acquired much useful experience of traffic conditions, although it can also be speculated that they would have displayed more 'patterned' behaviour than their younger colleagues who were more mentally 'agile' and adaptable. There can be no doubt that any difference in accident rate related to age (if it existed) was disappearing during the second year. Fortunately some other relevant information can be presented. In this study (Chapter 3) accidents were categorised into one of three types, viz. Collision, if

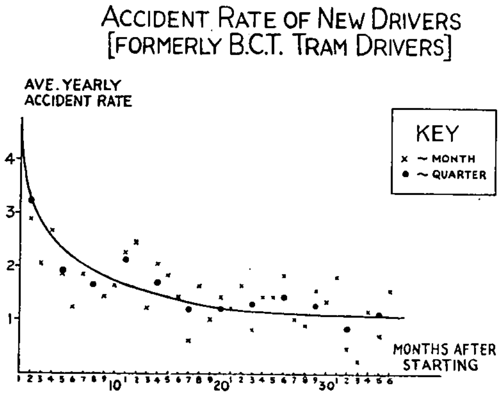
Table 4.10 *Accident Rate by Type of Accident, of Former B.C.T. Tram Drivers during their First Two Years of Driving Buses*

Date of birth	*'Collision'*		*'Other'*	
	1st year	*2nd year*	*1st year*	*2nd year*
Up to 1904	0·79	0·27	1·68	1·11
1905–1910	0·47	0·18	1·82	1·29
1911 onwards	0·18	0·32	1·77	0·95

another bus, trolley-bus or tram were involved, Pedestrian, and Others. If the accidents providing the data for Table 4.9 are subdivided by type (pooling Pedestrian and Collision because of the very small numbers of the former), as in Table 4.10, a different picture emerges. Whereas with Other accidents there is no difference between age groups as to the accident rate in either year, this is not so of pooled Collision and Pedestrian accidents. Here there is considerable disparity between the first-year rates in the three age groups but not in the second-year rates, indicating that the older drivers' greater initial difficulty, compared with the younger drivers', was in avoiding accidents with pedestrians, buses, trolley-buses and trams; but that they can 'learn' is shown by the improvement, significant on the 5 per cent level ($t = 2{\cdot}14$), in the second year's experience over the first's for those born before 1905. Unfortunately accidents with other moving vehicles could not be identified from the records; these must necessarily, although not logically, be included in Others. In this latter category, when the age groups were pooled the decline in the accident rate for the second year compared to the first was significant on the 1 per cent level ($t = 2{\cdot}97$). This very real improvement, at a late stage in the career of many of the drivers, could only be logically associated with a gain in experience achieved from actually driving a bus.

There seems little doubt that what is apparent is a 'learning-curve' (Graph 4.1) but the data were too scanty to establish its precise

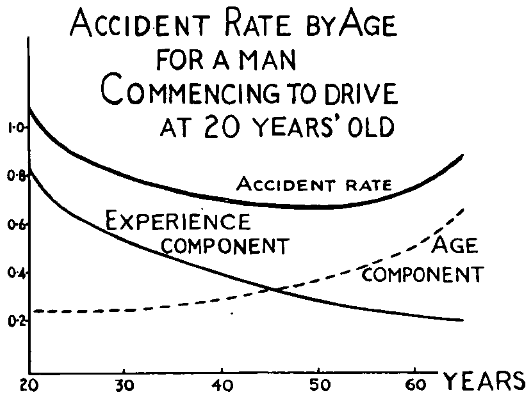
Graph 4.1



nature, and on field data of this type speculation as to the relationship between accident liability and age is unjustified since only the accident record is available as a measure of the former. However, the evidence adduced is broadly in accord with the general conclusions of experimental psychologists (e.g. Belbin, 1956), to which the data of Shooter *et al* (1956) are of immediate relevance. In the latter study nearly 700 London tram drivers, aged 26 to 67 years, attended a three-week training course for the post of bus driver. The course was rigorous and consisted of 40 hours at the wheel and 8 in the class-room. After its completion drivers were categorised as 'passes' or 'failures', and many of the latter were allowed to retake the entire course. The results showed: 'The proportions passing in three weeks show a continuous fall after the early thirties. . . . The difficulties of the unsuccessful older trainees included poor control, poor road sense, poor retention of the London positioning rules, and a lack of comprehension of the gear-box. . . . Most of those who failed at three weeks did, however, pass in four or seven weeks, so that in the proportion who passed eventually there was little fall until the sixties'. The findings of the present study are not at variance with these.

The results of this chapter show that both age and experience had independent effects on the accident rate of the drivers studied.

Graph 4.2



Without a cohort study or a planned prospective investigation it would be imprudent to draw firm conclusions, although it would appear reasonable to postulate these factors as influencing the accident rate *throughout* life and acting additively to produce a U-shaped curve of the accident rate through time. Such a curve, based on U.T.A. drivers' records, is shown in Graph 4.2. This is perforce only a sketch and not intended as an exact portrayal. This curve can be seen to be the net result of the factors of age and experience each acting independently, other things being equal. In fact its flat middle region might mask the cancellation of the experience by the age constituent, and only at the limit, in either case, is the appropriate component's action adequately revealed. But whereas the influences due to these two factors have been demonstrated to exist as group properties, the individual variation within groups is marked. This is broadly in accord with the evidence of experimental psychology that the mean performance of a group of individuals on a skilled task not only deteriorates towards later life but the scatter of individual performances around the mean if anything becomes greater. As Welford (1962) puts it: 'On the whole, however, the absence of correlation between performances at different tasks is more striking than its presence: variety seems more prominent than unity in the changes that come with age'.

The results of this chapter clearly emphasise that before examining the distributions of the accidents among the various populations considered, and before calculating certain correlation coefficients, each population must be further restricted by omitting those drivers with very little experience and also those near retirement. The net result will be to ensure, as far as possible, that each population is homogeneous not only for environmental risk (Chapter 2), but for the demonstrated influences of age and experience. 1,007 U.T.A. drivers, 244 B.C.T. trolley-bus drivers and 183 B.C.T. bus drivers provide the data for Chapters 6, 7 and 9 as they did for Chapter 3.

Section 2

Chapter 5 The Theoretical Distributions and Hypotheses

a Introduction

Epidemiology is concerned with the distribution of events in a population; it must use the tools and conform to the discipline of the science of statistics, and this is so whether the event be a biological aberration such as cancer, or an ostensibly chance happening such as an accident. To appreciate many of the theories of accident genesis requires a knowledge of complex statistical methods. For the benefit of the more general reader an attempt is made in this chapter to present the fundamental reasoning in as simple a form as possible without sacrificing accuracy or, we hope, lucidity. Such an effort must be inelegant; specialists are referred to Chapters 12 and 13 where the theoretical distributions employed by previous investigators, and those developed for this work, are treated with more sophistication.

Neither here nor in Chapter 12 is an exhaustive review of either literature or methodology attempted; for this, and especially for the rationale of bivariate as distinct from univariate analysis, readers are referred to Arbous and Kerrich (1951) whose classic article makes such a labour superfluous.

b Theory and Literature

Dr. May Smith (1943) wrote: 'When during the last war two statisticians, Professor Greenwood and Mr. Yule, had their curiosity aroused by some accident figures in munition works history was made'. By such an hyperbole May Smith did not mean to imply that these were the first two to comment on the truism that some individuals have clumsier fingers or slower reflexes than their colleagues; she was referring to the fact that they were the first (so far as is known) to formulate and express, in terms of theoretical probabilities, specific hypotheses to explain the distribution of accidents amongst individuals exposed to an equal risk of incurring an accident in an unchanging environment. Historically their paper (Greenwood and Yule, 1920) was preceded by another (Greenwood and Woods, 1919), but the two are complementary and can be considered as a single thesis.

The first hypothesis considered was that accidents were accidents in the strictest sense and their allocation to human beings at risk was analogous to the throwing of a six or the dealing of an ace. In this event the statistics of multiple accidents would conform to a type of 'pure chance' distribution, and to arrive at such a distribution the authors argued to accidents amongst persons from the situation of pigeon-holes being bombarded with billiard balls. For various reasons, some of which will be described, they adjudged the analogy to be, in the strictest sense, inapposite in the context: 'For the reasons just set out, we consider the range of experience within which the pigeon-hole schema is applicable to be narrow and dissent from the opinion that such a problem as that of random or not random distribution of [say] cases of disease in houses can be solved by an appeal to the method' (Greenwood and Yule, 1920). Suppose (they argued) that x pigeon-holes, all of equal and immutable size, are bombarded with y billiard balls in truly random fashion, i.e. the probability of a pigeon-hole receiving a billiard ball is equal and always so for all pigeon-holes, then an expression can be derived from which the probability of a pigeon-hole containing any number of billiard balls can be calculated. By direct analogy the probability of an individual incurring any given number of accidents can be reached, supposing each individual to have an equal and unchanging possibility of incurring an accident.

But there are serious objections to the pigeon-hole schema as an analogy in this context, for example the assumption is made that a specified number of accidents *must* happen to a specified number of people, the sole problem being to distribute them, whereas in the actual accident situation this is not so. But when the probability of incurring an accident is small, as is the rule, the analogy provides an answer sufficiently accurate to serve our purpose. It is emphasised that as derived in this way each individual's likelihood of incurring an accident is reckoned equal and moreover constant through time.

However the same theoretical distribution can be reached (Irwin, 1941; Arbous and Kerrich, 1951) on the more general assumption that, although each individual's likelihood of incurring an accident must be the same for all and independent of the number of accidents already sustained, it *can* change through time, but if it does so the relative rate of change must be identical for each individual.

In practice this distribution, which is similar to Poisson's (1837) approximation to the binomial, inadequately graduated the observed statistics of accidents amongst munition workers. An example is given in Table 5.1; the formula is:

$$P(r) = e^{-\lambda}.\lambda^r/(r!)$$

where $P(r)$ is the probability of an individual incurring r accidents,
λ is the mean number of accidents,
and e is the exponential.

Table 5.1 *Distribution of Accidents to 647 Women Munition Workers over 5 Weeks. (Greenwood and Yule, 1920)*

Number of Accidents	*Frequency*	
	Observed	*Poisson Series*
0	447	406
1	132	189
2	42	45
3	21	7
4	3	1
5	2	0·1

$P < 0{\cdot}001$.

Compiled from data presented by GREENWOOD, M. and YULE, G. U. (1920), 'An enquiry into the nature of frequency distributions representative of multiple happenings, with particular reference to the occurrence of multiple attacks of disease or repeated accidents', *J.R. statist. Soc.*, **83**, 255–279.

Clearly an alternative hypothesis was necessary. The first obvious modification is that after incurring an accident an individual becomes *ipso facto* subsequently more or less likely to incur another, i.e. first accidents distributed at random, subsequent accidents on some other law of probability. In the pigeon-hole schema the analogue is that the probability of a pigeon-hole receiving a billiard ball is not independent of the number of billiard balls it already contains, i.e. it is not always equal to the reciprocal of the number of pigeon-holes. Greenwood and Yule were able to arrive at a general solution to this problem but in a form unsuitable for computation; however, by making the simplifying assumption that the probability changes after the first accident but not again no matter how many accidents are subsequently incurred, a solution was reached which was easy to apply and in fact frequently reproduced the observations successfully (Table 5.2).

Table 5.2 *Distribution of Accidents to 198 Machinists over 6 Months. (Greenwood and Yule, 1920)*

Number of Accidents	*Frequency*	
	Observed	*Modified 'Biassed'*
0	69	71
1	54	49
2	43	41
3	15	23
4	13	10
5	1	3
6	2	1
7	1	0·2

$P = 0{\cdot}14.$

Compiled from data presented by GREENWOOD, M. and YULE, G. U. (1920), 'An enquiry into the nature of frequency distributions representative of multiple happenings, with particular reference to the occurrence of multiple attacks of disease or repeated accidents', *J.R. statist. Soc.*, **83,** 255–279.

The writers were, however, circumspect as to the theoretical justification for this 'biassed' schema: 'Since . . . we do not believe that the theoretical basis for this schema either in the modified or original form is appropriate to the class of problems with which we are dealing, the resultant expressions are at best mere smoothing formulae, and when their application involves a large amount of arithmetic do not have any value from that point of view' (Greenwood and Yule, 1920). But the real *gravamen* of their criticism of the theory is as follows. In the pigeon-hole schema the total area of pigeon-holes is constant; consequently this modification, which allows a pigeon-hole to expand (or contract), must accept that this happens at the expense of the other pigeon-holes. When applied to the accident situation the argument, namely that after an individual has sustained an accident his colleagues will become *ipso facto* less (or more) likely to incur one, is an apparent absurdity, but in fact it is not entirely invalid. The occurrence of an accident to a member of a group may influence the attitude of his colleagues in such a way as to affect *their* accident liabilities for a greater or lesser time; or so is the opinion of experience.

Nonetheless, because the analogy from the 'biassed' schema appears inapposite, this is not to say that the hypothesis is discredited. Suppose each person's predisposition to accident reacts in a single direction; then, when the individual accident records are examined, some should invariably show an increase with time and some a decrease, phenomena which are controverted by observation. But suppose each individual's likelihood of incurring an accident can increase after some 'types' of accident and decrease after others, then the hypothesis becomes coherent and not discordant with observation. However, in practice the problem of incorporating both these aspects into one single theoretical distribution of events is formidable.

In its 'single bias' form this theoretical distribution is of practical value in supplying a solution to the unusual frequency distribution where the mean exceeds the variance.

The next obvious modification is that of *ab initio* differentiation among the population members, by which it is supposed that individuals do not start equal but that some are inherently more likely to incur accidents than others. On the pigeon-hole schema this is analogous to supposing that the size of the pigeon-hole is a continuously distributed variable. As with any such variable the form of its distribution is of paramount importance. On the purely practical basis that accident liability (pigeon-hole size) would range from zero far into the positive direction and would be skew, a particular skewed curve, viz. the Pearson Type III, was chosen. Its selection from the range of skewed curves then available was quite arbitrary and largely for the technical reason that it was easy to fit in practice. This emphasis on technical considerations has become obscured, but Greenwood and Yule (1920) used unambiguous language: 'The choice of the binomial curve to represent the distribution of the continuously varying liabilities throughout the 'population' *has been* *dictated by considerations of practical convenience.* An infinity of skew curves fulfilling the required conditions might be imagined but no objective evidence favouring one more than another can be produced'. (Our italics).

The emergent distribution was a binomial with negative index and was termed the Distribution of Unequal Liabilities. As a rule it reproduces published accident frequency distributions appreciably better than do either the Poisson or Biassed distributions, including those compiled from data from the 14 groups of female munition workers in the original series. An example is given in Table 5.3; the formula is

$$P(r) = \left(\frac{c}{c+1}\right)^p . \frac{p(p+1)\ldots\ldots(p+r-1)}{r!(c+1)^r}$$

where p and c are determined from the first two observed moments

Mean $= p/c$.

Variance $= (p/c) + (p/c^2)$.

Since the Distribution of Unequal Liabilities (subsequently termed the Negative Binomial) successfully reproduces the statistics of most

Table 5.3 *Distribution of Accidents to 414 Machinists over 3 Months. (Greenwood and Yule, 1920)*

Number of Accidents	*Frequency*	
	Observed	*Negative Binomial*
0	296	299
1	74	69
2	26	26
3	8	11
4	4	5
5	4	2
6	1	
7	0	2
8	1	

$P = 0{\cdot}64$.

Compiled from data presented by GREENWOOD, M. and YULE, G. U. (1920), 'An enquiry into the nature of frequency distributions representative of multiple happenings, with particular reference to the occurrence of multiple attacks of disease or repeated accidents', *J.R. statist. Soc.*, **83**, 255–279.

accident frequency distributions, many investigators have imprudently concluded that the existence of unequal initial liability to accident is 'proved', and therefore it should be possible to detect persons especially susceptible to accident *before* they incur any accidents at all. The immediate corollary is that their exclusion from risk must greatly reduce the accident rate. This approach—which is discussed in detail later—has generally proved unsuccessful in that no test or battery of tests has so far been devised which would allow one to identify and exclude these *infortunés* without also excluding a large proportion whose subsequent accident record suggests that they were not in fact specifically bad risks.

The failure of such pragmatism initiates three trains of thought. Firstly, it is a serious and inconvenient snag; since only the distribution of accidents is available the *actual* distribution of accident liability (which was arbitrarily assumed to be distributed in the form of a Pearson Type III curve) cannot now be precisely computed, it can only be theorised. It is opportune to recall that Miss Ethel Newbold's (1926; 1927) extensive consideration of the Negative Binomial could not induce her to conclude that the choice of the Pearson Type III for the requisite skewness of liability was necessarily a good one, only that it was mathematically reasonable. Secondly, the assumption of 'proof', when a theoretical distribution is in concordance with the observations, is a *non sequitur* because there is in logic an infinite number of hypotheses which may produce theoretical models to graduate the data with equal success. Thirdly, since the theoretical implications of the Negative Binomial (as derived) have not been adequately supported in practice, it is mandatory to examine the known alternative hypotheses on which this theoretical distribution can arise.

These are several. The first is contained in the assumption of a population homogeneous for exposure to the risk of incurring an accident, which in the pigeon-hole schema is analogous to accepting that no pigeon-hole is especially favoured to receive a ball by virtue of its position alone. But if in fact some members of the population were more (or less) exposed to risk than their colleagues, then the resultant form of the distribution of the accidents would be compromised. In practice this reduces to the conditionality that, if the population in fact comprised several sub-populations of disparate risk exposure and in each of which accidents were randomly distributed, a Negative Binomial will emerge. In fact the difference between the mean numbers of accidents in each group need only be of a small order. This is of great practical significance because perfect homogeneity for accident risk in a reasonably sized group is an almost unattainable ideal.

The second alternative hypothesis is, that if the probability of sustaining an accident is altered by the occurrence of a previous accident then a Negative Binomial may arise if the law of change for the probability is suitably chosen: 'Our solution of the problem of *a priori* differentiation was empirical in the sense that our only justification of the particular choice [of the Pearson Type III curve] was that it ranged from $\lambda = 0$ and led to a statistically useful form. We did not suggest that no law connecting λ with r [the number of accidents] on the other [this] hypothesis would give an identical graduation' (Greenwood, 1941). On the pigeon-hole schema the analogue is, that each pigeon-hole covers initially a similar area, but after the reception of a billiard ball the size changes under a particular law which is not identical for each pigeon-hole. Such a method was formulated by Kermack and McKendrick (1925), and, although specifically applied to accident data by Irwin (1941) and elaborated by Kerrich (Arbous and Kerrich, 1951), it has inspired little comment in the literature.

The third alternative hypothesis is as follows. Suppose accidents occur at random, then the distribution of equal time intervals containing 0, 1, 2, 3 . . . individual accidents can in certain circumstances be Negative Binomial in form (Lüders, 1934). But this is the distribution of time intervals containing certain numbers of accidents *not* the distribution of accidents among persons in a given time interval which is the present problem. However, if the probability of a particular individual incurring an accident is proportional to the total number of individuals involved but is otherwise equal and immutable for all, the distribution will still be Poisson (Irwin, 1941). Recourse to the pigeon-hole analogy fails to clarify the argument.

These hypotheses are clearly coherent in the accident situation, but there must be many which are not but which can also produce a theoretical distribution, Negative Binomial in form. As an example the following may be cited. Thyrion (1960) investigated the theoretical case of events occurring in clusters ('les grappes') in which each event happened simultaneously and at least one event occurred in each cluster. On making a certain assumption as to the probability law governing the number of events within a cluster, the Negative

Binomial emerged. But to the present problem the application of such an argument would be absurd since multiple accidents cannot happen to an individual at the same point in time. Logically, if the Negative Binomial reproduces the observed statistics, then any, all or none, or a combination, of the known relevant hypotheses on which such a distribution may be derived, may be the correct one. As Greenwood (1949) stated: 'A Negative Binomial could arise in a great many ways, and if one had a Negative Binomial and it was a good fit, accident proneness might be involved or it might not'. Readers familiar with the problems of inverse probability will already have reached this conclusion.

The fact that a Negative Binomial distribution adequately graduates the observed data must not be taken to imply that it necessarily does so to the exclusion of any other; logically a large number of such distributions, each possibly derived from a number of hypotheses, could be successful. Since the assumptions contained in Greenwood's derivation of the Negative Binomial have not been satisfactorily fulfilled in practice and in the road accident situation fail to impress as realistic, one is obliged to formulate more coherent hypotheses and derive theoretical distributions from their assumptions. Then, if the distributions successfully reproduce the observations, other aspects of the data must be adduced to allow one to judge which of the hypotheses considered was the most likely in the particular circumstances. Two such theoretical distributions and their properties are derived from first principles in Section 4. A simple description of their form and underlying hypotheses is now given.

c The Long and Short Distributions

Much of the elegant simplicity of Greenwood's approach stemmed directly from his *first* postulating a readily comprehensible model, and *subsequently* tackling from first principles the problem, sometimes a very difficult one, of deducing the mathematical equation of the distribution in terms of the parameters entailed. (The parameters of a distribution are quantities which, when their values are known or estimated, enable the theoretical distribution to be calculated in any particular instance). But he paid for such simplicity; the distributions which successfully graduated the original statistics, namely the Single Bias and Negative Binomial, were derived from hypotheses so mechanistic in concept that their validity in the human situation seems hardly credible. Greenwood was well aware of this, and in his papers on the subject laboured the point that his approach had been dictated largely by considerations of practical convenience, *not* by an inherent belief in the rationale of the hypotheses involved: 'While we may, I think, be reasonably confident that the hypothesis just mentioned [that associated with the biassed pigeon-hole schema] is not of great importance in practice—which does *not* mean it is not worth further mathematical study as a matter of intellectual interest—we may be *quite* confident that the [accident] proneness hypothesis could not provide a complete description of the "universe" of industrial accidents. I am sure that no field investigator ever thought it could; all that the most enthusiastic would have inferred from the evidence, statistical and experimental, would be that [accident] proneness had an important share in fashioning the events' (Greenwood, 1941).

The hypothesis of 'proneness', about whose validity in the industrial situation one may be sceptical, seems to the present writers if anything even less coherent for road transport accidents. Here there are other individuals on the road, and any hypothesis which assigns to each driver the *animus* of a marionette seems *ab initio* discredited. Consequently, the Long and Short distributions (described below) were constructed on a less mechanistic basis, and their parameters have readily meaningful interpretations. Basically the models depend on the concept of a human being as a creature of altering efficiency and subject to 'spells', i.e. periods of time, during which his performance in a complex task, such as bus-driving, is liable to be substandard. It is fundamental that during such spells he is more likely to incur an accident.

The Long Distribution

This is derived on the hypothesis that every driver is liable to 'spells', and that no accident can occur outside a spell. It is assumed that spells are rare events, and that they occur by chance, i.e. the number of spells suffered by a driver in any one period is independent of the number he sustains in any other period. Further, all drivers are reckoned equally liable to the occurrence of a spell, and the chance of an accident occurring within a spell is taken to be constant and in no way dependent on the individual having a spell. It is speculated that a spell is associated with anything which can reasonably be assumed to interfere with a driver giving of his best at the job.

The main assumptions, stated in more precise form, are:

1 the occurrence of an accident during a spell is a rare event, so that 0, 1, 2, ... accidents could occur during any spell, with the associated probabilities $P(0)$, $P(1)$, $P(2)$, ... decreasing rapidly to zero,
2 the occurrence of a spell is a rare event in the same sense,
3 all drivers are equal in the sense that no man is more liable to sustain a spell than is another; further, all men incurring a spell are equally likely to have an accident during their respective spells, and
4 an accident cannot occur except during a spell.

If the mean number of spells per driver during a given period is represented by parameter λ, and the mean number of accidents per spell by parameter θ, then it can be shown that the probability of a man having no accidents over the whole period is given by

$$P(0) = \exp[\lambda(e^{-\theta} - 1)]$$

Let us call a spell 'fruitful' if at least one accident occurs within it, or 'abortive' if no accident results. The chance of a driver having r accidents (where $r \geqslant 1$) is now considered. The r accidents may occur in r distinct ways—

(1) in one single fruitful spell,
(2) in two separate fruitful spells,
(3) in three separate fruitful spells,
.
.
.
.
.
.
(r) in r separate fruitful spells.

In each case any further spells suffered are abortive.

Thus we may write the probability of a man suffering r accidents over the period as

$$P(r) = \sum_{k=1}^{r} P(r, k) \tag{1}$$

where $P(r, k)$ is the probability of suffering r accidents in k separate and fruitful spells.

It can be established that

$$P(r, k) = P(0).\frac{\theta^r}{r!}\begin{bmatrix} r \\ k \end{bmatrix}\frac{(\lambda\,\mathrm{e}^{-\theta})^k}{k!} \tag{2}$$

where $\begin{bmatrix} r \\ k \end{bmatrix}\Big/\{(r!)(k!)\}$ is the number of ways in which the r accidents can occur in k fruitful spells. In any particular instance this can be readily calculated using a table of the leading differences of zero. Thus immediately from (1) and (2) can be written

$$P(r) = P(0).\frac{\theta^r}{r!}.\sum_{k=0}^{r}\left\{\begin{bmatrix} r \\ k \end{bmatrix}\frac{(\lambda\,\mathrm{e}^{-\theta})^k}{k!}\right\} \tag{3}$$

For the purpose of illustration, the first four terms of the probability distribution are supplied below.

$$P(0) = \exp[\lambda(\mathrm{e}^{-\theta} - 1)]$$

$$P(1) = P(0).\theta\{(\lambda\,\mathrm{e}^{-\theta})\}$$

$$P(2) = P(0).\frac{\theta^2}{2!}\{(\lambda\,\mathrm{e}^{-\theta}) + (\lambda\,\mathrm{e}^{-\theta})^2\}$$

$$P(3) = P(0).\frac{\theta^3}{3!}\{(\lambda\,\mathrm{e}^{-\theta}) + 3(\lambda\,\mathrm{e}^{-\theta})^2 + (\lambda\,\mathrm{e}^{-\theta})^3\}$$

By the very nature of the problem we do not know what values to assign to the parameters λ and θ in any particular case in practice. However the following simple equations relating to the mean and variance of the distribution can be readily established.

$$\text{Mean} = \lambda\theta$$
$$\text{Variance} = \lambda\theta\,(1 + \theta).$$

Given the data from a reasonably large sample, substitution of the values of the sample mean and variance into the above equations will yield estimates of λ and θ to be employed. Thus the frequencies of those drivers expected, (according to the model), to incur 0, 1, 2, . . . accidents over the period can be calculated.

It can be demonstrated (Section 4) that the Long distribution and the Neyman Type A (Neyman, 1939) are formally equivalent in the mathematical sense that the actual frequencies obtained in any case in practice are identical. This is of interest; but the fact that a distribution can adequately graduate two such disparate classes of data as those from the present study and those used by Neyman, neither credits nor discredits either hypothesis. Probability laws are not unique to one set of phenomena.

However assumption (4) in the premises leading to the Long model seems unduly restrictive in the present circumstances. More precisely there are human beings on the roads other than bus drivers, and it therefore appears unrealistic to require every accident sustained by a bus driver to coincide with his having a 'spell'. Only if culpable accidents were alone considered would this thesis be defensible. Thus a way was sought to relax this stringency, and the more general Short distribution was evolved.

The Short Distribution

Assumptions 1–3 as listed in the previous sub-section are retained, and it is now specifically assumed that accidents *can* occur outside a spell. Such accidents, which are for the moment termed 'chance' accidents, are assumed to be rare events (in the previous sense), and all drivers are reckoned to be equally liable to incur such an accident. Further, chance accidents are assumed to occur independently both of spells and accidents within spells.

If ϕ denotes the mean number of 'chance' accidents per man and the parameters λ and θ retain their previous meanings, then the following formula can be shown to yield the probability of a driver incurring r accidents over the period, where $r \geqslant 1$.

$$P(r) = P(0) . \sum_{j=0}^{r} \left[\frac{\theta^{r-j}}{(r-j)!} . \frac{\phi^j}{j!} . \sum_{k=0}^{j} \left\{ \begin{bmatrix} j \\ k \end{bmatrix} . \frac{(\lambda\, e^{-\theta})^k}{k!} \right\} \right]$$

where $\quad P(0) = \exp[\lambda(e^{-\theta} - 1) - \phi]$

This expression, while appearing formidable, can be evaluated using a desk calculating machine, and with ease using an electronic computer.

Again it is mandatory to estimate the values of the three parameters to be employed in a particular case. These are obtained from the first three moments, the second two being taken about the mean of the observed distribution. If the first three moments are written as μ_1', μ_2 and μ_3, then the following equations can be established.

$$\mu_1' = \lambda\theta + \phi$$

$$\mu_2 = \lambda\theta(1 + \theta) + \phi$$

$$\mu_3 = \lambda\theta(1 + 3\theta + \theta^2) + \phi$$

Substitution of the sample values, in the case of a large sample, into the above three equations leads to the estimates of the parameters required to enable the distribution to be fitted in practice. However it is to be emphasised that the observed third moment is unlikely to provide a reliable estimate of the population third moment in the case of a small sample. Consequently, for small samples a modification of the procedure is introduced. The resultant Modified Short Distribution makes the assumption that the proportion of 'chance' accidents to all accidents is known to be, say, q. Then the use of the equation

$$\phi = q\mu_1'$$

in place of that involving the third moment will yield the required values of the parameters.

The graduations obtained with the Poisson, Negative Binomial, Long and Short distributions, applied to the present data, are given in Chapter 9, but an example is tabulated here (Table 5.4). Full details relating to these distributions appear in Section 4; examples of how to fit all but the Poisson are given in the Appendix (Tables A. 39 to A. 43).

Since both the Negative Binomial and Short distributions adequately reproduce the observed frequency distributions compiled from the present data, the respective abilities of their associated hypotheses to describe other aspects of the statistics must be considered. Such a comparison is the main objective of the rest of this Section.

Table 5.4 *U.T.A. (Excluding Ballymena, Derry and Newry) 1952–1955. Observed and Various Theoretical Frequencies for differing Numbers of Accidents (r)*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = Neyman Type A*	*Short*
0	117	71·5	110·4	116·7	110·4
1	157	164·0	168·5	162·0	169·7
2	158	187·9	156·8	153·1	156·0
3	115	143·6	114·7	115·3	113·9
4	78	82·3	72·5	74·6	72·5
5	44	37·7	41·5	43·2	41·9
6	21	14·4	22·1	22·8	22·5
7	7		11·2	11·3	11·3
8	6	6·5		5·3	5·4
$\geqslant 9$	5		10·3	3·7 } 9·0	4·4 } 9·8
χ^2		64·174, $\nu = 6$	3·436, $\nu = 6$	2·705, $\nu = 6$	3·787, $\nu = 5$
P		$P < 0{\cdot}001$	$0{\cdot}80 > P > 0{\cdot}70$	$0{\cdot}90 > P > 0{\cdot}80$	$0{\cdot}70 > P > 0{\cdot}50$
Significance		Very Highly Significant	Not Significant	Not Significant	Not Significant

Chapter 6 The Association between the Numbers of Accidents sustained in Different Periods of Time

a Introduction

In Greenwood's derivation of the Negative Binomial, 'personal liability to accident' (λ) was postulated to be a variable parameter with a skewed distribution among the population, and in addition each individual's 'personal liability' was assumed constant through time. Consequently, if *ab initio* differentiation between individuals is responsible for the particular skewness of the frequency distributions of accidents, this should be reflected in the correlation between the numbers of accidents incurred by individuals in two periods of exposure, always provided the accident record is accepted as a reliable criterion of accident liability. To quote Greenwood and Woods (1919): 'It is evident that if the C.D. [Chance Distribution] principle held, the previous record of any individual would be without influence upon his or her subsequent experience, just as if in one particular set of tosses a certain coin fell heads five times running, that coin would be neither more nor less likely to fall heads five times in a subsequent experience. But if some one coin were biassed in favour of falling heads, then its records in successive experiments would naturally be interrelated'.

Accepting the thesis of initial unequal liability one would expect the correlation coefficients to be as follows:

1 significant and reasonably stable,
2 independent of the length of the interval between the time-periods the accidents within which are being correlated, and
3 not tend to become non-significant even if these periods are separated by a very long interval.

On the hypothesis underlying the Short distribution, anticipating the behaviour of the correlation coefficients is more hazardous but certain points should be affirmed. The hypothesis, although denying stable liability to accident, does not require one to accept that accidents incurred in one period are necessarily independent of the number incurred in any other; and certain accidents are allowed to occur entirely 'by chance'. It can be surmised that, if this hypothesis were tenable, the correlation coefficients between the numbers of accidents incurred in two observational periods might behave as follows:

1 be small and possibly significant,
2 tend to decrease as the interval between the observational periods gets longer, and
3 tend to become non-significant provided sufficient time elapses between the observational periods.

But a caution is necessary. When formulating the expected behaviour of the correlation coefficients in these instances, homogeneity among the population as to the risk of incurring an accident was assumed. Although the relevant variables of age and experience can be controlled to some extent, an equal-risk environment cannot be exactly realised in practice; thus a small correlation in itself may only indicate a departure from this ideal. This simple fact has been too seldom stressed in the literature, but an example from the present study serves as an illustration. The correlation coefficient between the numbers of accidents sustained by U.T.A. drivers (omitting Derry drivers) in the two periods 1952–1953 and 1954–1955, was 0·275. When Ballymena and Newry drivers, whose risk exposure appeared to differ from that of the principal U.T.A. population, were excluded, the value of the correlation coefficient fell to 0·236.

In this chapter the results of the present study are given first, followed by an appraisal to judge whether they, and those from the reliable literature, specifically favour one or other hypothesis. Further implications of the findings are discussed elsewhere in this work.

b Results

The Association between Accidents in Different Years

The data available for individual years indicated that only in the case of B.C.T. drivers was it worthwhile considering so short a period. Successive coefficients of correlation were calculated for B.C.T. bus drivers; they are of a small order and certainly not significant (Table 6.1).

Data from B.C.T. trolley-bus drivers presented a different picture

Table 6.1 *B.C.T. Bus Drivers. Correlation Coefficient (r) between the Numbers of Accidents sustained in Individual Years*

Years	*r*
1952 and 1953	−0·031
1952 and 1954	−0·061
1952 and 1955	+0·084

(Table 6.2). Here the coefficients are larger, and the fluctuation in their values is quite considerable.

In order to include the information from the U.T.A., and because of the equivocal results obtained from considering intervals of only one year, each observational period was extended to two years. The

Table 6.2 *B.C.T. Trolley-Bus Drivers. Correlation Coefficient (r) between the Numbers of Accidents sustained in Year x and Year y*

y	*x*			
	1951	*1952*	*1953*	*1954*
1952	0·097			
1953	0·111	0·266		
1954	0·148	0·136	0·259	
1955	0·052	0·216	0·118	0·185

relevant results appear in Table 6.3; the bivariate frequency distributions for the six populations under review and on which these results are based, are tabulated at the end of the chapter.

In Table 6.3 the column headed 'Theoretical' supplies the values which the correlation coefficients would assume if the Bivariate Negative Binomial distribution was the theoretical basis for the incidence of accidents. These values are in fair agreement with those observed, except in two instances. The 'Standard Error of *r*' is that derived from customary theory; the 'Standard Error for Zero *r*' is that for a large sample where the population is assumed to have zero correlation (its value is $1/\sqrt{(N-1)}$, where N is the number of individuals). The respective values in these two columns are nearly identical.

Table 6.3* *Correlation Coefficients (r) between the Numbers of Accidents sustained during the Periods 1952–1953 and 1954–1955*

Population (Drivers)	*Correlation Coefficient (r)*		*Standard Error of r*	*Standard Error for Zero r*
	Observed	*Theoretical*		
U.T.A. (minus Ballymena, Newry and Derry)	0·236	0·200	0·036	0·038
U.T.A. Ballymena	0·231	0·119	0·095	0·098
U.T.A. Derry	0·244	0·232	0·092	0·094
U.T.A. Newry	0·420	0·237	0·103	0·113
B.C.T. Bus	0·262	0·267	0·072	0·074
B.C.T. Trolley-Bus	0·297	0·335	0·061	0·064

* Terms explained in text.

The precise evaluation of the significance of a correlation coefficient obtained in the present circumstances is conjectural. However the fact that, for the populations in order, the ratio of the coefficient to its standard error is given by 6·56, 2·43, 2·65, 4·08, 3·66 and 4·83 would suggest that the correlations observed are indeed real. Thus it may provisionally be assumed that the number of accidents an individual driver sustained in any period was not independent of the number sustained by him in the preceding period. This is patently inconsistent with the thesis that accidents are due solely to 'pure chance', as classically defined.

The statistics from the largest three populations, viz. U.T.A. drivers (excluding Ballymena, Derry and Newry), B.C.T. bus drivers, and B.C.T. trolley-bus drivers, were examined to determine how far the regression of the following period's accidents on the preceding period's could be regarded as linear. Relevant information is presented in Table 6.4. The difference between the correlation coefficient and the correlation ratio is of the same order as the standard error of the correlation coefficient; thus it may be anticipated that the regression could well be linear in each case. The standard errors of the three regression coefficients in Table 6.4 are (in order), 0·032, 0·076 and 0·055; thus it can be surmised that the three populations may be regarded as having identical regression coefficients, so that those drivers having x accidents in the first period are likely to have y

Table 6.4 *Relationship between the Number of Accidents (x) sustained during 1952–1953 and the Number (y) sustained during 1954–1955*

Population (Drivers)	*Correlation Coefficient*	*Regression Coefficient of y on x*	*Correlation Ratio of y on x*
U.T.A.	0·236	0·204	0·260
B.C.T. Bus	0·262	0·280	0·336
B.C.T. Trolley-Bus	0·297	0·268	0·360

in the second period if working in the same environment, where x and y are connected by a relationship of the form $y - \bar{y} = b(x - \bar{x})$, with b independent of the environment. This hypothesis is now put to the test.

The Linearity of the Regression of the Following Period's Accidents on the Preceding Period's Accidents

Information relating to the bivariate distributions of the three populations considered in Table 6.4, is displayed in Table 6.5, where x refers to the accidents of the preceding period (1952–1953) and y to those in the following period (1954–1955).

If we write

$$\gamma_j = \sum_{i=1}^{N_j} (y_{ij} - \bar{y}_j)^2$$

$$\alpha_j = \sum_{i=1}^{N_j} (x_{ij} - \bar{x}_j)^2$$

and

$$\beta_j = \sum_{i=1}^{N_j} [(x_{ij} - \bar{x}_j)(y_{ij} - \bar{y}_j)]$$

then of the total sum of squares corresponding to γ_j, the linear regression accounts for $(\beta_j)^2/\alpha_j$ for each population j, where $j = 1$, 2, 3. Thus for the regression to be a reasonable fit in each case the variance ratio arising from the sums of squares $(\beta_j)^2/\alpha_j$ and $[\gamma_j - \{(\beta_j)^2/\alpha_j\}]$, with $(1, N_j - 2)$ degrees of freedom, should be significant. Table 6.6 shows that in fact the variance ratio in each

Table 6.5 *Information derived from the Bivariate Distributions*

Population (j)	U.T.A. Bus Drivers (1)	B.C.T. Bus Drivers (2)	B.C.T. Trolley-Bus Drivers (3)
Σx^2	2,310	1,170	2,217
Σx	914	358	561
Σxy	1,146	863	1,453
Σy	709	374	524
Σy^2	1,555	1,298	1,880
N	708	183	244

case is very highly significant on the 0·1 per cent level, and consequently the regression of the following period's accidents on the previous period's will be assumed, *ad interim*, to be linear.

Table 6.6 *Information on the relevant Sums of Squares*

Population (j)	U.T.A. Bus Drivers (1)	B.C.T. Bus Drivers (2)	B.C.T. Trolley-Bus Drivers (3)
γ_j	844·998 588	533·650 273	754·688 525
α_j	1,130·062 147	469·650 273	927·159 836
β_j	230·709 040	131·349 727	248·229 508
$(\beta_j)^2/\alpha_j$	47·100 650	36·735 315	66·458 755
$\gamma_j - [(\beta_j)^2/\alpha_j]$	797·897 938	496·914 958	688·229 770
$N_j - 2$	706	181	242

To establish whether the three regression lines can be accepted as having the same slope, a method, discussed by Tippett (1952 a), is employed below.

The sum

$$\sum_{j=1}^{3} [\gamma_j - \{(\beta_j)^2/\alpha_j\}]$$

with $$\sum_{j=1}^{3} (N_j - 2)$$ degrees of freedom

provides an estimate for the residual variance of y, which is initially assumed to be identical for each population. Allowing the three populations to have different means for y, but assuming the same slope obtains, the residual sum of squares from the regression lines with common slope is given by

$$\sum_{j=1}^{3} \gamma_j - \left\{ \left(\sum_{j=1}^{3} \beta_j \right)^2 \Big/ \sum_{j=1}^{3} \alpha_j \right\}$$

with $\sum_{j=1}^{3} (N_j - 1) - 1$ degrees of freedom.

But these two estimates are not independent, hence

$$\sum_{j=1}^{3} \{(\beta_j)^2/\alpha_j\} - \left\{ \left(\sum_{j=1}^{3} \beta_j \right)^2 \Big/ \sum_{j=1}^{3} \alpha_j \right\}$$

with two degrees of freedom provides the required independent estimate, which may be compared with the first.

Table 6.7 presents the relevant statistics for the problem under discussion. Since the first variance is less than the second the slopes of the regression lines are not significantly different. This finding was not anticipated; one might intuitively have expected the regression line to vary with the mean number of accidents.

Table 6.7 *Analysis of Variance*

Residual Variance	*Sums of Squares*	*D.F.*	*Mean Squares*
Difference due to Common Slope assumption	2·898 358	2	1·449 179
Due to Completely Independent Lines	1,983·042 666	1,129	1·756 459
Due to Common Slope Lines	1,985·941 024	1,131	

Tests for Non-Linearity of Regression

Previously the regression of the following period's accidents on the previous period's was taken to be linear. This is a simple and coherent hypothesis which can be readily given an immediately meaningful interpretation. Nevertheless, while it is much more difficult to understand what real construction can be attached in the present instance to, say, a second order regression, it is necessary to examine if curvilinear regression would describe the data more completely than the linear hypothesis. A formal development follows.

Consider the data on U.T.A. bus drivers in Table 6.18. Suppose the columns in this table are divided into 7 arrays, corresponding to $x = 0, 1, 2, 3, 4, 5, \geqq 6$. Then the array means, $\bar{y}_i$, of 0·77, 0·95, 1·07, 1·25, 1·96, 1·45 and 2·50 respectively, indicate the curved regression of y on x. Denote the numbers of individual drivers within the arrays by n_i, where $1 \leqq i \leqq 7$. It is seen that $n_1 = 224$, $n_2 = 226$, and so on. Let $\bar{y}$ denote the overall mean number of accidents per driver over 1954–1955, (in this case $\bar{y} = 1{\cdot}00$). The following equation holds for any array i, where the summation is over the individuals in array i,

$$\sum (y - \bar{y})^2 = \sum (y - \bar{y}_i)^2 + n_i(\bar{y}_i - \bar{y})^2.$$

Now sum over all arrays,

$$\sum\sum(y - \bar{y})^2 = \sum\sum (y - \bar{y}_i)^2 + \sum n_i(\bar{y}_i - \bar{y})^2.$$

The left-hand side is the total sum of squares with $(N - 1)$ degrees of freedom (where N is the total number of drivers), and the second term on the right-hand side corresponds to the sum of squares between arrays with $(m - 1)$ degrees of freedom (where m is the number of arrays). Of the latter sum of squares, linear regression accounts for $r^2 \sum\sum (y - \bar{y})^2$ with one degree of freedom. In order to test for non-linearity it is necessary that the mean square corresponding to the difference between the last two sums of squares, i.e. deviation from linear regression, should be significantly greater than the residual.

Since the distributions within arrays are not normal the customary variance ratio test is not strictly valid. Whereas it is conceivable that an appropriate transformation of the variate y would have 'normalised' the variance and enabled more confidence to be placed in the test, this was not performed because of the patent difficulty of subsequently ascribing a coherent interpretation to such a result if, in fact, significance (which is more than doubtful) had been achieved. The Analyses of Variance (Tables 6.8–6.10) provide some guidance as to whether curvilinear rather than linear regression is more appropriate.

There can be little doubt that in each instance the assumption of linear regression is reasonable; in fact there is scant indication from the figures that the improvement due to introducing curvilinear

Table 6.8 *Analysis of Variance, U.T.A. Drivers*

Source of Variation	*D.F.*	*Sums of Squares*	*Mean Squares*	*Variance Ratio*
Linear Regression (L.R.)	1	47·100 7		41·82***
Deviation from L.R.	5	8·281 2	1·656 2	1·47
Between Arrays	6	55·381 9		
Residual within Arrays	701	789·616 7	1·126 4	
Total	707	844·998 6		

Table 6.9 *Analysis of Variance, B.C.T. Bus Drivers*

Source of Variation	*D.F.*	*Sums of Squares*	*Mean Squares*	*Variance Ratio*
Linear Regression (L.R.)	1	36·735 3		13·36***
Deviation from L.R.	5	12·791 1	2·558 2	0·93
Between Arrays	6	49·526 4		
Residual within Arrays	176	484·123 9	2·750 7	
Total	182	533·650 3		

Table 6.10 *Analysis of Variance, B.C.T. Trolley-Bus Drivers*

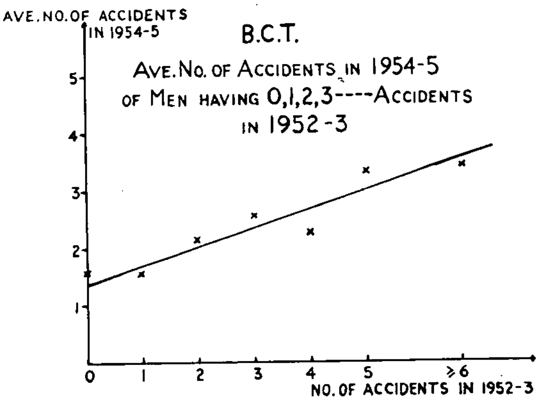
Source of Variation	*D.F.*	*Sums of Squares*	*Mean Squares*	*Variance Ratio*
Linear Regression (L.R.)	1	66·458 8		23·85***
Deviation from L.R.	6	30·705 8	5·117 6	1·84
Between Arrays	7	97·164 6		
Residual within Arrays	236	657·523 9	2·786 1	
Total	243	754·688 5		

*** Significant on the 0·1% level.

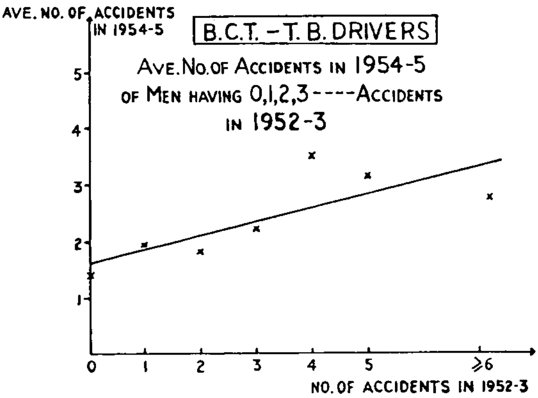
regression is real since the variance ratio is not significant in each case. It is worth noting that in the case of B.C.T. bus drivers the mean square due to the improvement is even less than that of the residual!

Graphs 6.1 and 6.2 illustrate the relationship between the numbers of accidents sustained in each two-year period. It is emphasised that since the scatter about the regression lines is considerable these graphs contain only part of the story.

Graph 6.1



Graph 6.2



c Discussion and Conclusions

Most studies, both of industrial and road accidents, which evaluate the correlation coefficient between the numbers of accidents sustained by a group in certain periods, do so between one pair of observational periods only. Some of the coefficients obtained are appreciable and frequently many times their probable error (e.g. Greenwood and Woods, 1919; Newbold, 1926) or standard error (e.g. Häkkinen, 1958); some are of a small order and often not significant (e.g. Bransford, 1939; Forbes, 1939; Adelstein, 1952; Moffie and Alexander, 1953). In some of these studies the experimental groups have been patently heterogeneous with respect to risk, and/or the observational periods have been short. Also, some are concerned with minor industrial data where the 'tendency to report' error plays an important role in the ascertainment. It is probably not irrelevant that in such instances the coefficients are usually of a higher order. But some investigators have presented more complete statistics. Of these, the studies of Farmer and Chambers (1929; 1939), Farmer, Chambers and Kirk (1933), and Häkkinen (1958) are the most reliable; they, together with the present investigation, provide the data which are now further examined.

The statistics can best be appreciated in tabular form (Tables 6.11–6.15). These are not all the tables of this type which can be compiled from the literature, but they contain data which the writers adjudge to be reasonably valid. This is not to infer that the data are completely convincing or even that they fully satisfied their propagators: 'The intercorrelations between different periods of exposure, given in Report No. 55 [Farmer and Chambers (1929)], are higher . . . the mean being 0·358, but this was obtained from groups that were not strictly homogeneous. Each year's entry into the dockyard was treated as a group in spite of the fact that the members were employed in different trades; not allowing for this in the previous investigation would account for the greater magnitude of the correlation coefficients between successive years' accidents, for the members of the groups would be constantly exposed to unequal accident risks throughout the observed period . . . ' (Farmer, Chambers and Kirk, 1933). Again, when describing the data in Table 6.14, Häkkinen (1958) wrote: 'There are among the group members both drivers who had been hired just at the beginning of the period of exposure and drivers who had been employed for several years prior to it. There are also great variations in the ages of the drivers'. But the statistics derived during the present study do not invite such strictures: very inexperienced drivers, and also those near retirement, were excluded because of the findings in Chapter 4.

Scrutiny of Tables 6.2 and 6.11–6.15 invites the following tentative conclusions as to the correlation coefficients.

1 Although always positive the majority are of a small order. This is especially true of those computed from transport data.
2 They vary, often considerably.
3 That between the numbers of accidents in the first and any other equal period of time is greatest for the first two periods.
4 That for the first and any other period gets progressively smaller as the periods become more remote (the sole exception is in Table 6.13, but those concerning the fifth year seem unusual).
5 Generally the value of those obtained between contiguous periods decreases as time goes on.

The results indicate that (if the environmental risk is assumed to be constant) the group, each member of which has a higher number of accidents than each member of another group in one period, is more likely also to have a higher average number of accidents per man than the other group in a subsequent period. It is emphasised that this is a group property and that prediction as to any individual driver's performance in a succeeding period, having sole regard for his accident record in the past, would be hazardous.

However, the valid interpretation of the results poses fundamentally difficult problems. If one assumes, although such an assumption may not be justified, that the description of a correlation coefficient (in the present instance) as significant or not significant is accurate, then the apparent significance of the correlation between the numbers of accidents in successive periods of time might seem to favour the hypothesis of *ab initio* differentiation. But clearly the hypothesis underlying the Short model could equally well explain the obtained values of the correlation coefficient, because sufficient 'spells' can be imagined to straddle the junction between the consecutive periods and hence provide a small correlation. Again, the small order of the correlation coefficient might be thought to weigh against the concept of *ab initio* differentiation, but it is shown in Chapter 10 that accident liability, as conceived by Greenwood, is imperfectly reflected in the accident record. If of course the correlation coefficients were not significant, this would nearly be sufficient *ipso facto* to discredit completely the theory of *ab initio* differentiation between drivers as regards their accident liability.

The only conceivable way, in this context, to adjudge the merits of the hypotheses underlying the Negative Binomial and Short distributions, would be to demonstrate unequivocally whether the correlation coefficient is stable or whether it decreases as the gap between the relevant periods widens. The suspicion (and it can be no more) is that the value of the correlation coefficient does in fact decrease through time, a suspicion which was awarded the dignity of a conclusion by Farmer and Chambers (1929; 1939), Farmer, Chambers and Kirk (1933), and Häkkinen (1958). The following quotations will serve as illustration. 'It is interesting to note that the correlation between *successive* years' accidents is in all cases slightly higher than that between *non-successive* years' (Farmer and Chambers, 1929). 'The correlation between the accidents sustained in the contiguous periods is slightly larger than that of the non-contiguous periods. . . . but still much lower than that obtained by previous investigators' (Farmer, Chambers and Kirk, 1933). 'The correlations decrease, on the average, as the interval between the two periods increases' (Häkkinen, 1958).

Thus while there seems little to choose between the two hypotheses under test, the one associated with the Short model appears slightly more plausible in explaining the statistics with respect to correlation.

Tables 6.11–6.15. Correlation Coefficients between the Numbers of Accidents incurred in Different Years

Table 6.11 *Data from Farmer and Chambers (1929).*

Group III (524 R.A.F. Apprentices)

Years	*1*	*2*
2	0·382	
3	0·338	0·443
Group IV (259 R.A.F. Apprentices)		
Years	*1*	*2*
2	0·390	
3	0·223	0·360
Group VII (100 Royal Dockyard Apprentices)		
Years	*1*	*2*
2	0·327	
3	0·327	0·246

Re-cast from FARMER, E. and CHAMBERS, E. G. (1929), *A Study of Personal Qualities in Accident Proneness and Proficiency.* Rep. Industr. Fat. Res. Bd., London, No. 55. H.M. Stationery Office.

Table 6.12 *Data from Farmer, Chambers and Kirk (1933).*

Shipwrights (101 Boy Apprentices)

Years	*1*	*2*	*3*	*4*
2	0·440			
3	0·357	0·187		
4	0·278	0·178	0·195	
5	0·245	0·199	0·136	0·104

Re-cast from FARMER, E., CHAMBERS, E. G. and KIRK, F. J. (1933), *Tests for Accident Proneness.* Rep. Industr. Hlth. Res. Bd., London, No. 68. H.M. Stationery Office.

Table 6.13 *Data from Farmer and Chambers (1939).*

Group A. (166 London Bus Drivers)

Years	*1*	*2*	*3*	*4*
2	0·298			
3	0·235	0·328		
4	0·177	0·176	0·212	
5	0·274	0·265	0·273	0·224

Re-cast from FARMER, E. and CHAMBERS, E. G. (1939), *A Study of Accident Proneness amongst Motor Drivers.* Rep. Industr. Hlth. Res. Bd., London, No. 84. H.M. Stationery Office.

Table 6.14 *Data from Häkkinen (1958)*

Group A. (101 Helsinki Bus Drivers)

Years	*Correlation Coefficient*
6/5	0·370
6/4	0·191
6/3	0·250
6/2	0·242
6/1	0·034

Reproduced completely from HÄKKINEN, S. (1958), *Traffic Accidents and Driver Characteristics. A Statistical and Psychological Study*, p. 35. Helsinki: Finland's Institute of Technology, Scientific Researches, No. 13.

Table 6.15 *Present Investigation.*

U.T.A. Bus Drivers (380 men)

Years	*1952–1953*	*1954–1955*
1954–1955	0·239	
1956–1957	0·198	0·246

Tables 6.16 and 6.17 *Number of B.C.T. Drivers having x Accidents in 1952–1953 and y Accidents in 1954–1955*

B.C.T. Bus Drivers

	x										
y	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
0	8	13	6	0	2	1					30
1	9	15	16	8	4	1	1		1		55
2	4	14	10	7	1		1			1	38
3	3	7	8	3	3	1					25
4	5	4	2	5	3	1	1				21
5		1	3	1	1	1	1				8
6			2								2
7						1					1
8			1	1							2
9							1				1
Total	29	54	48	25	14	6	5	0	1	1	183

B.C.T. Trolley-Bus Drivers

	x												
y	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*15*	*Total*
0	12	9	12	6	1	2	1	0					43
1	11	16	18	6	0	1	2	1					55
2	9	8	15	12	4	6	2	1			1		58
3	5	11	9	5	11	1	0	2					44
4	3	5	4	2	3	3	1						21
5		1	3	3	2	0	0					1	10
6		2	1	2	2	2	1						10
7				0	0	0	1						1
8					0	0							0
9					1	0							1
10						0							0
11						1							1
Total	40	52	62	36	24	16	8	4	0	0	1	1	244

Tables 6.18 and 6.19 *Number of U.T.A. Drivers having x Accidents in 1952–1953 and y Accidents in 1954–1955*

U.T.A. (excluding Ballymena, Derry and Newry)

	x								
y	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*Total*
0	117	96	55	19	2	2	0	0	291
1	61	69	47	27	8	5	1	0	218
2	34	42	31	13	7	2	3	0	132
3	7	15	16	7	3	1	0	0	49
4	3	3	1	1	2	1	1	1	13
5	2	1							3
6					1				1
7				1					1
Total	224	226	150	68	23	11	5	1	708

U.T.A. Ballymena

	x						
y	*0*	*1*	*2*	*3*	*4*	*5*	*Total*
0	12	22	9	6	0	1	50
1	7	12	11	1	1	1	33
2	5	5	6	0	0		16
3	1	0	1	2	2		6
4						1	1
Total	25	39	27	9	3	3	106

Tables 6.20 and 6.21 *Number of U.T.A. Drivers having x Accidents in 1952–1953 and y Accidents in 1954–1955*

U.T.A. Derry

y	x							
	0	*1*	*2*	*3*	*4*	*5*	*6*	*Total*
0	12	10	13	2	1	1	0	39
1	11	11	10	3	0	0	1	36
2	10	3	3	3	2	1	0	22
3	1	0	4	2	2	1	0	10
4	1	1	2	0	0	1	1	6
5	0	1	0	0	0	0	0	1
Total	35	26	32	10	5	4	2	114

U.T.A. Newry

y	x								
	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*Total*
0	5	6	4	1	1				17
1	4	9	3	4	3				23
2	2	5	5	4	2				18
3	1	6	4	1	1	2	1		16
4			0	2	0				2
5			1		0				1
6					1			1	2
Total	12	26	17	12	8	2	1	1	79

Chapter 7 The Time-Interval between Successive Accidents

a Introduction

Inquiries into the frequency of events in a population at risk over a fixed period of time are many; those into the time-interval between such events are few. Among the latter the study of Maguire, Pearson and Wynn (1952) of the temporal distribution of mine-explosions is notable. However, though there are practical and technical problems which are hard to resolve, by omitting such an examination the investigator fails to utilise the complete information afforded by his data. Consequently in this chapter such an analysis is attempted. The method employed is so devised that the results are not irrelevant to the current problem, viz. whether they can be adduced to favour specifically one or other of the hypotheses under consideration.

Only time-intervals between successive accidents *both* of which occur within the period 1952–1955 are examined. This must be less than satisfactory, but the problem of 'open' intervals, e.g. where an accident has occurred after the start of the period and another has not occurred by the end of the period, is difficult of solution. Also, it is acknowledged that in this context four years must be adjudged a short observational period.

It is emphasised that the approach employed here is largely exploratory.

b Method

The following result, originally due to Whitworth (1901), is of prime importance in the sequel.

Let an accident occur at random on the average once in a time of m units, when observed over a long period. Then the probability of an accident occurring in the small period of time δt, is $\delta t/m$, and the probability of non-occurrence is given by $1 - (\delta t/m)$.

Consider a total time $t = n.\delta t$. Then the probability of non-occurrence in time t equals $[1 - (\delta t/m)]^n$. For finite t, let $n \to \infty$. Then the probability of non-occurrence, in time t, is

$$q = \operatorname*{Lt}_{n\to\infty}\left[1 - \left(\frac{t}{m}\cdot\frac{1}{n}\right)\right]^n = \exp(-t/m).$$

Consequently, the probability of at least one accident occurring from time zero up to time t,

$$p = 1 - \exp(-t/m).$$

Since $dp/dt = (1/m)\exp(-t/m)$, a monotonically decreasing function of time, clearly the first accident is more likely to occur in the earlier of two equal time-intervals.

Repeaters

The following treatment is approximate and the error involved may be the greater the larger the value of the number of accidents sustained (r).

Consider, for example, a man having precisely r accidents over 4 years. Then, by the previous result, the (approximate) probability of any particular accident not being followed by another within a month, $q = \exp(-r/48)$. Also, the probability of any particular accident being followed by another within one month,

$$p = (1 - q) = 1 - \exp(-r/48).$$

But the man considered had r accidents and hence $(r - 1)$ observed time-intervals between consecutive accidents. Thus the probability that none of his $(r - 1)$ time-intervals is less than one month is given by

$$q^{r-1} = \exp[-r(r - 1)/48].$$

Hence the probability of his experiencing at least one time-interval of less than one month is

$$1 - q^{r-1} = 1 - \exp[-r(r - 1)/48].$$

A man incurring at least one time-interval of less than one month is subsequently called a 'Repeater'. If N men have in fact incurred r accidents each, then the expected number of Repeaters is given by

$$E(N) = N\{1 - \exp[-r(r - 1)/48]\}.$$

For example, for four men each having seven accidents over four years, the expected number of Repeaters is

$$\begin{aligned} E(4) &= 4\{1 - \exp(-42/48)\} \\ &= 4 \times 0{\cdot}583\ 1 \\ &= 2{\cdot}33. \end{aligned}$$

Double-Repeaters

As before, consider N men each having precisely r accidents over four years. Then the distribution of repeated time-intervals of less than one month is approximately given by expansion of the binomial $(q + p)^{r-1}$. In particular, the probability of a man having no time-intervals of less than one month is given by

$$P(0, r) = q^{r-1},$$

and the probability of his having exactly one such interval is

$$P(1, r) = (r - 1)pq^{r-2}.$$

Thus the probability of a man incurring fewer than two time-intervals less than one month is

$$\begin{aligned} P(<2, r) &= P(0, r) + P(1, r) \\ &= q^{r-1} + (r - 1)pq^{r-2} \\ &= (r - 1)q^{r-2} - (r - 2)q^{r-1} \\ &= \{(r - 1)\exp[-r(r - 2)/48]\} \\ &\qquad - \{(r-2)\exp[-r(r-1)/48]\} \end{aligned}$$

Hence the probability of a man suffering at least two such time-intervals is

$$P(\geqq 2, r) = 1 - P(<2, r).$$

Such a man, experiencing at least two such time-intervals, each less than one month, is subsequently termed a 'Double-Repeater'. If in fact N men have been observed to incur r accidents each, then the expected number of Double-Repeaters is given by

$$E(N) = N.P(\geqq 2, r).$$

For example, consider nine men each having five accidents over four years. Here

$$q = \exp(-5/48), \quad \text{and} \quad p = 1 - q, \quad \text{i.e.,} \quad p = 0{\cdot}098\,9.$$

Thus	$P(1, 5) = 4pq^3$	$= 0{\cdot}289\ 4$
and	$P(0, 5) = q^4$	$= 0{\cdot}659\ 3$
giving, by addition	$P(<2, 5)$	$= 0{\cdot}948\ 7$

Hence	$P(\geqq 2, 5)$	$= 0{\cdot}051\ 3$
and	$E(9)$	$= 0{\cdot}461\ 7$

The Time between Accidents, if Accident Proneness exists in the Population

The following development is approximate and tentative.

If a man's liability to accident over a given (long) period of time is represented by λ, then the probability of his having r accidents is

$$e^{-\lambda}.\lambda^r/(r!).$$

Assume that liability is distributed among the population in a Pearson Type III curve, i.e. the proportion with liability λ is

$$\frac{c^p}{\Gamma(p)}.e^{-c\lambda}.\lambda^{p-1}.$$

Then the combined probability of a man being subject to liability λ and also having r accidents is given through multiplication of both the above probabilities, i.e.

$$P(\lambda, r) = \frac{c^p}{r!\Gamma(p)}.e^{-(c+1)\lambda}.\lambda^{p+r-1}$$

Integration of this over all λ, $0 \leqq \lambda \leqq \infty$, provides the probability of a man (selected at random) having r accidents as

$$P(r) = \left(\frac{c}{c+1}\right)^p.\frac{\Gamma(p+r)}{r!\,\Gamma(p).(c+1)^r}$$

which is of course the Negative Binomial, with parameters c and p as before.

Now the probability that a man, who incurred r accidents, has liability λ is given by

$$P(\lambda|r) = P(\lambda, r)/P(r)$$

$$= \frac{(c+1)^{p+r}}{\Gamma(p+r)}.e^{-(c+1)\lambda}.\lambda^{p+r-1}$$

The most probable value of λ (say $\bar{\lambda}$) for a man having r accidents is obtained by differentiation of this equation with respect to λ and equating to zero.

The solution is readily seen to be

$$\bar{\lambda} = \frac{(p + r - 1)}{(c + 1)}$$

To take an example, this means that, to a man who had incurred r accidents over an observed period of four years, an accident would most probably occur on the average (over a long time) once every m months, where $m = 48/\bar{\lambda}$, if $\bar{\lambda}$ refers to a period of four years. Thus the probability of an accident not occurring inside one month is given by $q = \exp(-\bar{\lambda}/48)$.

Now it is recognised that the above probability applies to a period of four consecutive years, this period being selected at random. However the theory of 'accident proneness', as classically conceived (see later), implies that deduction as to the (average) individual's underlying accident liability can be made from the number of accidents incurred over the observational period; further, this liability is *ex hypothesi* constant and independent of the period selected for observation. From this it follows that the above probability *must* apply equally to all periods, including the observational period. Accordingly, it is possible to compare the merits of the following alternative hypotheses in the present instance.

Briefly, time-interval analysis is here used to test whether accidents occur at such intervals as to suggest that the individual incurring a certain number of accidents was in fact liable to incur that number in that environment during that period of time (the Random hypothesis), or whether accidents do not occur at random intervals, as for instance implied by the accident proneness hypothesis. Consequently, to examine the time-intervals between successive accidents over a completely fresh period of time would be profitless since at best the accident proneness hypothesis would provide as good a match as the Random hypothesis (when the latter is taken for the specific conditions of the fresh period). If the accident proneness hypothesis proved inadequate then its adherents would not necessarily be inconvenienced because they could then postulate a change in general environmental circumstances.

It is acknowledged that some readers may be unable to accept the argument as presented. The authors believe in its validity, but those who dissent can omit the rest of the chapter.

Repeaters and Double-Repeaters

As before, consider N men each having r accidents in four years. Each man had r accidents and hence $(r - 1)$ time-intervals between successive accidents. Therefore the probability that none of his $(r - 1)$ time-intervals was less than one month is given by

$$q^{r-1} = \mathrm{e}^{-\xi},$$

where

$$\xi = \frac{(p + r - 1)(r - 1)}{48(c + 1)}$$

Immediately follows the probability of his being a Repeater as

$$1 - q^{r-1} = 1 - \mathrm{e}^{-\xi},$$

and the expected number of Repeaters as

$$E(N) = N(1 - \mathrm{e}^{-\xi}).$$

A corresponding formula for the expected number of Double-Repeaters is readily deducible.

c Conclusion

Information on the numbers of Repeaters and Double-Repeaters observed and those expected on the hypotheses considered in this chapter, is presented in detail in Tables 7.3–7.8, and in abbreviated form in Tables 7.1 and 7.2. E(Ran.) is the number expected if accidents *did* occur at random; E(A.P.) is the number to be expected on the hypothesis of accident proneness, as associated with the Negative Binomial distribution. The statistics indicate that the Ran-

Table 7.1 *Numbers of Repeaters (All Drivers)*

Number of Accidents	*E(Ran.)*	*Observed*	*E(A.P.)*
Lower Values	129·3	139	113·0
Upper Values	124·5	141	94·8
Total	253·8	280	207·8

Table 7.2 *Numbers of Double-Repeaters (Largest Three Populations)*

Number of Accidents	*E(Ran.)*	*Observed*	*E(A.P.)*
Lower Values	34·7	37	22·1
Upper Values	27·1	30	17·7
Total	61·8	67	39·8

dom hypothesis provides the closer correspondence with the observations, and the accident proneness hypothesis leads to consistent underestimation of the numbers of Repeaters and Double-Repeaters, especially for men with the higher numbers of accidents.

If the straight choice lies between reckoning

1 that any individual incurring, say, six accidents was indeed liable to have six accidents *in that environment and at that time*, or

2 that an individual's incurring six accidents implies that he is inalienably subject to a particular degree of accident proneness,

then on the evidence the correct choice is more likely to be the former.

Further information on the data is supplied in the Appendix (Table A.44–47). Such information supports the conclusion that accidents tended to occur at shorter intervals than was to be expected on the Random hypothesis. Consequently, particular attention was directed to those drivers, subsequently termed 'Chronic Repeaters', during the course of the clinical investigation, as well as to those incurring the larger number of accidents over the period.

Table 7.3 *Numbers of Repeaters—U.T.A. Bus Drivers (1952–1955)*

U.T.A. Derry				*U.T.A. Newry*			
Number of Accidents (r)	*E (Ran.)*	*O (r)*	*E (A.P.)*	*Number of Accidents (r)*	*E (Ran.)*	*O (r)*	*E (A.P.)*
2	1·4	3	1·4	2	0·6	0	0·8
3	1·9	2	1·6	3	5·3 { 1·2	4 } 7	1·2 } 5·0
4	8·2 { 1·8	5 } 16	1·3 } 6·4	4	3·5	3	3·0
5	3·1	6	2·1	5	3·8	6	3·0
6	3·3	6	2·2	6	1·4	1	1·1
7	2·3	4	1·6	7	2·3	2	1·7
8	8·0 { 0·7	1 } 13	0·5 } 5·4	8	11·6 { 1·4	1 } 11	1·0 } 8·9
9	0·8	1	0·5	9	0·8	0	0·6
10	0·9	1	0·6	10	0·9	1	0·7
				13	1·0	0	0·8
Total	16·2	29	11·8	Total	16·9	18	13·9

Table 7.4 *Numbers of Repeaters—U.T.A. Bus Drivers (1952–1955)*

U.T.A. (Excluding Ballymena, Derry and Newry)							*U.T.A. Ballymena*						
Number of Accidents (r)		*E (Ran.)*	*O (r)*		*E (A.P.)*		*Number of Accidents (r)*		*E (Ran.)*	*O (r)*		*E (A.P.)*	
2	20·0	6·5	5	14	6·0	16·1	2	5·4	1·1	2	8	1·0	4·0
3		13·5	9		10·1		3		2·7	3		2·0	
4		17·3	14		11·4		4		1·6	3		1·0	
5		15·0	13		9·3		5	4·4	1·0	3	6	0·6	2·4
6		9·8	12		6·0		6		1·4	0		0·8	
7	12·4	4·1	7	15	2·5	7·9	7		1·2	2		0·6	
8		4·1	3		2·6		9		0·8	1		0·4	
9		0·8	1		0·5								
10		2·5	3		1·7								
11		0·9	1		0·6								
Total		74·5	68		50·7		Total		9·8	14		6·4	

Table 7.5 *Numbers of Repeaters—B.C.T. Drivers*

Bus Drivers (1952–1955)

Number of Accidents (r)		*E (Ran.)*	*O (r)*		*E (A.P.)*	
2		1·0	0		1·4	
3	12·0	3·9	5	12	4·1	11·9
4		7·1	7		6·4	
5	11·9	8·2	6	13	6·8	9·8
6		3·7	7		3·0	
7	12·5	7·0	7	15	5·5	9·8
8		5·5	8		4·3	
9		2·3	3		1·8	
10		2·5	3		2·1	
11	9·4	2·7	3	11	2·2	7·8
12		0·9	1		0·8	
15		1·0	1		0·9	
Total		45·8	51		39·3	

Trolley-Bus Drivers (1951–1955)

Number of Accidents (r)		*E (Ran.)*	*O (r)*		*E (A.P.)*	
2		0·8	0		1·3	
3	21·0	1·7	3	20	2·2	22·6
4		6·9	6		7·6	
5		11·6	11		11·5	
6	17·7	7·1	6	22	6·9	16·3
7		10·6	16		9·4	
8	23·6	11·0	13	27	9·6	20·5
9		12·6	14		10·9	
10		5·4	6		4·7	
11		10·9	11		9·6	
12		3·6	4		3·2	
13	29·6	2·8	3	31	2·5	26·5
14		1·0	1		0·9	
15		3·9	4		3·6	
21		2·0	2		2·0	
Total		91·9	100		85·9	

Table 7.6 *Numbers of Double-Repeaters—B.C.T. Drivers*

Bus Drivers (1952–1955)				*Trolley-Bus Drivers (1951–1955)*			
Number of Accidents (r)	*E (Ran.)*	*O (r)*	*E (A.P.)*	*Number of Accidents (r)*	*E (Ran.)*	*O (r)*	*E (A.P.)*
3	0·1	0	0·1	3	0·0	1	0·1
4	0·6	1	0·5	4	0·5	1	0·6
5	1·2	0	0·8	5	9·9 { 1·4	3 } 15	1·4 } 8·3
6	8·7 { 0·9	1 } 9	5·2 { 0·5	6	1·3	2	1·2
7	2·3	2	1·3	7	2·8	4	2·2
8	2·4	3	1·3	8	3·9	4	2·8
9	1·2	2	0·7	9	8·5 { 5·6	5 } 7	3·9 } 5·9
10	1·6	2	0·9	10	2·9	2	2·0
11	5·1 { 1·9	3 } 7	3·1 { 1·1	11	9·2 { 6·7	7 } 10	4·7 } 6·5
12	0·7	1	0·4	12	2·5	3	1·8
15	0·9	1	0·7	13	2·1	2	1·6
				14	8·3 { 0·8	1 } 9	0·6 } 6·7
				15	3·4	4	2·6
				21	2·0	2	1·9
Total	13·8	16	8·3	Total	35·9	41	27·4

Table 7.7 *Numbers of Double-Repeaters—U.T.A. Bus Drivers (1952–1955)*

U.T.A. (Excluding Ballymena, Derry and Newry)							*U.T.A. Ballymena*				
Number of Accidents (r)		*E (Ran.)*	*O (r)*			*E (A.P.)*	*Number of Accidents (r)*		*E (Ran.)*	*O (r)*	
3		0·4	0			0·2	3		0·1	0	
4		1·4	0			0·6	4	0·4	0·1	0	1
5	7·7	2·3	2	6	2·8	0·8	5		0·2	1	
6		2·3	2			0·8	6		0·3	0	
7		1·3	2			0·4	7	1·1	0·4	0	1
8		1·8	1			0·6	9		0·4	1	
9	4·4	0·4	1	4	1·6	0·1					
10		1·6	2			0·6					
11		0·6	0			0·3					
Total		12·1	10			4·4	Total		1·5	2	

Table 7.8 *Numbers of Double-Repeaters—U.T.A. Bus Drivers (1952–1955)*

U.T.A. Derry					*U.T.A. Newry*				
Number of Accidents (r)	*E (Ran.)*		*O (r)*		*Number of Accidents (r)*	*E (Ran.)*		*O (r)*	
3		0·1	0		3		0·0	0	
4		0·1	0		4		0·3	0	
5	2·3	0·5	2	4	5	2·0	0·6	1	2
6		0·8	0		6		0·3	0	
7		0·8	2		7		0·8	1	
8		0·3	1		8		0·6	0	
9	1·2	0·4	1	3	9	2·7	0·4	0	1
10		0·5	1		10		0·5	1	
					13		0·8	0	
Total	3·5		7		Total	4·7		3	

Chapter 8 Clinical Study

a Introduction

Elsewhere in this work it was educed that few U.T.A. or B.C.T. bus drivers, when observed over a period of four years, appeared consistently each year in the group with the worst accident experience. Nonetheless the practical importance of identifying (if possible) drivers who are more likely than their colleagues to appear in such a group at any time justifies searching for some characteristic, biological or otherwise, which might correlate with accident experience, or striving to establish some criterion whereby a driver's accident record can be predicted. Many studies suggest that such differences exist and that valid prediction criteria can be identified, but in few are data and technique wholly acceptable, and in these few the results are conflicting. Consequently the examination of certain drivers was considered of paramount importance in the present investigation.

Originally it was intended to interview drivers from both the B.C.T. and U.T.A., the B.C.T. to be taken first on the grounds of expediency, but during the study it was decided that, owing to a change in circumstances, the clinical inquiry would not be extended to the U.T.A. unless considered imperative because of the B.C.T. findings. These did not, in fact, warrant such an extension: only B.C.T. drivers were therefore examined.

In this chapter, where the results of statistical tests of significance have been referred to in the text, the description of a difference as significant indicates that the observed or a greater difference was unlikely to occur by chance in more than 5 per cent of trials, i.e. the difference is likely to be genuine.

b Selection of Subjects

Selection was based on the accident records of drivers in continuous employment during the four-year period 1952–1955 and who did not incur more than 10 weeks of certified sickness (i.e. sickness of more than 3 days' duration for which a medical certificate was furnished) in either two-year sub-period 1952–1953 and 1954–1955. Two groups of drivers were chosen, the first comprising those with a bad accident record, and the second those with a good accident record, over the period. Members of the former group are subsequently referred to as 'cases'; those of the latter group as 'controls'.

Selection of Cases

Two possible methods were considered. The first, selecting drivers with the greatest number of accidents over the whole four-year period; the second, selecting drivers who appeared in the worst accident experience group in both the two-year sub-periods 1952–1953 and 1954–1955.

Using either method it can be argued that the upper tail of the frequency distribution will contain a proportion of drivers whose accident experience was only to have been expected on an hypothesis of chance determination. This is so, but the results obtained previously suggest that this proportion is likely to be smaller if the second in preference to the first method is used. Also, if personal characteristics are fundamental in accident causation or correlate with accident experience, then, by virtue of the very concept of accident proneness, they should be more sensibly sought in a driver whose accident record is consistently poor. Consequently the second method, viz. selecting drivers who appeared in the worst accident experience group in both two-year sub-periods 1952–1953 and 1954–1955, was adopted.

Accident Criteria for Selection

Twenty-one bus drivers with at least 3 accidents, and 18 trolley-bus drivers with at least 4 accidents, in each of the two-year periods 1952–1953 and 1954–1955, were initially selected as cases. Four trolley-bus drivers who did not exactly satisfy these criteria but who had incurred at least 7 accidents over the four-year period, of which at least 2 had occurred within one calendar month of a preceding accident, were also included. One additional case (T. 17) was subsequently added. Accident data of cases are summarised in Tables 8.1–8.2.

Table 8.1 *Numbers of Accidents incurred in 1952–1955 by the Sixteen B.C.T.Bus (B) 'Cases' interviewed*

Driver	*1952–1953*	*1954–1955*	*Total*
B. 1	3	3	6
B. 2	4	3	7
B. 3	4	5	9
B. 4	4	4	8
B. 5	3	3	6
B. 6	3	4	7
B. 7	4	3	7
B. 8	6	9	15
B. 9	3	3	6
B.10	3	5	8
B.11	3	4	7
B.12	3	8	11
B.13	3	4	7
B.14	6	4	10
B.15	3	4	7
B.16	5	5	10
Total	60	71	131
Mean Accidents per Driver	3·8	4·4	8·2

Selection of Controls

Age and experience are variables which have been shown to have independent effects on the accident rates in the present study. Therefore one control, individually matched for age and Corporation driving experience (as defined in Chapter 4), was selected for each case. Although there was no indication that the type of vehicle driven, i.e. omnibus or trolley-bus, significantly affected the accident rate, only those driving similar vehicles were matched.

Two populations from which to draw controls were considered. The first, the population remaining after cases had been excluded; the second, that composed of drivers with the best accident experience over the entire period of study. The latter group was ultimately chosen because if some personal characteristic correlates with accident experience it should be more readily recognised if groups, extreme for accident rates, are compared. All controls had zero, one

Table 8.2 *Numbers of Accidents incurred in 1952–1955 by the Twenty-Two B.C.T. Trolley-Bus (T) 'Cases' interviewed*

Driver	*1952–1953*	*1954–1955*	*Total*
T. 1	4	4	8
T. 2	5	6	11
T. 3	4	5	9
T. 4	4	6	10
T. 5	6	2	8
T. 6	10	2	12
T. 7	6	6	12
T. 8	5	11	16
T. 9	4	5	9
T.10	5	2	7
T.11	6	7	13
T.12	15	5	20
T.13	4	4	8
T.14	4	6	10
T.15	3	5	8
T.16	4	4	8
T.17	1	4	5
T.18	5	4	9
T.19	4	9	13
T.20	5	6	11
T.21	6	4	10
T.22	6	2	8
Total	116	109	225
Mean Accidents per Driver	5·3	5·0	10·2

or two accidents over the entire four-year period 1952–1955. Table 8.3 shows the similarity of the experimental groups for age and experience.

Some authors (e.g. Whitfield, 1954) have recommended selecting two matched controls for each case, one from the group with the best accident record, and the other from those persons with about an average number of accidents over the period. In the present investigation, where the number of accidents is small, this appears pointless.

The Search for Co-operation

The Belfast Corporation Transport management and the drivers' Trade Unions generously agreed to facilitate this inquiry as far as

Table 8.3 *Age and Experience of B.C.T. Cases and Controls*

Variable†	*Population*											
	Bus Drivers				*Trolley-Bus Drivers*				*All Drivers*			
	Cases (16)		*Controls (16)*		*Cases (22)*		*Controls (22)*		*Cases*		*Controls*	
	Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Age (in years)	41·9	7·6	42·3	7·8	43·1	8·7	42·6	8·0	42·6	8·1	42·5	7·9
Experience (in years)	5·1	3·1	5·5	3·2	6·6	3·8	6·7	3·9	6·0	3·5	6·2	3·4

† Age attained on 31st December, 1953.
Experience to nearest year on 31st December, 1953.

possible, including (in the case of the former) the payment of each interviewed driver for one and a half hours at basic rate. Of the 44 cases initially selected, 3 had retired, left voluntarily or been dismissed since 1955. A letter was sent by one of us to the remaining 41 cases and their controls requesting co-operation and explaining the nature of the interview and the purpose of the investigation, followed by a similar letter from the Corporation Industrial Medical Officer to the non-respondents two months later. No personal approach was made to any driver.

In all, 39 cases (90 per cent) and 33 controls (80 per cent) agreed to co-operate; 5 'second-choice' controls were subsequently added, but no satisfactory matched control could be picked for one of the cases: he was excluded. Ultimately, 38 cases and their controls were interviewed.

c The Interview

All the interviews were conducted by the same investigator. He was given a list of cases and controls, pooled in alphabetical order, and in only five instances, viz. the second-choice controls, did he know to which group any driver belonged before the entire investigation was completed. Trolley-bus drivers were interviewed before bus drivers, and the order in which the men were taken depended on who was off duty when the investigator was available. Appointments were made through Traffic Control, and were arranged on a weekly basis.

The interviews were conducted in a room adjoining the medical department of the Belfast Corporation, about half a mile from the administrative offices. Each driver who agreed to attend was given an appointment time during his off-duty period. Any driver who failed to attend at the appropriate time was given another appointment. Four drivers failed to keep their first appointment but attended subsequently. Not more than two interviews were scheduled for each day because the investigator wished to keep himself available if the interview seriously overran its time, as many did, and so as not to encroach on the drivers' domestic arrangements or driving duties.

Content of the Interview

Careful attention was paid to the practicability of reproducing all adopted procedures in an industrial medical department with reasonable facilities, and since U.T.A. drivers might have been included and examined at county depot level, only portable apparatus was used. The interview was planned to last about one hour, and, since a favourable impression of its nature was essential if the co-operation of the drivers was to be obtained, it was designed to resemble a traffic and driving skill enquiry.

The interview itself consisted basically of three parts. The first, which followed a fairly consistent pattern, aimed at obtaining views on traffic problems, road and bus design, and similar topics: this was intended to establish a rapport with the driver and obtain his confidence. The second consisted of measuring certain biological variables, viz. visual functions, phenotype, androgyny and personality. In the third part, information was obtained on marital, social, industrial and educational backgrounds, and in addition certain dates relating to each driver's domestic circumstances were noted (see later).

We acknowledge that certain of the measuring techniques might have been made with greater precision by someone with special skill and experience. Consequently, only comparisons between groups of cases and controls (which were interviewed 'blind') are presented since it is assumed that technical errors will have affected each group equally. No comparisons are made with other investigators' results even if similar techniques were employed.

The first part of the interview is considered later; the results of the second and third parts are now described in detail, and the rationale of their content explained.

d Vision

Review of the Literature

It is not intended to give a detailed account of all relevant studies; instead, each is classified depending on the approach used. More detailed, if incomplete, reviews appear in Thorndike (1951), Smeed (1953), McFarland, Moore and Warren (1955), and Häkkinen (1958).

1 *Examination of correlation coefficients between accident record and measured aspects of visual function.* This approach was adopted by Cobb (1939) with private licence holders, by Kraft and Forbes (1944a,b), and Ghiselli, Brown and Minium (1946), with street-car motormen, by Ghiselli and Brown (1949) with taxi drivers, and by

Brandt (Thorndike, 1951) with army drivers. None of these studies is completely satisfactory because the accident criterion used was either unsuitable or insufficiently described, the group was not homogeneous for risk, or other pertinent factors, e.g. age and experience, were not adequately considered. Reported correlations are small and most are not significant.

2 *The comparison of visual function between an 'accident' and a 'safe' group of drivers.* Lauer (Weiss, Lauer, *et al.*, 1931), DeSilva (1939), DeSilva, Robinson and Forbes (1939), DeSilva, Clafflin and Simon (1939), Brody (1941; 1957), and Davis and Coiley (1959) all used groups of private licence holders chosen on recorded accidents. The results are disparate, not unexpectedly because in no instance were the groups adequately matched. Fletcher (1939) studied private licence holders, police patrolmen and commercial truck drivers, and the ENO Foundation (1948) used private licence holders supplied by the Michigan State Police and Connecticut M.V. Department as 'cases', and 'good' drivers from industrial and commercial fleets as controls. Both reported significant differences in vision between drivers with good and bad accident records—but again the groups were, for many variables, not uniform. Parker (1953), using data from 104 truck drivers in one company, reported significantly different scoring on certain visual function tests between an 'accident' and a 'non-accident' group, and between the upper and lower halves of the accident group. This study has limitations but in this context it is one of the most convincing.

3 *Special studies.* Using data from groups of private licence holders, Johnson (1938) and Fletcher (1949) tried to equate the type of accident sustained with the nature of any specific visual defect of the driver, but with controversial results. Bransford (1939) tested visual functions of 481 private licence holders in the District of Columbia and obtained very low correlations between their accident experience and their measured visual qualities. Lauer (1955) reported a highly significant correlation coefficient between scores on a 'driving skill' instrument (TAGO Army Ratings for Drivers, PRT 2408), and a word matching test claimed to measure visual acuity. Davey (1956) tested 40 volunteers possessing certain standards of vision, and concluded that the level of vision affected the choice reaction time. Finally, in a model study, Norman (1960) found that the blameworthy accident experience of 149 London Transport bus drivers with defective colour vision was identical with that of a

similarly sized group of drivers with normal colour vision, each member of which had been carefully matched with a colour defective driver for age, experience and routes driven. Similar findings were obtained for the severely defective compared with the less severely affected.

Experimental Method

A driver is continually receiving ocular information; consequently uncompensated impairment of visual function might be expected to reduce his safety. Since all relevant studies, except Norman's (1960), are either wanting in description or in sound methodology, it was decided to measure certain aspects of visual function in the present investigation.

The U.K. Optical Orthorater (Bausch and Lomb) was used. This instrument combines the requirements of portability, economy of time and space, and facility of use, and has certain additional advantages over wall methods (Gordon *et al.*, 1954; Kephart and Deutsch, 1954). The technique followed in this study is outlined elsewhere (Bausch and Lomb, 1944; Jobe, 1944). The validity of the results can be expected to be of a high order and comparable with those obtained using more sophisticated clinical methods (Imus, 1949). Glasses when normally used for driving were worn during the reading of the appropriate slides. The orthorater does not, however, measure visual fields, and these were estimated by the confrontation method, and by Amsler's charts (Amsler, 1949).

In this part of the study only 37 cases and their controls were considered, and in all instances only functions of far vision were routinely measured. Near vision, although reckoned less important, would have been tested but many drivers who normally wore glasses for reading did not have them at the interview.

Discussion and Results

Visual acuity. Certain visual standards are generally adjudged essential for safe driving; in fact some writers have declared this to be axiomatic. It seems apposite to discuss the causes of visual impairment, whether temporary or permanent.

Environmental Factors

1 *External environmental conditions.* These are temporary and due mainly to bad weather conditions, glare, flashing lights, night driving, etc. Many investigators have measured the effects of these factors on visual perception and reaction time; and Smeed (1953), after reviewing much of the relevant work, concluded: 'making seeing more difficult resulted in an increase in the liability of a driver to become involved in a road accident'. This may well be so if other variables remain constant, but bad environmental conditions are frequently compensated to some extent by slower driving and greater care and concentration. Consequently the effect of impaired visibility alone on the likelihood of having an accident is difficult to estimate, and has never been satisfactorily assessed.

In the present investigation it was impossible to compute each driver's exposure to environmental conditions of this type, but it seems reasonable to infer that this was identical between the two experimental groups. Consequently even if bad environmental conditions are accepted as an important factor in accident causation, then, in the present instance, there must have been differences in drivers' compensatory behaviour. One possible compensation was slower driving. Each driver had to adhere to a strict schedule but could 'turn short' if he were seriously delayed, although drivers seldom did this consistently since it involved writing a report. Although the investigators are aware that the factors operating on each driver to keep to his schedule are many and related to personal qualities as well as to the environmental hazards of heavy traffic or bad conditions, each driver was asked whether he tried to adhere rigidly to his schedule on the supposition that those who did not might have been expected to drive more slowly, if not necessarily more carefully, in bad conditions, than those who did. Fifteen cases (40 per cent) and 13 controls (35 per cent) denied that they worried about their time schedule.

2 *Vehicular design.* Complete deprivation of visibility in any direction may result in a 'blind spot'; partial impairment, e.g. by tinted glasses, anti-dazzle visor, etc., can lead to reduced perception (Miles, 1955). No bus cabin or mirror system can give complete all round visibility, but the content of most blind areas is constantly changing because of the continual vehicle, traffic and pedestrian movement. Recent design aims at increasing cabin vision, as 'wrap-

around' car windows indicate, on the plausible but controversial hypothesis that better vision will reduce a driver's accident liability. Certainly several studies have implicated inadequate cabin visibility in particular types of traffic collision accident (Bayley-Pike, 1947), and in taxiing aircraft accidents (Pinson and Chapanis, 1946), but the part played by this factor alone is difficult to assess. Within certain bounds, personal qualities can compensate for imperfect visibility, but to an unknown extent.

In the present study it was assumed that cases and controls drove all available types of omnibus or trolley-bus equally often; there was no reason to suppose otherwise. It is not denied that imperfect visibility arising from the cabin design, including siting of instruments, may have contributed to accidents in certain instances, but this cannot by itself explain the differential accident rates between the two groups.

Personal Visual Qualities

1 *Visual acuity.* The sharper the image that falls on the retina the quicker is it perceived (Miles, 1933); and visual perception time is an essential component of choice reaction time (Davey, 1956). Certain aspects of visual acuity decrease insidiously with age, and this deterioration is not always recognised and corrected until some other circumstance leads to sight testing.

Table 8.4 *Visual Acuity of Cases and Controls*

Orthorater Score	*Both Eyes*		*Right Eye*		*Left Eye*	
	Cases (37)	*Controls (37)*	*Cases (37)*	*Controls (37)*	*Cases (37)*	*Controls (37)*
0–6	5	5	7	8	10	13
7 and 8	19	18	15	17	17	16
9+	13	14	15	12	10	8

χ^2 (Both eyes) = 0·064
$0{\cdot}98 > P > 0{\cdot}95$
χ^2 (Right eye) = 0·528
$0{\cdot}80 > P > 0{\cdot}70$
χ^2 (Left eye) = 0·640
$0{\cdot}80 > P > 0{\cdot}70$
Degrees of Freedom (ν) = 2

In the present study all drivers during the period under review had to attain certain standards of vision at pre-employment examination (a system of more frequent examination roughly parallel to that used in London Transport, and described by Norman (1958), was introduced in 1958), and if uncorrected deterioration of vision, or unilateral amblyopia, was a significant factor in accident causation in this study, the absolute measure of acuity should have differed between cases and controls. Table 8.4 shows the two groups to be similar for visual acuity as measured using both eyes and each eye independently; Table 8.5 shows the distribution by orthorater score. Three drivers, all of them cases, admitted to wearing glasses while driving, but none of them had first worn their glasses between the last year of the accident data (1955) and the year of testing (1960).

This approach neither assessed how readily any change in his vision was recognised by any driver, nor the adequacy of any compensatory mechanisms, but since any change must have been small these factors may not have been important. Also, the components of vision tested may not be relevant to the many aspects of driving where assessment of speed and motion vectors is important. Measurement of vision under actual driving conditions could be more informative, but such a study would have its own inherent problems.

2 *Visual fields.* Apart from any restriction by an environmental agency, a driver's visual field may be reduced by an intrinsic factor. Such reduction is often insidious and could be detrimental to, or even incompatible with, safe driving. Some of the previously cited investigators correlated visual field measurements with accident experience, but with inconclusive results; others incriminated field defects in certain intersection accidents, and these accidents were not always on the same side as the defect (e.g. Schwarz, 1939). In the present study no driver had serious contraction of his visual field as tested, although we recognise the comparative coarseness of the tests used.

3 *Depth perception.* The perception of depth is primarily a function of binocular vision. This function is most marked in distances up to about twenty yards; beyond this the difference in judgements made using one or both eyes is slight (Darcus, 1953). The many physiological and pathological factors involved in adequate stereopsis and binocular acuity are described in any text-book on ophthalmology. As computed in this study depth perception measures the ability of the brain to appreciate and interpret disparity.

Table 8.5 *Cases and Controls distributed by Orthorater Score*

Orthorater Score	*Theoretical Snellen Equivalent*	*Both Eyes*		*Right Eye*		*Left Eye*	
		Cases	*Controls*	*Cases*	*Controls*	*Cases*	*Controls*
0	<6/60	—	—	—	—	—	—
1	6/60	—	—	—	—	—	—
2	6/30	—	—	—	—	—	—
3	6/20	—	—	—	—	1	—
4	6/15	1	—	2	2	4	3
5	6/12	2	2	1	1	3	4
6	6/10	2	3	4	5	2	6
7	6/9	9	10	7	9	12	12
8	6/7·5	10	8	8	8	5	4
9	6/6·6	6	4	8	7	5	3
10	6/6	5	6	3	4	4	3
11	6/5·4	0	3	1	—	1	—
12	6/5	2	—	3	1	—	2
13	6/4·5	—	—	—	—	—	—
14	6/4·2	—	1	—	—	—	—
15	6/4	—	—	—	—	—	—

As with most other visual qualities, studies relating depth perception, or stereopsis, with accident rates give diverse results. In the most acceptable relevant investigation, Parker (1953) reported significantly better depth perception in a non-accident group compared with an accident group, using data on 'non-preventable' accidents only. In the present study there was no difference between the two selected groups (Table 8.6).

Table 8.6 *Depth Perception of Cases and Controls*

Orthorater Score (0–9 = Bad–Good)	*Cases* (*37*)	*Controls* (*37*)
0	11	11
1–4	11	12
5–9	15	14

4 *Colour vision.* About 8 per cent of the male population, and nearly 1 per cent of the female, have defective colour perception. Tests of colour vision are usually included in pre-employment examination for professional drivers on the seemingly reasonable rationale that effective colour perception is essential for accurate and speedy identification of coloured signals, and hence for safer driving. No substantial evidence exists to support this hypothesis (American Medical Association, 1959).

Table 8.7 *Colour Vision of Cases and Controls*

Orthorater Score	*Cases* (*37*)	*Controls* (*37*)
0–2 (unsatisfactory)	3	3
3+ (satisfactory)	34	34

Table 8.7 shows the similarity of colour vision scoring on the orthorater between cases and controls. Score dichotomy is that suggested by Kephart and Tieszen (1951) which in their study correctly classified 96 per cent of colour defectives, and over 90 per cent of normals, as rated by the Ishihara method and pseudo-isochromatic

plates. The present findings are comparable to those of Norman (1960) already described.

5 *Ocular muscle imbalance* (*heterophoria*). Heterophoria may be important to drivers in at least three ways:

a if uncompensated it may lead to double vision,
b it may cause tiredness and fatigue with a consequent adverse effect on a driver's equanimity, and
c to compensate for a hyperphoria a driver may tilt his head thus secondarily diminishing his visual field.

Parker (1953) reported significantly increased (on the 1 per cent level) vertical phoria in the lower half of his accident group, for 'preventable' accident data only. The ENO (1948) researchers obtained significantly better stereoscopic depth perception and vertical and lateral ocular muscle balance among their controls in the 100 'Michigan' pairs, but the controls were professional drivers—and therefore presumably highly selected—while the cases were mostly private licence holders. Cobb (1939) did not confirm this finding. Finally, Farmer and Chambers (1926), in their industrial groups, found that 'excessive hyperphoria (vertical) showed a relationship to accident rate'.

In the present study, Tables 8.8 and 8.9 show the similarity in heterophoria obtained between the two groups. In view of these results esophoria and exophoria scores were pooled as shown in Table 8.10. This latter finding exaggerates the trend which is in the opposite direction to Parker's and the ENO findings. In no instance was the heterophoria sufficiently severe or uncompensated to cause

Table 8.8 *Esophoria and Exophoria of Cases and Controls*

Orthorater Score (and Prism Diopters)	*Cases (37)*	*Controls (37)*
0–6 (14–1) (Esophoria)	17	21
7 and 8 (Normal)	17	9
9–15 (1–14) (Exophoria)	3	7

$\chi^2 = 4{\cdot}48, \quad \nu = 2, \quad 0{\cdot}20 > P > 0{\cdot}10$

Table 8.9 *Hyperphoria of Cases and Controls*

Orthorater Score (and Prism Diopters)	*Cases (37)*	*Controls (37)*
1–4 (1·3–0·1) (Left hyperphoria)	12	11
5 (Normal)	15	15
6–9 (0·1–1·3) (Right hyperphoria)	10	11

Table 8.10 *Pooled Esophoria and Exophoria of Cases and Controls*

Orthorater Score	*Cases*	*Controls*
0–6; 9–15	20	28
7–8 (Normal)	17	9

$\chi^2 = 2{\cdot}906, \quad \nu = 1, \quad 0{\cdot}10 > P > 0{\cdot}05$

double vision; the secondary effects of fatigue and irritability, and visual field limitation, could not be measured, but clearly all may adversely affect a susceptible driver's mood.

e Physique

Introduction

Many authors have drawn attention to alleged differences in physique between bus or truck drivers and other occupational groups. Damon and McFarland (1955) reviewed much of this work. Such a comparison was not attempted in this study, but certain physical qualities of cases and controls were compared.

Despite the possible association, on a number of hypotheses, between body build and accidents, there are few published works in which the physique of persons with poor accident records, or in which differences in body measurements between groups selected by accident experience, have been discussed. Some studies have tried to associate body type and 'success', e.g. in airline and combat operatives; these are referred to although the qualities leading to 'success', or to a good accident record, may not be comparable.

Review of the Literature

Sheldon (1943a, b), working with Army flyers, found a higher mesomorphy somatotype component among good than among less-good flying instructors ranked by colleagues for flying ability under stress, and also among high ranking graduate flyers than among those eliminated at an early stage from training. These findings were not confirmed on graduate fighter pilots by Draper (1945) using training and combat records. McFarland and Franzen's (1944) study of U.S. Naval cadets suggests a positive correlation between mesomorphy and graduation success, while Damon (1955), in a large study of U.S. Army flyers, described differences in many aspects of physique between groups of good and less-good pilots, rated as such after many and heterogeneous selection processes. Amongst a small group of successful civil airline pilots, Clinton and Thorn (1943) found 'a wide variation in body type, from underweight asthenic to obese'; while McFarland (1953) described a large group of successful airline pilots to be predominantly 'mesomorphic with few bodily disharmonies or disproportions'. More relevant is Whitfield's (1954) investigation of accidents among colliery workers, in which he subdivided the 'accident-prone' into younger and older groups, the former 'being heavier than their [non-accident-prone] contemporaries and judged to be of superior physique'. Finally, Kraft and Forbes (1944a) were unable to demonstrate any relationship in street-car operatives between body weight and the number of accidents they incurred, but Damon and McFarland (1955) described differences in certain physical qualities, including a higher mesomorphy rating, between a group of champion truck drivers in the United States—'unquestionably amongst the country's finest drivers'—and a group of 'regular' truck and bus drivers.

None of the above studies is comparable to the present investigation for type of data used, and not all can escape criticism of their methodology.

Experimental Method

In this study the measurements taken are those essential for estimating phenotype using the M.4 Deviation Chart (Parnell, 1957;

1958), and for estimating androgyny by the method suggested by Tanner (1951). The calliper used for skinfold measurement was of the type developed during the Harpenden growth study (Tanner, 1955). Its advantages have been described in many papers (e.g. Tanner and Whitehouse, 1955; Hammond, 1955), and the accuracy and reproducibility of the results obtained have been investigated by Edwards *et al.* (1955).

Each driver was weighed in his stockinged feet without coat or jacket, and an arbitrary figure of 7lb. allowed for clothing. Such approximation was considered justified since the cube root of the weight is used in the phenotype rating, and the 'ponderal index' scale on the M.4 Chart is graduated coarsely in 0·2 unit intervals; and further it was adjudged unwise to ask each man to strip because of the limited amenities and the importance of subsequent co-operation.

Results

These are presented in Tables 8.11–8.13. The terms fat (*F*), muscularity (*M*) and linearity (*L*) are used instead of the more usual terms endo-, meso-, and ectomorphy.

Table 8.11 *Physique of B.C.T. Cases and Controls (Bus Drivers)*

Phenotype Component	*Cases (16)*		*Controls (16)*		*Significance of the Difference*
	Mean	*S.D.*	*Mean*	*S.D.*	
Fatness (*F*)	3·2	0·6	2·9	1·0	$0{\cdot}30 > P > 0{\cdot}20$
Muscularity (*M*)	4·2	1·2	4·5	0·7	$0{\cdot}40 > P > 0{\cdot}30$
Androgyny	88·8	5·9	89·7	5·9	$0{\cdot}70 > P > 0{\cdot}60$

Discussion

A number of hypotheses can be advanced associating physique and accident experience. The following are the most obvious.

1 *A driver may be hampered by his build from adequately handling all controls, obtaining reasonable vision from the driving cabin, or being comfortably seated.* The possible importance of driver biomechanics in accident causation has been fully discussed by McFarland *et al.*

Table 8.12 *Physique of B.C.T Cases and Controls (Trolley-Bus Drivers)*

Phenotype Component	*Cases (22)*		*Controls (22)*		*Significance of the Difference*
	Mean	*S.D.*	*Mean*	*S.D.*	
Fatness (*F*)	2·8	0·8	3·1	0·6	$0{\cdot}30 > P > 0{\cdot}20$
Muscularity (*M*)	4·0	0·7	4·2	0·9	$0{\cdot}60 > P > 0{\cdot}50$
Androgyny	84·6	4·8	87·6	3·0	$0{\cdot}02 > P > 0{\cdot}01$

(1953), and McFarland and Moore (1957). The latter authors concluded: 'Drivers made fewest errors on the simulated driving task when the adjustments were set in the positions that provided the most comfort to the individual subject'. For professional drivers, performance on simulated driving tasks may be a poor prognosticator of actual or prospective accident experience, but anything that produces frustration or fatigue, or reduces equanimity, quite apart from purely physical considerations, may have an adverse effect on a

Table 8.13 *Physique of B.C.T. Cases and Controls (Bus and Trolley-Bus Drivers Pooled)*

Phenotype Component	*Cases (38)*		*Controls (38)*		*Significance of the Difference*
	Mean	*S.D.*	*Mean*	*S.D.*	
Fatness (*F*)	3·0	0·8	3·0	0·8	
Muscularity (*M*)	4·1	0·9	4·3	0·8	$0{\cdot}40 > P > 0{\cdot}30$
Linearity (*L*)	3·6	1·1	3·4	1·0	$0{\cdot}50 > P > 0{\cdot}40$
Androgyny	86·4	5·6	88·5	4·5	$0{\cdot}10 > P > 0{\cdot}05$

driver's performance. In the present study the cabin seat was adjustable within certain limits, and all controls easily within reach of even the smallest driver. Equal phenotype scores between the groups of cases and controls suggested that strength and build alone could not explain the disparate accident rates. The problems of frustration and fatigue are discussed later.

2 *Body build may be related to known qualities which contribute*

to increased accident liability. Many investigators have obtained an association between physique on the one hand, and intellectual capacity, temperament or certain types of physical and constitutional illness on the other; this is reckoned important because there may be a connection between these functions and accident liability on the roads. Cobb (1939), in his Connecticut study, obtained coefficients of the order of −0·2 when an accident criterion was correlated, firstly with educational attainment, and secondly with intelligence. This suggested that the less intelligent or less educated drivers had the worse accident experience. However this group of drivers was too heterogeneous and uncontrolled as regards many important variables to allow firm conclusions to be drawn. Farmer and Chambers (1939) obtained similar mean accident rates among groups of London omnibus drivers divided into interquartile groups on the results of two intelligence tests. They commented however, 'it would be unwise to draw the conclusion from these data that differences in intelligence are not related to differences in accident rate.' Ghiselli and Brown (1949) obtained findings similar to those of Farmer and Chambers, but their data were imperfect and the periods of observation usually extremely short. McFarland and Moseley (1954) emphasised the importance of intelligence for safe driving, an association inferred from the high I.Qs. of truck drivers with a good accident record who competed in the Roadeo of the American Trucking Association. McGuire (1956d) reported similar mean intelligence test scores between an accident group and an accident-free group of naval transport drivers, but the difference in accident experience between the two groups appears to have been marginal.

The rather ingenuous approach of several investigators (Raphael *et al.*, 1929; Selling, 1944) showed, not surprisingly, that a substantial proportion of traffic offenders referred to a psychopathic clinic by the Court, were in fact psychopathic or of low intelligence. Finally, Häkkinen (1958) quoted several Continental studies, and stated emphatically: 'it has been proved quite convincingly that the drivers who are considerably below the average in intelligence are clearly prone to accidents'.

Some investigators, including many of the above, have suggested that poor mechanical knowledge, as measured by paper and pencil tests, is a more reliable predictor of accident liability than are tests of intelligence. This function may also be related to physique. Other results in this field have been recorded by Bartelme *et al.* (1951), Moffie, Symmes and Milton (1952), Moffie and Alexander (1953), Brown and Ghiselli (1953), Parker (1953), Lauer (1955), and McGuire (1956a). A detailed discussion of all these articles is outside the scope of this work, but we suggest that the data and/or the methodology in each paper may allow alternative interpretations to the conclusions drawn. This is unfortunate, because knowledge of the relationship, if any, between these factors and accident liability (over their whole range) would be of considerable practical importance.

In the present study neither intelligence nor mechanical knowledge was measured because it would have necessitated further paper and pencil tests. This was considered undesirable, and priority was given to inventorial 'measurements' of personality. Also, the uniformity of the groups for background and education, and the strong selective processes operating, suggested that such tests were not likely to prove informative.

It has long been recognised that physique and temperament are related, and that temperament may be associated with certain types of illness or behaviour. Hippocrates' phthisic and apoplectic habitus, Rostan's (1828) types digestifs, musculaires, cérébrals, and respiratoires, Viola's (1909) microsplanchnic, macrosplanchnic and normosplanchnic types, and others, all imply this in their nomenclature. Kretschmer's (1921) classification of morphology into pyknic, asthenic, and athletic, Sheldon's (Sheldon *et al.* 1940) concept of endo-, meso-, and ectomorphy, and more recently Parnell's (1958) adoption of phenotype rating by fatness, muscularity, and linearity components, have all been followed by investigations relating certain personal qualities with these categories. Sudden death, loss of consciousness, dizziness or other misfortune at the wheel, may be due to conditions more commonly associated with certain types of body build than with others, but in such instances the public transport driver will be rapidly removed from risk. Association of physique with personality is more important since temperament may not by itself affect a driver's risk exposure, and it may be a factor in accident causation. This association is dealt with in detail later.

3 *Other hypotheses.* Body build may be related to unspecified functional qualities which are in turn associated with driving skill; or one of the phenotype components may be correlated with some attribute of success or perseverance, or with some factor which is independent of the driving record and which controls selection into (or influences selection out of) a job. The investigations of Donnan

(1959), and the work of Parnell (1958), are relevant to this problem.

In the present study, the groups tested showed no significant difference for any phenotype component between cases and controls (Tables 8.11–8.13). This was not so of the androgyny ratings. As a class the B.C.T. trolley-bus cases were significantly more androgynous—in the sense that Tanner (1951) used the term—than their controls. This finding did not obtain with B.C.T. bus drivers, but with the pooled results the difference almost achieved the 5 per cent level. Since trolley-bus cases were also more androgynous than bus cases it might be unwise to deduce a relationship between androgyny rating and accident liability in this instance, unless the selection processes operating among bus and trolley-bus cases were noticeably different. This could not be asserted from the available information.

No claim is made that physique is completely unconnected with road accidents, only that some other factors must operate to explain the differential rates between the two groups in the present investigation.

f Personality

Introduction

No facet of accident causation has received such close attention as the role played by personality and temperament. It is now a generally held belief that in any given situation those having more than their share of accidents in some way differ psychologically from their safer colleagues; the way and the degree to which they differ are more enigmatic. In the last twenty-five years serious works have described members of selected 'accident groups' as exhibiting not only mild temperamental anomalies, but often severe and bizarre psychological traits. These range from Dunbar's (Dunbar *et al.*, 1939) emphasis of Freud's 'traumatophilic diathesis', through aggression and intolerance (e.g. Schulzinger, 1956; McFarland and Moore, 1957), neuroticism and social maladjustment (Smiley, 1955), to comparative equanimity in which nervous or mental illness is less frequent than in a low accident control group (Moffie *et al.*, 1952; Davis and Coiley, 1959). Nor is this the whole story since less complete studies have further described accident drivers as, 'on the average [they] have a higher motility rate, are stronger, live in large towns and tend to compensate' (Lauer and Kotvis, 1934), as, 'poor types . . . from bad homes' (Chambers, 1939), as attending more frequently at credit bureaux, social agencies, V.D. clinics, and adult or juvenile courts, than control groups (Tillman and Hobbs, 1949), as scoring significantly differently on such devices as the Ego-Defensive and Need-Persistence percentages in the Rozenzweig Picture Frustration study (McGuire, 1956d), in parts of multiple personality inventories including Bohemianism-Practical Concernedness, and Will Control—Character Stability (Suhr, 1953), and even Artistic and Literary Interest (Parker, 1953), compared to their chosen controls. In short it is currently unfashionable and even inexcusable to consider an 'accident individual' as having a 'normal' personality.

Review of the Literature

The literature dealing with personality in accident causation is vast. No attempt is made here to present a comprehensive précis; for this, readers are referred to other works, more particularly to McFarland and Moseley (1954). Instead the trend of thought and the main experimental evidence leading to the present concepts are outlined. It is hoped that this will prove more intelligible than a mere recital of a large body of published results.

There is a basic unity in folklore. In the absence of a category of natural causes primitive man regarded injury and disease as the dispensation of unplacated spirits, or the effect of human malevolence manifested through the evil eye which could destroy him as surely as Wotan destroyed Hunding. Personal qualities were only important aetiologically with reference to the response they invoked. Scientific objectivism, dominant in nineteenth century European thought, countenanced no polemics; accidents were accidents, the causative agent external and there for all to see. In industrial accidents, largely ignored by Agricola (1556) and Ramazzini (1705), Thackrah (1832) unambiguously apportioned the blame: 'scarcely one would occur, I believe, if proper care were taken to case the dangerous parts'. William Farr dissented. After drawing attention to 'the great increase in the mechanical forces in action in the country, and to a want of a corresponding increase in the means of protection against their destructive application' (Registrar-General, 1865), he stated, 'what are called accidental deaths are often the result of negligence, wilfulness or rashness' (Registrar-General, 1873), and whether he was referring to operator, designer or employer, or to all three, is more apparent from the following passage: 'The introduction of every new force is followed by a certain number of deaths. The chances of death are increased. And the people about the machines or instruments, which the force animates, are untrained in their use, and so do not avoid fatal dangers that with the requisite precautions are not inevitable' (Registrar-General, 1875). In industry, increased protection rapidly reduced the accident rate, but this beneficence clearly exposed the fallacies of considering only environmental factors: 'it is perhaps not generally recognised that machinery is responsible for only a minority of accidents. . . . The Home Office records show that more than two-thirds of such accidents are due to other causes . . . It has been estimated that the percentage of avoidable accidents in some industries is as much as sixty per cent' (Safety Committees in Factories and Workshops, 1918).

There were two possible approaches towards elucidating these 'other causes'. The first lay in research into the physical environment. A legacy of the abnormal production pressures of the First World War was the realisation that fatigue and speed of production could be important factors in accident causation, with the hypothesis that these are influenced largely by the physical environment or physico-chemical states of the body (Vernon, 1918). This was a reasonable supposition before Elton Mayo's investigations at the Hawthorne factory in Chicago challenged its experimental basis (Roethlisberger and Dickson, 1949), and its veracity was energetically investigated in the early reports of the Industrial Fatigue Research Board. The modern work, reviewed by Provins (1958), is in direct succession to these pioneer studies. The second approach, which concerns us here, followed directly from the work of Greenwood and Woods (1919), and Greenwood and Yule (1920) whose results 'indicate that varying individual susceptibility to "accident" is an extremely important factor in determining the distribution.' In 1922 the Chief Inspector of Factories and Workshops (Factories, 1922) indicated where he thought the seat of this 'varying individual susceptibility' lay, by referring to 'accidents against which no material safeguard can be provided . . . described as accidents belonging to the mental field'; and four years later Newbold (1926) cautiously concluded, 'there are many indications that some part [of the accident distribution] is due to personal tendency.' In the same year Farmer and Chambers (1926) endeavoured to measure these 'personal tendencies', and in this and subsequent papers (Farmer and Chambers, 1929; Farmer *et al.*, 1933) emphatically concluded that the personal differences between members of their high and low accident groups were related to skill and lay in the performance of simple 'sensori-motor' or 'aesthetokinetic' tests.

In a sense these results were not novel. Some years previously, at the suggestion of the American Association for Labour Legislation, Munsterberg (1913) had investigated the problem of 'human frailty' in accident causation by devising a motorman selection test based on measuring certain fundamental sensori-motor skills. He claimed: 'a far reaching correspondence between efficiency in the experiment and efficiency in the actual service.' On the Continent more sophisticated tests of a similar nature had been swiftly developed (e.g. Stern, 1918), some of which were adopted in 1921 as a basis for selection of transport drivers in Paris (Lahy, 1927; Bacqueyrisse, 1935).

Contemporaneous with Farmer and Chambers' work were studies in the United States in which the same aesthetokinetic qualities were investigated among groups of high accident drivers. The best known is that of Slocombe and Brakeman (1930) which was based on data from drivers on the Boston Elevated Railway. These authors reported findings similar to those of Farmer and Chambers, but with inadequate and justly criticised mathematics (Mintz and Blum, 1949). By the early nineteen-thirties selection tests, including those of an aesthetokinetic nature, had been adopted for various purposes by many bodies in both the United States and Europe, including the National Institute of Industrial Psychology in Britain (Miles and Vincent, 1934). This was the peak: from then on scepticism as to their efficacy mounted, although they are still relied on for professional driver selection in some countries (Shaw, 1959).

By the early nineteen-forties the principal authors, while still convinced that the existence of 'accident proneness' had been demonstrated and that aesthetokinetic tests were important in its prediction, had become aware of the possible role played by other personal qualities. In 1939 they wrote: 'accident proneness is no longer a theory but an established fact . . . this does not mean that knowledge of the subject is complete. When other factors, as yet unidentified, have been found capable of detection by appropriate tests, prediction may gain further reliability' (Farmer and Chambers, 1939). Originally they had been cautious but more optimistic: 'the present results suggest that it is practicable to determine in a rough way the probability of any individual sustaining an undue number of accidents;

and as more research work is done . . . this probability should tend to approximate more and more to certainty' (Farmer and Chambers, 1926). From some of their writings (Farmer, 1938; Chambers, 1939) it is patent that they supposed these 'unidentified' factors to lie in the field of higher cognitive functions, on which emotional factors may play an essential part, although they never specifically 'measured' personality (Chambers, 1955).

The beliefs of the 'purposeful' nature of accident school (e.g. Klein, 1932; Ackerman and Chidester, 1936; Menninger, 1936), and the findings of Flanders Dunbar (Dunbar, Wolf and Rioch, 1936; Dunbar *et al.*, 1939) that a 'relatively large number' of a group of hospital fracture patients (originally chosen as psychologically normal controls for cardiac and diabetic patients) displayed well marked temperamental traits, re-orientated the emphasis from the aestheto-kinetic field to the now transcendent realm of personality. In subsequent studies, interests and attitudes were the first qualities measured and correlated with accident experience (Cobb, 1939; Brody, 1941), and to these were soon added such aspects of emotion as could be estimated by 'emotionality inventories', such as the Cornell Word Form Inventory used in the ENO (1948) study. These early investigations gave encouraging results and their methods were soon more widely applied. Ghiselli and Brown (1949), Tillman and Hobbs (1949), Bartelme, Fletcher *et al.* (1951), Parker (1953), Suhr (1953), Lauer (1955), and many others, administered paper and pencil personality tests in preference to apparatus tests, with equal or superior results. McGuire (1956a, b, c, d) carried this line of enquiry to its inevitable conclusion by devising a 'Safe-Driver Inventory'. This had an efficiency of prediction as high as eighty-eight per cent: 'that is, the test scores correctly labelled eighty-eight per cent of the individuals according to the [accident] group in which they belonged' (McGuire, 1956a). On the other hand Häkkinen (1958) 'measured' thirteen facets of personality among 'good' and 'bad' public transport drivers in Helsinki by paper and pencil methods, with 'negative' results. Present opinion is divided on the relationship between measurable qualities of personality and accident experience.

To dismiss this bizarre array of findings as spurious arising from imperfect methodology is tempting, but would be incorrect. Most of the conclusions are validly drawn from the data used. It is the data themselves which are often suspect and appear to be primarily responsible for the heterogeneous results. Four studies, namely those of Tillman and Hobbs (1949), Smiley (1955), McGuire (1956a, c, d), and Häkkinen (1958), are considered in more detail because their results have been widely accepted and applied. Other studies, e.g. that of Parker (1953), may deserve closer attention, but unfortunately they are published in an inadequate form.

The results of Tillman and Hobbs' (1949) investigations in London, Ontario, constitute the principal basis on which the widely accepted 'drive as you live' hypothesis was formulated. This hypothesis was later tested by R. A. McFarland (McFarland and Moseley, 1954), and has been promulgated in his influential writings (McFarland and Moore, 1957). The original work is now discussed in detail.

The authors' study is essentially in three parts. The first is a statistical study of accidents sustained by bus drivers employed by the London Street Railway, over the years 1941–1946: the authors concluded, 'in the present study the existence of accident-prone drivers among bus drivers has been established from a statistical point of view'. From the data presented this conclusion is debatable, but the second and third parts of the study are of more immediate relevance. In the second part, basic data were derived from 'the local taxi firms' in which 'the records of accidents were largely non-existent. However, considerable information was obtained from the insurance company for the firm, the memory of the management, and the various drivers as to their own experience and that of other drivers'. The authors further remarked, 'it was not possible to carry out an accurate statistical study of the accident rate in terms of mileage as had been done with the bus drivers. However, by pooling the information from various sources, the drivers could be classified roughly into the high, low and average accident frequency group'. Forty drivers, i.e. 20 from each of the high and low accident groups, were interviewed by one of the authors, who spent 'the better part of 3 months in constant association with these drivers.... It was our feeling that this approach was more informative than a formal interview, even under the most satisfactory conditions'. From the results a table was constructed part of which is reproduced as Table 8.14.

It is surely unsatisfactory to rely on an ascertainment largely dependent on individual memory. To compare groups of drivers selected on the basis of an accident record which was uncontrolled for experience, miles driven or estimated exposure to risk, and types and road worthiness of taxis driven, or at least to present some

Table 8.14 *Personality Survey on Groups of Taxi Drivers (Tillman and Hobbs, 1949)*

Characteristic	*High Accident Group (20 men)*	*Low Accident Group (20 men)*	χ^2
Birth place—urban	15	15	
Parents divorced	6	1	4·63
Excess strictness and disharmony	13	5	6·28
Excess childhood phobias	11	5	4·48
Excess aggression in childhood	11	0	23·60
Completing school grade	15	15	
Truancy and disciplinary problems	12	2	10·98
Five or more previous jobs	13	7	3·60
History of being fired	10	4	3·98
Member of armed service	15	9	
Frequent A.W.L's	11	1	8·60
Married	8	11	
Admitting sexual promiscuity	8	2	4·00
Having two or more hobbies	9	17	8·50
Admitting bootlegging on job	14	3	12·20
Conscious of physique	11	3	5·40

When $P = 0{\cdot}05$, $\chi^2 = 3{\cdot}84$.

Compiled from Tillman, W. A. and Hobbs, G. E. (1949), 'The accident-prone automobile driver', *Amer. J. Psychiat.*, **106,** 321–331, Table 1.

statistics on these factors, seems wrong. Also, nowhere is the population at risk clearly defined; nor is the accident distribution, the period for which data were obtained, the rotation of drivers to available taxis, the employee turnover, and many other variables, considered. Also, a 'blind' interview, and an exact probability calculated on a 2 × 2 table for each variable, would have been advisable. Nevertheless it must be noted that the difference between some items is extreme, and all the trends are in the 'expected' direction.

To test their hypothesis further the authors, in the third part of the study, collected data relating to private licence holders. As cases, they selected '96 male drivers in the London district who had suffered from 4 or more automobile accidents. This information was obtained from the Ontario Department of Highways. Only accidents of 50 dollars or more damage were reported to the department. All accidents are reported whether the driver is apparently at fault or not.' As a control group, 'we also obtained the names of 100 drivers in the same district. This selection was unbiassed except that they were accident-free and of the same age and sex as the high accident group.' Information as to the social character, both past and present, of these drivers was obtained from the records of the local credit bureau, social service agencies, public health and V.D. clinics, and adult and juvenile courts. The general result was that 66 per cent of the high accident group, compared with 9 per cent of the control group, were known to at least one agency.

These data have limitations; as before, many essential variables were not adequately considered, and, surprisingly, no attempt was made to standardise for risk exposure either in terms of years of holding a licence, or in estimated mileage driven.

Solely from these results the authors concluded: 'It would appear that the driving habits, and the high accident record, are simply one manifestation of a method of living that has been demonstrated in their personal lives. Truly it may be said that a man drives as he lives. If his personal life is marked by caution, tolerance, foresight and consideration for others then he will drive in the same manner. If his personal life is devoid of these desirable characteristics then his driving will be characterised by aggressiveness, and over a long period of time he will have a much higher accident rate than his more stable companion.' It is surely imperative to confirm these conclusions, which have obvious and vital implications, by using more reliable data and techniques. The question, viz. whether for equal risk exposure accidents occur to certain psychological 'types' of driver more frequently than to others, has never been satisfactorily answered. A reliable answer is vital to any responsible policy of driver selection.

Smiley's (1955) study was of industrial accidents as ascertained by visits to the factory medical or first-aid departments. Less than 1 per cent were serious enough to warrant two or more days' absence from work; his data are therefore comparable to those of the classic investigations of Greenwood and Woods (1919), Farmer and Chambers (1926), and Newbold (1926). His conclusions were carefully reached and emphatically stated: '[that] the accident prone are socially maladjusted, [that] they lose time as a result of complaints which at present are not recognised as having an organic basis, and that under the influence of a relatively minor emotional stimulus they tend to perspire freely on the hands and feet and, less frequently, to exhibit albuminuria. In addition a significant proportion have peptic ulceration'.

A possible source of bias is the reliance on visits to a first-aid department as a basis for accident ascertainment. This is so of all similar data. Smiley was acutely aware of this, but suggested that special circumstances operated in the factory at the time to reduce substantially the 'tendency to report' error. He also fully appreciated the many additional factors which motivate a visit to a first-aid department ostensibly because of minor trauma, such as the looks or personality of the nurse or the attitude of workmates, factors which are not expressible, at least for this purpose, in statistical terms. An equally important factor, and one whose mathematical influence Smiley perhaps underestimates, is that of unequal risk. After showing that all trades were equally represented in the selected accident and control groups, and that all subjects were working in the same shop, he concluded: 'this is evidence that . . . no worker is rendered more liable to accidents than another by reason of the nature of his occupation. It does not mean, of course, that there are no jobs involving a higher degree of risk than others. There are, but they are so relatively few and of such short duration that they are unimportant.' Perhaps so, but Smiley's accident cases were the 'tail' of a Negative Binomial distribution, a distribution that can arise from accidents to a population which, unknown to the investigator, in fact comprises several sub-populations, each being differently exposed to risk, and in each of which accidents are chance determined. In fact, as shown later in the present work, the differences in exposure to risk need only be of a small order. The excess of days lost through illness and absenteeism by the members of the accident group might have nullified any increased risk they may have encountered compared to the control group, but the net result of these factors on the ultimate form of the distribution is not clear. Nonetheless Smiley's work is the best of its type, and his findings deserve more serious attention than Whitfield's (1955) brusque dismissal: '. . . the main conclusion to be drawn is that proneness to report minor injury can be added to the other known signs of emotional disturbance.'

McGuire (1956a, c, d) demonstrated personality differences between two groups of drivers: 'The accident group was selected after an examination of Camp Lejune [North Carolina] accident records and was comprised of those persons who had been involved in an accident and had also been cited as being guilty of a moving violation. The non-accident group was selected from those whose answers to a questionnaire indicated that they might be completely accident and violation free.' He then matched his two groups for experience 'in years' driving on state highways', age, marital status, 'estimated miles over the previous two years', education and years in service.

Some comments seem justified. It is not clear whether these drivers were exclusively whole-time service drivers or included more part-time performers, what vehicles were driven and whether there was a difference in accident rates between types, by what means an accident appeared on the 'Camp Lejune accident records', and what exactly being 'cited as being guilty of a moving violation' implied especially with Service drivers possibly of differing ranks, and what were the factors involved in excluding a man from driving. In addition the 'accident group' was selected from recorded accident experience, the non-accident drivers apparently by their own statement; and the accident criterion used to produce a dichotomy of drivers seems inadequate. Finally, there is no indication that the groups were interviewed 'blind', important in even *objective* 'measurements' of personality. It seems probable that the three principal potential sources of invalidity in accident investigations, viz. ascertainment not independent of severity, incomputable differences in exposure to risk, prescience of the group to which each person interviewed belongs, were operating in the study. McGuire's findings require substantiation.

Häkkinen (1958) used data derived from Helsinki bus and tram drivers. His efforts to ensure valid data, especially as regards exposure to risk, were probably as thorough as possible in the circumstances. Criticism of method on this point is of comparatively minor details many of which were dealt with by Smeed (1960). An item not fully elaborated is the method of accident ascertainment, the reader not being allowed to judge how accurately a minor accident was assigned to the driver responsible. In the absence of inspection systems or consequences for non-reporting of sufficient deterrence, wrong assignation may occur and be an important factor in a study where the accident rates are small. Admittedly these points may be unimportant to the thesis as a whole and to mention them at all is an indication of the high standard of Häkkinen's work. Perhaps more serious is the comparatively poor response (96 out of 140) of those drivers requested to volunteer for interview and tests; and apparently an interview which was not strictly 'blind'. The volunteers were biassed in known as well as unknown ways, for example the 'oldest drivers' and those 'colour blind and weak-sighted' were excluded. Häkkinen frankly admitted this: 'it is difficult to judge the effect of the use of only volunteer subjects upon the result of the study. . . . This may particularly be the case with respect to the attitude and adjustment variables, since the individuals departing from others in these respects—the majority of whom are likely to belong to the accident drivers—did not volunteer'. He applied sophisticated mathematics to his results, which showed no significant difference between accident and control groups for personality paper and pencil tests, but significant differences for eye-hand co-ordination, choice reaction time, and 'ambiguous situation' tests.

To have attempted to review some of the literature of road accidents without many detailed references to the considerable experimental output of the Driving Research Laboratory both before and after its domicile at Iowa State College in 1937, and to the Road Research Laboratory, Langley, Bucks., must seem to many curious; certainly their work covers most facets of road accident research, and throughout their existence they have proved constant sources of influence and inspiration. Unfortunately, in the case of the former, much of its experimental work is reported in journals which inadequately describe the data or experimental methodology, and in consequence the reader is often unable to assess the validity of the reported findings. In the case of the latter much of its considerable output has been in fields of study which are not strictly relevant to the central thesis of the present investigation.

Experimental Method

The literature suggests that tests of complex skills may distinguish drivers with different accident records more certainly than simple sensori-motor tests. Häkkinen (1958) reported significant differences between the performance of some of his groups in sophisticated choice reaction time and ambiguous situation tests, but not with tests measuring simple motor speed and reaction time. Other writers have concurred (e.g. Farmer, 1938). In the present study complex apparatus could not be used for the reasons already outlined; consequently we had to choose between paper and pencil or sensori-motor tests. Mainly for administrative reasons both were not adopted. It was decided that with a highly selected driver group the former might prove the more profitable procedure.

Method of Measurement

The instrument used is the two-part personality measure designed and fully described by Heron (1956b).* It is in questionnaire form and was adopted here because of its thorough and reliable validation, and its proven suitability for a British Isles population. The first part is intended as a measure of emotional maladjustment; the second as a measure of sociability, as far as possible independent of the first measure. A break of about five minutes for measuring physique was allowed between the two parts. Each driver completed both questionnaires; the alternative method of administration using a sealed box and cards (Heron, 1953) was not considered essential in view of Heron's (1956b) later findings.

Results

These are presented in Tables 8.15 and 8.16. Results from the first part of the inventory are presented as an asymmetrical trichotomy, those from the second part as a symmetrical one. Heron (1956b) wrote: 'it seems justifiable to regard scores of ten and above (in Part One) as "probably maladjusted"; scores from 0 to 7 as "probably well adjusted"; and to reserve scores 8 and 9 as "doubtful".' Doubts

Table 8.15 *Personality Measure of Cases and Controls* (*Heron I*)

Score (Heron I)	*Category of Driver*	
	Case	*Control*
0–7	32	29
8 and 9	6	5
10+	0	4

Exact Probability (Double-Tail), $P = 0{\cdot}115$

* The writers thank Dr. Alastair Heron for his kind permission to use these two inventories in this project.

Table 8.16 *Personality Measure of Cases and Controls (Heron II)*

Score (Heron II)	*Category of Driver*	
	Case	*Control*
0–4	24	22
5–8	12	13
9–12	2	3

about the interpretation of a low score in other questionnaires had previously been expressed by Super (1942), and by Landis and Katz (1934), and Heron (1956b) added, 'it is indeed unsafe to assume that a respondent obtaining a score lower than 8 on the present measure *is* well adjusted; all that can be said is that in the light of the available evidence such a respondent is likely to be well adjusted, and that the probability that this is so is reasonably high.'

Discussion

To Kant, 'personality exhibits palpably before our bodily eyes the sublimity of our nature.' As such it influences every facet of human behaviour affecting our thoughts and actions. A discussion of the interaction of personality and behaviour is outside the scope of this work and beyond the ability of the writers. The books of H. J. Eysenck (1952, 1953, 1957) are standard works. Nonetheless three possible ways in which personality may affect accident rates require elaboration.

Smiley's (1955) ideas are representative of the first of these. He saw the 'accident-prone' as neurotic individuals with exaggerated emotional response due, 'either to stimulation of the hypothalamus by impulses from the cortex, or to a diminution of the inhibitory impulses from that area', and that these impulses produced minor imbalances of adrenaline or acetylcholine which in turn resulted in muscular disharmony with resultant decrease in performance, especially skilled or fine performance. Types of personality in fact 'caused' accidents by readily producing a neuro-muscular state where sustaining an accident became more likely. The data on which Smiley built this hypothesis have already been discussed.

The only trend discernible in the present study was that those 'probably maladjusted' were more numerous among controls (4) than cases (0). This finding may not reflect a true difference since Heron (1956a) has drawn attention to the lower scores achieved on this part of the inventory if used under conditions obtaining at employment selection. All drivers were assured of the confidential and research nature of the interview, but it can be argued that those with a poor accident experience may have been less convinced by this assurance than their safer colleagues, although the high proportion of cases volunteering for this study would not be in full accordance with this argument.

Some authors have adopted a very different approach; by observing that errors on simulated tasks were more commonly made by certain psychological types they have argued that accident experience can correlate with personality since performance on simulated tasks predicts accident liability. This is the line of reasoning behind Davis's (1948a, b; 1949) and Venables' (1955; 1956) important papers. Davis (1948) wrote: 'The following evidence confirms the view that the errors observed in the laboratory tests [Cambridge Cockpit] are essentially the same as those which are made in the air and which lead to flying accidents. If this is true, it would be expected that the pilots who made relatively serious errors in these tests would tend to sustain accidents in flying; that is, that the incidence of accidents in a group of pilots making serious errors in the tests would be higher, other things being equal, than in a group not making serious errors. This has proved to be the case.' This may be so, but in point of fact the accident experience of 355 'fit' pilots graded nil, slight, or moderate for 'predisposition to neurosis' proved to be similar, a fact which Davis tried to explain by the difference in the rating criteria adopted by the two psychiatrists involved. In later papers he further developed the hypothesis that features of skilled performance are related to aspects of personality and also to actual accident experience. Employing data from colliery workers, subsequently used by Whitfield (1954), Davis (1949) concluded, '[the results] strongly support the view that the behaviour recorded in the [Skilled Response] test reflected the disorder of function reponsible for the abnormal accident history'.

Lewis (1956) demonstrated that consistency of driving performance (as measured) was higher in groups of skilled compared to unskilled drivers, and Venables (1956) showed that driving consistency (as measured) was related negatively to both neuroticism and extremes of introversion-extroversion. But it has not yet been satisfactorily demonstrated that consistency of performance (as measured experimentally) and accident experience are in fact associated, and without this the last link connecting personality measures and accidents, in this context, cannot be forged. The experimental work of Cation, Mount and Brenner (1951) supports this assertion. It could be that the personality traits leading to the alleged driving inconsistency, or to the overactive-inert continuum of performance in the simulated cockpit, are identical with, or related to, those which may facilitate the avoidance of an accident when a potentially dangerous situation has arisen. Also, it would seem injudicious to use results on a simulator as a predictor of typical performance, because an individual's normal mental attitude and approach to a job or situation cannot always be obtained on an experimental task, especially when he knows when and for what reason he is under observation. It is sometimes forgotten that Elton Mayo (Roethlisberger and Dickson, 1949) demonstrated this, on some groups of workers at any rate, over a quarter of a century ago. The elimination of the effect due to the experimenter must be a matter of concern especially in studies of human populations, otherwise inconsistencies might occur analogous with Heisenberg's Uncertainty Principle.

> '*Der* spiegelt ab das menschliche Bestreben
> Ihm sinne nach, und du begreifst genauer:
> Am farbigen Abglanz haben wir das Leben.'*
>
> Goethe (1831).

The third theory is that certain personality qualities can, under certain conditions, act temporarily to distract their possessor from his task, or to distort his judgement. The interaction of the 'certain conditions' and the 'personality qualities' is the important factor. In the present investigation the hypothesis considered was that the difference in accident experience between cases and controls was due to the former group being subjected to a greater number of environmental circumstances likely to produce distraction or disinterest. The immediate problem of defining what constitutes a universally distracting environmental circumstance could not be satisfactorily

* This reflects our human endeavour.
Think of it, and you will see exactly:
That in a coloured reflection we live our lives.

resolved; however it seemed possible that a serious home circumstance would produce a degree of worry or tension in all drivers.

At interview each man was closely questioned concerning hospital admissions of his wife and children, a family death in the house, and the dates of birth of his children. With hospital admissions each affirmative statement was checked from hospital records if suspected of being between about 1950 and 1956; where a discrepancy occurred the statement on the hospital record was taken. The exact date of every death in the household could not be uniformly substantiated. Only those events occurring between 1952 and 1955 inclusive, i.e. the years under study, were included. These environmental circumstances were not necessarily the most distracting ones in every case; financial matters or the performance of a football team may have been more important to certain drivers, but the circumstances chosen *are* landmarks and as such were likely to be fairly uniformly recalled by all those interviewed. The results are shown in Table 8.17.

Table 8.17 *Environmental Family Data of Cases and Controls*

Data 1952–1955	*Cases (38)*	*Controls (38)*
Number of children born	13	10
Number of hospital admissions of all children	8	4
Number of hospital admissions of wife	9	6
Number of deaths in household	1	0
Total number of children alive in December, 1955	107	97

All cases and controls had been married. In December, 1955, two cases and no controls were widowers who had not remarried. The data in Table 8.17 do not indicate any clear differences between the groups as to the relevant variables, but the fact that the trends are all in the one direction should not be ignored.

g Accidents and Absence from Work

Introduction

Absence from work may be taken for reasons other than illness, and, whatever the cause, some subjective decision is made affecting duration. The total period, or the number of instances, a driver is absent may be a poor criterion of his actual physical and mental fitness to be in charge of a motor vehicle on his working days. These facts are fundamental and should not be overlooked when considering absence data.

Review of the Literature

Three principal methods of relating accident and absence experience have been adopted by previous investigators.

1 *The correlation between the number of accidents sustained and the incidence of absence, total days lost, or some physical characteristic.* Greenwood and Woods (1919), Farmer and Chambers (1926), and Newbold (1926), correlated accidents and time (days) lost through sickness, with resultant coefficients of a small order both positive and negative. Newbold (1926) also calculated partial correlations between accidents and visits to the ambulance room for minor illness, the variables of age and experience and number of days exposed to risk being kept constant. The average values so obtained of +0·3 for both sexes prompted her to write: 'our data give a definite positive association between the number of accidents an individual has had and the number of visits to the ambulance room for minor sickness'; but she was characteristically circumspect as to the interpretation: 'the suggestion from the figures—and it seems a natural one—is, that so far as these ailments are a measure of lower general health—and this might be true of the 'tendency to report sickness' just as much as the 'tendency to be sick'—the tendency to accidents is associated with such a state' (Newbold, 1926). Farmer and Chambers (1929) reported similar findings in groups of R.A.F. and dockyard apprentices. Adelstein (1952) correlated, firstly, industrial injuries with the number of sicknesses among 302 railway shunters over five years, and among 122 shunters over eleven years, obtaining coefficients of +0·069 and +0·062 respectively; and secondly, accidents with days sick among the latter group, with a resultant coefficient of +0·234 which he considered significant. Adelstein's data are an improvement on those of the earlier writers in respect of the validity of reporting accidents, absence, and sickness, but are not perfect (Chambers 1952; Whitfield, 1952).

2 *The comparison of sickness experience between matched groups selected on the basis of their accident experience.* In a careful study,

Whitfield (1954) investigated those accidents incurred by 1,384 miners at one colliery during a period of over two years, and found no significant difference for presence of 'significant' disease or attitude to health between his accident and non-accident groups. In order to calculate the exposure to risk of each man, Whitfield used an index based on the product of the time worked on a certain shift at a certain occupation and the average risk per identical shift at the same occupation. This index is not so theoretically reliable as the method of calculation might suggest. Accidents were limited to those 'which resulted in injury sufficient to warrant compensation'.

Smiley (1955) noted the average number of days lost by his accident and control groups, both before and after time lost as a result of accident had been considered. He found that, 'after deducting time lost as the result of accidents, the accident-prone men still lost twice as much time as the controls'; also, 'they [the accident-prone] tended to have peptic ulceration more frequently. Excluding organic illness, both acute and chronic, on the average the accident-prone still lost twenty-two days as compared with the controls who lost six days as the result of conditions either not covered by medical certificates or diagnosed in vague terms like 'fatigue', 'neurasthenia', 'gastritis', suggesting the absence of organic disease. They attended the medical department three times more frequently than the controls for causes other than accidents'. Some of these findings are in accord with those of earlier writers, e.g. Newbold (1926); some not, e.g. Dunbar (1943b). Smiley's data and methodology have already been described.

Davis and Coiley (1959) used data derived from files kept by Cambridge City Police in order to identify an 'accident-prone' and a 'safe' group of drivers. Owing to deficiencies in their sampling methods, to which the authors themselves drew attention, little weight can be attached to the results. They found no relationship between their two groups as to serious physical illnesses or defects, minor medical disabilities or minor nervous symptoms, but they did find that all the subjects 'in the whole sample who had suffered from a definite nervous or mental illness were in the safe group'. Also, the trend in the incidence of psychosomatic affections was for it to be higher in members of the safe group.

3 *The comparison of accident experience between groups selected on the basis of certain physical characteristics or sickness experience.* From the aspect of methodology this is the least satisfactory approach

and was only adopted by pioneer investigators, e.g. Slocombe and Bingham (1927), and Viteles (1932). Using data relating to employees on the Boston Elevated Railway, Slocombe and Bingham reported that of the 69 drivers over 50 years of age, the 38 with normal blood pressure averaged less than half the collision accidents of those with abnormal blood pressure. Viteles found, perhaps not surprisingly, that a group of electrical sub-station operators without physical defect had a considerably better experience of lost time due to accidents than a group composed of men either with a physical defect, or for some other reason considered unfit for their position.

There are other parallel studies, but the above two are often quoted to illustrate a supposed relationship between sickness and 'accident-proneness'. For example, Vernon (1936), referring to the former study, wrote, 'accident proneness appears to be affected by abnormal blood pressure, or by some of the conditions with which it is associated,' and to the latter, 'a relationship between physical conditions and accident proneness is indicated by some observations made on 106 electrical sub-station operators'.

Results

It must be emphasised that these data are truncated in respect of illness since all drivers with more than 10 weeks' certified sickness absence in either two-year sub-period 1952–1953, and 1954–1955, were excluded from the investigation.

The data were divided into two groups, i.e. those of absence of three days or less duration (subsequently termed 'short-term absence'), and those of more than three days duration (subsequently termed 'long-term absence'). This is not an arbitrary division; the sick pay scheme, to which 30 cases and 30 controls belonged in 1952–1955, precluded any payment for the first three consecutive calendar days of absence from whatever cause. Thereafter benefit equal to two-thirds the normal weekly wage was paid for a maximum period of five weeks, followed by benefit equal to one-half the normal weekly wage for a further maximum period of seven weeks; but in no instance was more than twelve weeks' benefit paid in any period of twelve consecutive calendar months as counted from the fourth day after absence. No remuneration under the scheme was allowed for sickness or incapacity attributable to a driver's negligence or misconduct, or to an accident not arising out of his employment. To obtain payment under the scheme a medical certificate of sickness was essential.

All absence, other than that due to holidays, industrial injury, company business, attendance at Territorial Army camp or suspensions for disciplinary reasons, all of which were excluded from the data, is entered as 'Sick' (S), 'Leave' (L), or 'Absence' (A), in the record books. Essentially, 'S' signifies that a medical certificate was produced, 'A' that it was not, while 'L' indicates that the absence was officially sanctioned. With long-term absence all 'Leave' is prospectively sanctioned, while 'Absence' was only entered in three instances in the present data, two of which pertain to men who were non-members of the sick pay scheme. With short-term absence, decision to enter 'S' or 'A' is largely arbitrary; the entry of 'L' usually but not invariably implies that the absence was prospectively sanctioned. Consequently in both short- and long-term absence, spells entered as 'S' and 'A' were pooled, while those entered as 'L' were treated separately.

Each driver has one rest day per week as well as holidays. Where this occurred on the first or last day of an absence it was assumed that the man would have been fit for work on that day; where it occurred on any other day during an absence it was assumed that the man would not have been fit for work on that day. On these data therefore, absence time, but not incidence, was likely to be underestimated. The distribution of short-term absence by day of week on which each absence started was not considered, because with varying duties and rest days relevant data could not be completely reliable, and in this occupation the rhythm of the traditional working week is largely lost.

An attempt is made in Table 8.18 to classify long-term absence by broad diagnostic grouping for cases and controls. Medical certificates were only available for drivers who were members of the sick pay scheme during 1952–1955. In each instance the diagnosis appearing on the doctor's first certificate was used. Of the three broad diagnostic groups, Group 1 includes those conditions which are generally assumed to be basically due to infection, Group 2 those of a purely 'physical' nature, e.g. operation for varicose veins, and Group 3 those in which the symptoms are largely subjective, or in which the condition is frequently alleged to have a psychological basis, e.g. peptic ulcer. Clearly in some instances the categorisation

Table 8.18 *Distribution by Diagnostic Group of the Incidence of Certified Long-Term Sickness Absence, 1952–1955, among the Cases and Controls who are Members of the Sick Pay Scheme*

Diagnostic Grouping	*Category of Driver*	
	Cases (30)	*Controls (30)*
Group 1	15	20
Group 2	2	2
Group 3	14	9

was discretionary. The cases and controls each had thirty-one instances of long-term certified absence.

Discussion of the Results

Tables 8.19 and 8.20 suggest that the distribution of long-term sickness absence is similar between cases and controls. Table 8.21 presents parallel data for short-term absence, and Table 8.22 shows the similarity of distribution of the two driver groups for 'sickness' and 'absence' pooled; but over the period of study a significantly greater number of controls compared to cases had no incidences of absence entered as 'Leave' (L).

This last result is difficult to interpret with certainty. At least 95 per cent of short-term absence entered as 'L' is prospectively sanctioned and is usually for non-medical reasons. The immediate con-

Table 8.19 *Total Number of Occasions and Total Days' Absence taken 1952–1955, for Sickness, Absence, and Leave, among Cases and Controls (Long-Term Absence)*

Category of Driver	*(S) + (A)*		*(L)*	
	Occasions	*Days*	*Occasions*	*Days*
Cases (38)	43	916	9	53
Controls (38)	46	888	8	91

Table 8.20 *Distribution of Cases and Controls for Frequency of Long-Term Absence, 1952–1955, entered as Sickness or Absence*

Frequency of Long-Term Absence	*Cases (38)*	*Controls (38)*
0	16	11
1	11	16
$\geqslant 2$	11	11

$\chi^2 = 1{\cdot}85$
$\nu = 2$
$0{\cdot}50 > P > 0{\cdot}30$

Table 8.21 *Total Number of Occasions and Total Days' Absence taken 1952–1955, for Sickness (S), Absence (A), and Leave (L), among Cases and Controls (Short-Term Absence)*

Category of Driver	*(S) + (A)*		*(L)*	
	Occasions	*Days*	*Occasions*	*Days*
Cases (38)	50	82	42	53
Controls (38)	48	74	26	33

Table 8.22 *Distribution of Cases and Controls for Incidence of Short-Term Absence, 1952–1955, entered as Leave (L), Sickness (S), or Absence (A)*

Category of Driver	*Incidence*				
	Short-Term Absence (L)		*Short-Term Absence (S + A)*		
	0	*1*	*0*	*1, 2*	*3+*
Cases (38)	13	25	17	15	6
Controls (38)	23	15	19	11	8
Test of Significance	$\chi^2 = 4{\cdot}275$ $\nu = 1$ $0{\cdot}05 > P > 0{\cdot}02$		$\chi^2 = 1{\cdot}012$ $\nu = 2$ $0{\cdot}70 > P > 0{\cdot}50$		

clusion that the results reflect a true difference of incidence of short-term absence for non-medical causes cannot be confidently drawn: many absences entered as 'S' or 'A' are for such reasons, and even if a man intends to be absent on a certain day he does not always bother to obtain permission, and so become entered as 'L', since within reasonable limits no personal benefit derives from his so doing. In fact he risks having permission refused. Table 8.23 shows that when short-term absence for all causes is pooled the difference largely disappears.

Table 8.23 *Distribution of Cases and Controls for Incidence of Short-Term Absence 1952–1955 (All Causes)*

Incidence of Short-term Absence	*Cases*	*Controls*
0	9	13
1, 2. 3	22	17
$\geqslant 4$	7	8

$\chi^2 = 1{\cdot}44$
$\nu = 2$
$0{\cdot}50 > P > 0{\cdot}30$

h Accident-Repeaters

Introduction

Many authors have suggested that if an individual incurs an accident while performing a task then his attitude to that task must be subsequently affected, and further that this change in attitude may be either an isolated phenomenon or part of a more general response characterised by bizarre psychosomatic complaints. Oppenheim (1889) designated this symptom-complex 'traumatic neurosis'. An identical state has frequently been observed after 'psychic' trauma. The condition may be related to, or even be identical with, the syndrome currently termed by Miller (1961) 'accident neurosis'. On this evidence the hypothesis has been advanced that, after he has experienced an accident an individual's accident liability must be affected for a greater or lesser time. This hypothesis is attractive: certainly few persons can approach a task unaware of previous accident experience at that and parallel tasks; but it is a difficult one to test. Individuals who might be expected to sustain the greatest change in accident liability, for example sufferers from 'accident neurosis', often remove themselves from risk by prolonged absence from work or change of environment; those who experience only a post-accident change in attitude, or mild 'accident neurosis', cannot be retrospectively ascertained with any certainty. To argue that they may be identified by the occurrence of a subsequent accident, is illogical. The basic hypothesis has never yet been satisfactorily established.

Review of the Literature

Historically, Greenwood and Woods (1919) introduced the 'Biassed distribution' (later termed the 'burnt fingers' distribution by Arbous and Kerrich (1951)) on the hypothesis that incurring an accident will affect a person's subsequent liability, as measured by the occurrence of a second accident. In its statistically useful form, i.e. the Single Biassed distribution, the hypothesis allows only two levels of liability, namely that before and that after the first accident, with no possible variation in either. Its ability to graduate observed data is seldom satisfactory, and its structure was based on analogies which are too rigid and mechanistic to be seriously entertained as bases for human behaviour. Its uses and limitations have been previously discussed in this work. More recently, three studies have approached the problem using fresh data: Horn (1947) using the records of Army Air Force pilots over 4 years, Archibald and Whitfield (1947) with information relating to Royal Ordnance personnel over 5 months, and Mintz (1954) with taxi driver data supplied by Ghiselli. Horn wrote: '[the results] suggest that the disruptive effect of an accident is a crucial factor in predisposing the pilot to a second accident . . . but the role of pilot error in the first accident has nothing to do with the interval between accidents'. Archibald and Whitfield concluded: 'That individuals who have more than one accident are more likely to have accidents of the same type (as regards what they were doing at the time of the accident, as regards the body site of injury, and as regards the nature of injury) than is to be expected from the risks of their occupation'. In the last of the three studies considered, Mintz discussed some of the pertinent mathematical problems involved, and concluded: 'these [his own] results are clearly not in favour of the hypothesis of increased accident susceptibility with accidents. This conclusion requires qualifications. It should be noted that certain factors were not taken into consideration in this study . . . which are likely to have functioned as sources of variation of the accident rates. . . .' Bearing in mind the limitations of some of Ghiselli's previous data (Ghiselli and Brown, 1949), Mintz's circumspection seems justified.

It is unnecessary to discuss these papers in detail; in none are data and/or methodology wholly acceptable.

Procedure and Results

The results of Chapter 7 suggest that, on the present data, a driver having had *r* accidents over the period of study had these accidents at such intervals as to suggest that he was indeed liable to have *r* accidents in that environment during that time. Nevertheless the following hypothesis was considered: that drivers who incurred an accident within one calendar month of a preceding accident on at least three occasions during the period of this study, show no difference in physical or personality characteristics (when age and experience are discounted) compared to selected controls. Such drivers are subsequently referred to as 'chronic repeaters'.

To test this hypothesis two control groups were selected. The first consisted of each chronic repeater's matched control; the second, of those cases who were not chronic repeaters. The rationale underlying the selection of the control groups is, that if it is assumed that chronic repeaters possess certain qualities making them likely to repeat accidents, then the remaining cases and the matched controls will not possess these qualities. But it can also be argued that if these qualities do not exert their effect until an accident is experienced, then the matched controls constitute an invalid control group, since many of them have zero accidents over the period.

The writers are aware of some of the invalidities associated with the above over-rationalisation. Nevertheless, Tables 8.24 and 8.25 show that chronic repeaters were less fat than matched controls and the remaining cases, and possibly less well adjusted than the remaining cases. To test whether these differences were truly genuine, and to decide which of the two related variables, namely phenotype

Table 8.24 *Data on Chronic Repeaters (Chr), Controls (Con) and Rest of Cases (Rest)*

	Chr (16)		*Controls (16)*		*Rest (22)*		*Significance of Difference*	
	Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*	*Chr v Con*	*Chr v Rest*
Age (years)	42·0	7·7	43·4	7·4	43·1	8·6	$0{\cdot}70 > P > 0{\cdot}60$	$0{\cdot}70 > P > 0{\cdot}60$
Experience (years)	5·2	3·7	5·8	4·1	6·5	3·4	$0{\cdot}70 > P > 0{\cdot}60$	$0{\cdot}30 > P > 0{\cdot}20$
Linearity (L)	3·8	1·3	3·4	1·0	3·4	0·9	$0{\cdot}40 > P > 0{\cdot}30$	$0{\cdot}30 > P > 0{\cdot}20$
Muscularity (M)	4·2	1·1	4·1	0·9	4·0	0·8	$0{\cdot}90 > P > 0{\cdot}80$	$0{\cdot}60 > P > 0{\cdot}50$
Fatness (F)	2·7	0·7	3·2	0·7	3·2	0·7	$0{\cdot}05 > P > 0{\cdot}02$	$0{\cdot}05 > P > 0{\cdot}02$
Androgyny	85·4	4·8	87·8	3·4	87·2	6·2	$0{\cdot}40 > P > 0{\cdot}30$	$0{\cdot}40 > P > 0{\cdot}30$

Table 8.25 *Personality Measure. Data from Chronic Repeaters, Controls, and Rest of Cases*

Category of Driver	*Score on Heron I*		*Score on Heron II*	
	0 – 7	*≥8*	*0 – 4*	*≥5*
Chronic Repeaters (16)	11	5	9	7
Controls (16)	11	5	8	8
Rest of Cases (22)	21	1	15	7

Heron I
Chronic Repeaters—Rest of Cases
Exact Probability (Double Tail), $P = 0{\cdot}217$

Heron II
Chronic Repeaters—Rest of Cases
Exact Probability (Double Tail), $P = 0{\cdot}871$

and score on Heron I, was responsible for the differences, would require further experimentation.

The second hypothesis tested is, that absence from work after an accident has no measurable beneficial effect on the liability of a driver to incur an accident within the next month. In Table 8.26 accidents are classified as 'repeated' if they were followed by another accident to the same driver within one month, and 'not-repeated' if they were not. Each group was then dichotomised depending on whether the accident was followed by an absence, for whatever cause, which terminated within one month of the accident.

Table 8.26 *Accidents and Absence**

Accidents	*Absence*		*Total*
	Yes	*No*	
Repeated	2	76	78
Not-Repeated	20	258	278
Total	22	334	356

Exact Probability (Double Tail), $P = 0{\cdot}102$

* *Terms explained in text.*

This approach may be too simple; no claim is made that the hypothesis is definitely supported, merely that it is not positively disproved.

i The Drivers' Background

Introduction

During the first part of the interview certain data were noted relating to the social and educational backgrounds of each driver, and to his opinion on the hazards and advantages of his job. These data were unsuitable for rigorous statistical treatment, but in conjunction with additional information they allow one to form a judgement as to the nature and importance of some of the selection processes operating on a group of regular bus drivers in Northern Ireland. The following is based mainly on the B.C.T. data, but with only minor variation applies equally to the U.T.A.

Employment Conditions

Until the early nineteen-forties tramcars were the principal public transport vehicles in Belfast, but subsequently they declined in numbers finally becoming obsolete in February, 1954. Tram driving was officially reckoned to demand little skill and training; drivers were rated as unskilled and paid accordingly, and this grading is still preserved for bus and trolley-bus drivers even though their occupation is considerably more exacting. This policy may have had a bearing on the quality and character of recruit; for example many trainee drivers stay only long enough to obtain a P.S.V. licence before seeking more remunerative work. This level of grading and remuneration is not offset by sociable working conditions, ready opportunities of bonus and overtime payments, regular promotion, or specially generous holidays. The work, by its very nature and decentralisation, inflicts isolation with only limited opportunity for social contacts with colleagues. As against this must be placed the comparative security of job tenure, a pension, a generous sick-pay scheme, and hours of duty not unattractive to many men. A bonus is paid for a good driving record in the U.T.A. but not in the B.C.T.

Working conditions suggest the possible operation of a degree of self-selection dependent on 'personality'. Scores on Heron II for pooled cases and controls gave a mean of 4·03 compared to a value of about 4·45 obtained by Heron (1956a) with potential bus conductors, under rather different operative conditions. Distribution of scores on Heron I gave 80 per cent 'probably well adjusted', compared to about 70 per cent obtained by Heron (1956b) with a mixed group of omnibus conductor applicants, National Servicemen, university students, and police drivers and instructors. For reasons given previously, no conclusions are hazarded from these results.

Social, Educational and Industrial Backgrounds

The majority of drivers interviewed were from Belfast working class or lower middle class families. Few came from outside the city, and fewer still had received full secondary education. All were, or had been, married. About half admitted to taking up driving because there was no alternative employment, although there was a minority, about equally represented among cases and controls, who were clearly always interested in driving and things mechanical. Only a proportion seemed to have more than a basic knowledge of the internal combustion engine, and some not even that, although several drivers were clearly mechanically highly proficient and undertook private maintenance work in their spare time. Some men entered professional driving as early as possible, the majority only after several previous occupations. Some impressed as liking their occupation, some were unambiguous in their desire to leave if they could get 'a better job' elsewhere. All were members of a Trade Union, but few were active participants in Union affairs.

Driving Opinions

Most drivers clearly identified worry and bad temper as 'causes' of accidents, a small minority considered accidents as due to bad luck, and fewer still believed them to be in any way related to lack of driving skill on the busman's part. Most visualised the perfect driver as phlegmatic but attentive, with happy domestic circumstances, and more pay; few stressed any need for conscientiousness and a developed sense of responsibility. The great majority said that driving was becoming more hazardous. Opinion as to the driving merits of the current private licence holder was about equally divided; not so opinion on the lack of road sense of the pedestrian, which was roundly condemned. The isolation imposed by the driving cabin was liked by many and actively disliked by few.

Häkkinen (1958), using a scale +3 to −3, scored his drivers for calmness—insecurity—nervousness of behaviour at interview, and for 'clear and frank answers—vague, uncertain and concealed answers'. His interviews were conducted 'blind', but the interviewer may not have been uninfluenced by previous knowledge, since 'in most cases the interviewer had served, prior to the interview, as the administrator of some of the psychomotor tests, so that the knowledge of how the subject had behaved in the tests in question may have exerted some influence on the rating'. The results suggested that 'clear and frank' answers and calmness at interview were more common among low accident groups of both tram and bus drivers than among high accident groups, these results reaching significance in several instances.

The present authors are of the opinion that this class of data does not justify such rigorous statistical treatment; nevertheless the findings warrant attention because of their obvious implications. In the present study, the first sixty drivers were categorised, after interview, as either 'case' or 'control', the interviewer using as criteria the general impact of the man's personality, background, opinions, 'interview behaviour', and 'clarity of answers'. Those who impressed as possessing qualities of the 'accident personality', as conceived by some previous writers including Häkkinen, were graded as 'cases'; but often the categorisation was almost arbitrary. The full number of drivers was not graded in this way since inevitably the number already assigned to each group would have influenced the interviewer's decision in the later instances. Thirty-seven drivers (62 per cent) were classified incorrectly, 23 (38 per cent) correctly. This could suggest that the inexperienced interviewer should be cautious in predicting a driver's accident experience, whether previous or future, on impression at interview; of course other constructions are possible.

Chapter 9 Application of the Short Distribution

a Introduction

The results of the previous chapters in this Section justify the adoption of the Short model, and the hypothesis from which it was derived, in studies of accident distribution. This theoretical distribution was constructed so as to have parameters with readily interpretable meanings, and consequently it is mandatory to evaluate these parameters and judge how meaningful are their relative values in the accident situation. Also, since the coherence of the hypothesis may warrant wider application of the Short model, we tested whether this distribution could describe the observed statistics of several classical frequency distributions from outside the accident field.

For the Short distribution, the values of the parameters and their standard errors (relating to the populations under study) are supplied in Chapter 13. Since the third moment was involved these standard errors are comparatively large. Hence this chapter must be considered to some extent speculative in nature.

b Application of the Theory

To Accident Data

As indicated in Chapter 5 the various theoretical distributions under study were applied to the data derived from the six populations available in the present investigation, both for the period 1952–1955 and also for the sub-periods 1952–1953 and 1954–1955. Inevitably the number of drivers and the average number of accidents varied widely between populations (Table 9.1); thus most weight should be attached to the results emanating from the first, fifth and sixth populations as tabulated.

For each population, Poisson, Negative Binomial, Long and Short distributions were fitted to the data over the four-year period; for the two-year sub-periods the Modified Short distribution was substituted for the Short after making the necessary assumption that

Table 9.1 *Numbers of Men and Accidents for each Population*

Population (*Drivers*)	*Number of Men*	*Total Number of Accidents in 1952–1955*
U.T.A. (Excluding Ballymena, Derry and Newry)	708	1612
U.T.A. Ballymena	106	234
U.T.A. Derry	114	311
U.T.A. Newry	79	311
B.C.T. Bus	183	732
B.C.T. Trolley-Bus	244	1085

the value of $q = \phi/m$ (where m is the sample mean), calculated for the whole period 1952–1955, held for the two sub-periods. The fitting of these distributions to the current data is tabulated at the end of the chapter (Tables 9.6–9.25).

On testing, the Poisson fails in every instance to graduate adequately the data from the populations studied, with the exceptions of U.T.A. Ballymena and Newry over the entire period and both sub-periods. This was perhaps not unanticipated since these were the smallest two populations. In all instances there appears little difference between the respective abilities of the Negative Binomial, Long and Short distributions, to reproduce the observations. Only in the case of U.T.A. Derry drivers over 1952–1953 (the third smallest population) were all theoretical distributions inadequate. Moreover, this particular sub-period for this population produced an atypical bi-modal distribution. Bivariate Negative Binomial Marginal distributions were fitted for B.C.T. Bus and Trolley-Bus drivers over the two-year sub-periods, and these also were in reasonable accord with the data. This *embarras de richesse* is discussed in more detail later (Chapter 10).

At this stage further consideration is imperative of the dichotomy of accidents involved in the Short distribution. In the initial development of the Long distribution the driver was envisaged as being subject to 'spells', and only within a spell could he incur an accident. But such an hypothesis was adjudged to be unrealistic; consequently the Short distribution was derived which is more a general solution in the sense that accidents were also allowed to occur outside spells.

Since the concept of a spell is fundamental and the thesis has not been discredited by the results, it is appropriate to explain more precisely what we understand by this term.

Briefly, a spell is taken to be a period of time during which the performance of a human being in any complex task is liable to be sub-standard, and during which, therefore, mistakes (which might possibly lead to an accident) can occur. Such a period is visualised as being concomitant with a bout of emotional or physical disturbance, either from causes *in propria persona* or induced environmentally. Such fluctuation is in the nature of things. It is tempting to postulate that personal troubles, family stresses, the onset of illness or return to work before full faculties are restored, and parallel conceptions, are not unassociated with such spells since it can reasonably be argued that such factors may interfere with a man's giving of his best at the job. Since the individual himself is intimately involved as a human being in any such accidents occurring during a spell, the appropriate descriptive term for these accidents would seem to be 'personal'. For those accidents which are allowed to occur independently of spells, the unemotive term 'chance' is strictly apposite in view of their purely Poisson genesis.

It is acknowledged that the terms 'personal' and 'chance' have a wider connotation than their literal interpretation justifies; consequently it can be argued that their use may lead to ambiguity. We consider that their use here can be vindicated, as follows. On introducing the physical system under review the assumption was made that, within each population, the risk of an accident was equal for all drivers. Consequently in any theoretical model to fit such a system there is no need to consider the environment as differing from driver to driver within each population. If in fact the environment *did* change from time to time then, in accordance with the physical system under review, it *must* have changed for all men in an equal fashion. For example, in an area the size of Northern Ireland a period of frosty weather could make driving conditions hazardous everywhere. Now, as stated earlier (Chapter 5), Irwin (1941), and Arbous and Kerrich (1951) demonstrated, in their derivation of the Poisson series, that λ (the mean number of accidents per man per unit time) need not be immutable but could be allowed to vary over time providing the relative rate of change was equal for all individuals. Thus, in the Short distribution, what is termed the 'chance' component amply discounts general variation in the environmental risk through time. No such inexorable logic can be advanced on behalf of the 'personal' component. In practice this component *could* include accidents arising from spasmodic changes in environmental circumstances, these changes providing unequal risk for different men within each population. This is conceded; but a driver is not a machine geared precisely to predictable hazards of his environment; when fully fit he is supposed to be equipped to adjust (within limits) his driving to suit, say, denser traffic conditions, and failure to compensate in this way can surely be construed as a 'personal' characteristic.

The Short distribution was so devised that 'personal' and 'chance' accidents were mathematically independent of each other. This implies the corollary that a 'chance' accident *could* occur within the period of time comprising a 'spell'. Thus all accidents occurring temporally within spells cannot be confidently designated as

Table 9.2 *Dichotomy of the Mean Number of Accidents over 1952–1955 (Four largest Populations).*

Population (*Drivers*)	*Mean Number of Accidents* $m = \phi + \lambda\theta$		
	m (*total*)	ϕ (*chance*)	$\lambda\theta$ (*personal*)
U.T.A. (Excluding Ballymena Derry and Newry)	2·29	1·03	1·26
U.T.A. Derry	2·73	1·32	1·41
B.C.T. Bus	4·00	2·64	1·36
B.C.T. Trolley-Bus	4·45	3·12	1·33

'personal'. Nevertheless the statistical parameters as calculated in practice do yield useful theoretical information as to the relative importance of each class of accident. The value of ϕ/m may be of use in estimating, from an observed frequency distribution, the proportion of accidents attributable to 'chance' factors, e.g. other drivers, pedestrians, influences of weather, and so on. The values obtained in the present study (Table 9.2) suggest that this component accounted for 66 to 70 per cent of all accidents involving B.C.T. drivers, and 45 to 48 per cent of all accidents to U.T.A. drivers (excluding U.T.A. Ballymena and Newry). On reflection these findings seem reasonable in that Belfast may have been expected to provide an inherently more dangerous environment than routes predominantly rural. Further, it may be speculated that the average number of accidents for which a driver is 'personally' responsible might be expected to be independent of whether he drives in the city or the country, a thesis not discredited by the findings in Table 9.2. 'Personal' factors accounted for approximately the same mean number of accidents whatever the population, and the environment (as measured by the

Table 9.3 *Dichotomy of the Mean Number of Accidents (Häkkinen, 1958; Křivohlavý, 1958)*

Population	*Mean Number of Accidents*† $m = \phi + \lambda\theta$		
	m (*total*)	ϕ (*chance*)	$\lambda\theta$ (*personal*)
Křivohlavý (1958) 582 Prague Tram Drivers (over 2 years)	5·02	3·74	1·28
Häkkinen (1958) 101 Helsinki Bus Drivers (over 6 years)	4·53	3·18	1·35
363 Helsinki Tram Drivers (over 4 years)	4·16	1·84	2·32

† Converted to a 4-year basis.

Compiled from data presented by: HÄKKINEN, S. (1958) (see above), and KŘIVOHLAVÝ, J. (1958), *Accident Activity in Situations with a Different Level of Risk*. Prague: Industrial Safety Research Institute.

'chance' component) to which B.C.T. drivers were subjected was two to three times as hazardous as that to which U.T.A. drivers were exposed. A similar value for the 'personal' component was obtained from the comparable sets of data available from the literature (Table 9.3). Only the Helsinki tram drivers differed. With them the comparatively large 'personal' component as calculated is strikingly at variance with the fact that the proportion of accidents for which the tram drivers were responsible—as assessed from the accident cards of the Transport Department—was low: 'The proportion of accidents in which the driver has been regarded as guilty is very low, in 1947–

1950 only 15 per cent of all the accidents. This is primarily due to the fact that tramcars have in most cases the right of way and, further, to the fact that the tram drivers had, on the average, longer histories of employment in the Transport Department than the bus drivers ... it was found that the drivers having served for long in the Transport Department had relatively less accidents for which they were responsible than did the new drivers' (Häkkinen, 1958). From this description it is evident that the tram driver data are not comparable with the bus driver data, and thus their discordance may be irrelevant; but to find other data in apparent agreement with those from the present study is encouraging.

To Other Classes of Data

There is justification for adjudging the Short distribution to be strictly apposite for data from an 'open' community such as a group of transport drivers, i.e. ϕ corresponds (at least in part) to drivers outside the population studied. On the other hand the Long distribution might be a more appropriate model when dealing with data from a 'closed' community, such as can be easily envisaged in the factory situation; in such circumstances ϕ may well not exist at all. An attempt to fit the Short model to Greenwood and Woods' (1919) familiar data on 648 women munition operators working on 6-inch H.E. shells, gave $\phi = -0{\cdot}204$. In a different context Neyman (1939), in his paper introducing the Type A distribution, cited as an appropriate ecological example the distribution of certain larvae in 120 groups of 8 hills each. Our attempt to fit the Short distribution to Neyman's data yielded $\phi = -5{\cdot}154$. Clearly in this instance a model considering only the survival of larvae and their subsequent spreading out, is adequate to explain the observed frequency distribution without introducing the concept of 'chance' specimens. Again, an attempt to fit the Short model to 'Student's' (1907) classic data on the distribution of yeast cells in 400 haemocytometer divisions, yielded $\phi = -0{\cdot}268$. Once more the Neyman Type A (or Long) distribution adequately represents the observations.

That the Short distribution may have application to a class of problems beyond that for which it was specifically constructed is demonstrated in Table 9.4, where better graduation is obtained for Karl Pearson's (1912) data on 'Cancer Houses' by this model than

Table 9.4 *Distribution of 377 Cancer Cases among 2,865 Houses Observed. (Madeley Registration Subdistrict, 1837—1910)*

Cases	*0*	*1*	*2*	*3*	*4*
Houses Observed	2,523	315	20	6	1
Poisson	2,511·7	330·6	21·7	1·0	
Greenwood and Yule's Biassed Distribution	2,530	296	36	3	
Negative Binomial	2,527·2	301·8	32·0	3·2	0·8
Long Distribution = Neyman Type A	2,528·1	300·5	33·2	3·0	0·2
Short Distribution	2,524·1	310·7	25·4	3·6	1·2

Compiled from data presented by PEARSON, K. (1912), 'On "Cancer Houses" from the data of the late Thomas Law Webb, M.D.', *Biometrika*, **8**, 430–435.

by any of the other theoretical distributions tested. The parameters have values: $\phi = 0{\cdot}118$, $\lambda = 0{\cdot}013$, and $\theta = 0{\cdot}998$. Thus, since the mean number of cancer cases per house is 0·132, 'chance' cases (ϕ) contributed 89·8 per cent of the total number. The improvement over the Poisson is remarkable because the successful fit amounted to requiring just over 10 per cent of cases as not due to 'chance'.

Table 9.5 *Distribution of 3,512 Cases of Enteric Fever among 106,721 Houses in Manchester over 7 years. (Troup and Maynard, 1912)*

Cases	*0*	*1*	*2*	*3*
Observed	103,291	3,350	78	2
Poisson	103,266	3,398	56	1
Negative Binomial	103,289·9	3,349·1	78·9	3·1
Short	103,280·5	3,377·2	59·4	3·9

Compiled from data presented by TROUP, J. McD. and MAYNARD, G. D. (1912), 'Note on the extent to which the distribution of cases of disease in houses is determined by the laws of chance', *Biometrika*, **8**, 396–403.

However, when dealing with multiple illnesses in houses the Short distribution is not always successful in reproducing the observations. The data in Table 9.5 concern the distribution of 3,512 cases of enteric fever among houses in Manchester. The value of $\phi/m = 99{\cdot}27\,\%$, but even so the Short shows a considerable improvement over the Poisson. However, the successful Negative Binomial fit may well be regarded as the classical illustration of the use of this distribution, and further there would seem sound theoretical justification for its application in such an instance.

Table 9.6 *U.T.A. (Excluding Ballymena, Derry and Newry) 1952—1955*
Observed and Various Theoretical Frequencies for Differing Numbers of Accidents, (r)

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Short*
0	117	71·5	110·4	116·7	110·4
1	157	164·0	168·5	162·0	169·7
2	158	187·9	156·8	153·1	156·0
3	115	143·6	114·7	115·3	113·9
4	78	82·3	72·5	74·6	72·5
5	44	37·7	41·5	43·2	41·9
6	21	14·4	22·1	22·8	22·5
7	7	} 6·5 (7, 8, ≧9)	11·2	11·3	11·3
8	6		} 10·3 (8, ≧9)	5·3 } 9·0	5·4 } 9·8
≧9	5			3·7	4·4
χ^2		64·356 $\nu = 6$	3·436 $\nu = 6$	2·705 $\nu = 6$	3·787 $\nu = 5$
P		$P < 0{\cdot}001$	$0{\cdot}80 > P > 0{\cdot}70$	$0{\cdot}90 > P > 0{\cdot}80$	$0{\cdot}70 > P > 0{\cdot}50$
Significance		Very Highly Significant	Not Significant	Not Significant	Not Significant

Table 9.7 *U.T.A. Ballymena 1952—1955*
Observed and Various Theoretical Frequencies for Differing Numbers of Accidents, (r)

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Short*
0	12	11·7	15·0	15·3	13·3
1	29	25·7	26·1	25·8	26·9
2	26	28·4	25·5	25·2	27·5
3	23	20·9	18·4	18·4	19·0
4	7	11·5	10·9	11·0	10·2
$\geqq 5$	9	7·8	10·1	10·3	9·1
χ^2		2·792 $\nu = 4$	3·597 $\nu = 3$	3·903 $\nu = 3$	2·220 $\nu = 2$
P		$0{\cdot}70 > P > 0{\cdot}50$	$0{\cdot}50 > P > 0{\cdot}30$	$0{\cdot}30 > P > 0{\cdot}20$	$0{\cdot}50 > P > 0{\cdot}30$
Significance		Not Significant	Not Significant	Not Significant	Not Significant

Table 9.8 *U.T.A. Derry 1952–1955*
Observed and Various Theoretical Frequencies for Differing Numbers of Accidents, (r)

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Short*
0	12	7·5	13·5	14·7	13·3
1	21	20·3	22·9	22·0	23·3
2	34	27·7	23·8	23·0	23·9
3	16	25·2	19·5	19·4	19·3
4	8	17·2	13·8	14·1	13·7
5	9	9·4	8·9	9·2	8·8
6	7	6·7	5·3	5·5	5·3
≥ 7	7		6·3	6·1	6·4
χ^2		20·408 $\nu = 5$	8·386 $\nu = 5$	9·583 $\nu = 5$	8·164 $\nu = 4$
P		$0{\cdot}01 > P > 0{\cdot}001$	$0{\cdot}20 > P > 0{\cdot}10$	$0{\cdot}10 > P > 0{\cdot}05$	$0{\cdot}10 > P > 0{\cdot}05$
Significance		Highly Significant	Not Significant	Not Significant	Not Significant

Table 9.9 *U.T.A. Newry 1952–1955*
Observed and Various Theoretical Frequencies for Differing Numbers of Accidents, (r)

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Short*
0	5	2·2 } 10·1	4·9 } 15·7	5·5	4·0 } 14·8
1	10	7·9 }	10·8 }	10·6	10·8 }
2	15	14·1	14·0	13·4	15·0
3	10	16·8	13·8	13·5	14·6
4	16	15·1	11·6	11·6	11·6
5	11	10·8	8·7	8·9	8·3
$\geqq 6$	12	12·1	15·2	15·5	14·7
χ^2		5·245 $\nu = 4$	4·099 $\nu = 3$	4·132 $\nu = 4$	4·495 $\nu = 2$
P		$0{\cdot}30 > P > 0{\cdot}20$	$0{\cdot}30 > P > 0{\cdot}20$	$0{\cdot}50 > P > 0{\cdot}30$	$0{\cdot}20 > P > 0{\cdot}10$
Significance		Not Significant	Not Significant	Not Significant	Not Significant

Table 9.10 *B.C.T. Bus Drivers 1952–1955*
Observed and Various Theoretical Frequencies for Differing Numbers of Accidents, (r)

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long* = *N.T.A.*	*Short*
0	8	16·8	9·1	10·7	7·5
1	22		21·0	20·6	20·9
2	25	26·8	28·7	27·4	30·5
3	33	35·8	30·2	29·1	31·8
4	32	35·8	27·0	26·7	27·2
5	24	28·6	21·6	21·9	20·9
6	8	19·1	15·9	16·4	15·2
7	12	10·9	11·0	11·5	10·5
8	8	9·2	7·2	7·6	7·0
$\geqq 9$	11		11·3	11·1	11·5
χ^2		28·855 $\nu = 6$	6·224 $\nu = 7$	7·108 $\nu = 7$	6·225 $\nu = 6$
P		$P < 0·001$	$0·70 > P > 0·50$	$0·50 > P > 0·30$	$0·50 > P > 0·30$
Significance		Very Highly Significant	Not Significant	Not Significant	Not Significant

Table 9.11 *B.C.T. Trolley-Bus Drivers 1951–1955*
Observed and Various Theoretical Frequencies for Differing Numbers of Accidents, (r)

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Short*
0	12	2·9 } 15·6	11·3	14·8	7·4
1	20	12·7	24·9	24·0	23·3
2	37	28·3	33·9	31·6	37·5
3	37	41·9	36·4	34·3	41·4
4	36	46·6	33·8	32·8	36·2
5	28	41·4	28·6	28·6	27·9
6	16	30·7	22·5	23·2	20·4
7	26	19·5	16·8	17·7	14·9
8	11	10·8	12·0	12·8	10·8
9	8		8·3	8·8	7·8
10	5	9·2	5·6	5·9	5·5
$\geqq 11$	8		9·9	9·5	10·9
χ^2		51·555, $\nu = 7$	8·895, $\nu = 9$	9·484, $\nu = 9$	13·846, $\nu = 8$
P		$P < 0{\cdot}001$	$0{\cdot}50 > P > 0{\cdot}30$	$0{\cdot}50 > P > 0{\cdot}30$	$0{\cdot}10 > P > 0{\cdot}05$
Significance		Very Highly Significant	Not Significant	Not Significant	Not Significant

Table 9.12 *U.T.A. (Excluding Ballymena, Derry and Newry) 1952–1953*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Modified Short*
0	224	194·7	222·2	224·3	222·4
1	226	251·3	232·0	228·6	231·9
2	150	162·2	143·3	143·5	143·0
3	68	69·8	68·1	69·3	68·2
4	23	22·5	27·6	28·0	27·7
5	11			10·1	10·0
6	5	7·5	14·8	4·2 } 14·3	4·8 } 14·8
$\geqq 7$	1				
χ^2		19·964 $\nu = 4$	1·577 $\nu = 3$	1·751 $\nu = 3$	1·630 $\nu = 3$
P		$P < 0{\cdot}001$	$0{\cdot}70 > P > 0{\cdot}50$	$0{\cdot}70 > P > 0{\cdot}50$	$0{\cdot}70 > P > 0{\cdot}50$
Significance		Very Highly Significant	Not Significant	Not Significant	Not Significant

Table 9.13 *U.T.A. (Excluding Ballymena, Derry and Newry) 1954–1955*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Modified Short*
0	291	260·1	283·3	284·7	283·4
1	218	260·5	238·1	235·3	237·8
2	132	130·4	119·2	119·8	119·0
3	49	43·5	46·2	46·9	46·3
4	13	$\left.\begin{array}{r}10{\cdot}9\\2{\cdot}6\end{array}\right\}13{\cdot}5$	15·3	15·3	15·3
$\geqq 5$	5		5·9	6·0	6·2
χ^2		12·820 $\nu = 3$	3·933 $\nu = 3$	3·260 $\nu = 3$	4·008 $\nu = 3$
P		$0{\cdot}01 > P > 0{\cdot}001$	$0{\cdot}30 > P > 0{\cdot}20$	$0{\cdot}50 > P > 0{\cdot}30$	$0{\cdot}30 > P > 0{\cdot}20$
Significance		Highly Significant	Not Significant	Not Significant	Not Significant

Table 9.14 *U.T.A. Ballymena 1952–1953*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Modified Short*
0	25	26·5	26·6	27·4	26·5
1	39	36·7	36·9	37·9	36·7
2	27	25·5	25·6	26·3	25·5
3	9	11·8	11·8	12·2 } 14·4	11·8
$\geqq 4$	6	5·5	5·1	2·2 }	5·5
χ^2		1·026 $\nu \doteq 3$	1·116 $\nu = 2$	0·286 $\nu = 1$	1·026 $\nu = 2$
P		$0{\cdot}80 > P > 0{\cdot}70$	$0{\cdot}70 > P > 0{\cdot}50$	$0{\cdot}70 > P > 0{\cdot}50$	$0{\cdot}70 > P > 0{\cdot}50$
Significance		Not Significant	Not Significant	Not Significant	Not Significant

Table 9.15 *U.T.A. Ballymena 1954–1955*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Modified Short*
0	50	46·7	48·5	48·5	48·0
1	33	38·3	36·2	36·1	37·1
2	16	15·7	15·1	15·2	14·9
3	$\left.\begin{matrix}6\\1\end{matrix}\right\}7$	$\left.\begin{matrix}4·3\\1·0\end{matrix}\right\}5·3$	$\left.\begin{matrix}4·7\\1·5\end{matrix}\right\}6·2$	$\left.\begin{matrix}4·7\\1·5\end{matrix}\right\}6·2$	$\left.\begin{matrix}4·4\\1·6\end{matrix}\right\}6·0$
$\geqq 4$					
χ^2		1·517, $\nu = 2$	0·486, $\nu = 1$	0·457, $\nu = 1$	0·784, $\nu = 1$
P		$0·50 > P > 0·30$	$0·50 > P > 0·30$	$0·50 > P > 0·30$	$0·50 > P > 0·30$
Significance		Not Significant	Not Significant	Not Significant	Not Significant

Table 9.16 *U.T.A. Derry 1952–1953*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Modified Short*
0	35	25·2	31·7	32·4	31·6
1	26	38·0	34·7	33·6	34·9
2	32	28·7	23·8	23·7	23·7
3	10	14·4	13·0	13·3	13·0
≥ 4	11	7·7	10·8	11·0	10·8
χ^2		10·737 $\nu = 3$	6·042 $\nu = 2$	5·654 $\nu = 2$	6·239 $\nu = 2$
P		$0{\cdot}02 > P > 0{\cdot}01$	$0{\cdot}05 > P > 0{\cdot}02$	$0{\cdot}10 > P > 0{\cdot}05$	$0{\cdot}05 > P > 0{\cdot}02$
Significance		Significant	Significant	Not Significant	Significant

Table 9.17 *U.T.A. Derry 1954–1955*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Modified Short*
0	39	33·7	37·4	37·6	37·3
1	36	41·1	38·3	37·8	38·3
2	22	25·0	22·6	22·7	22·6
3	10	10·2 } 14·1	10·1	10·3	10·1
$\geqq 4$	7	3·9 } 14·1	5·6	5·6	5·7
χ^2		2·423, $\nu = 2$	0·573, $\nu = 2$	0·519, $\nu = 2$	0·528, $\nu = 2$
P		$0{\cdot}30 > P > 0{\cdot}20$	$0{\cdot}80 > P > 0{\cdot}70$	$0{\cdot}80 > P > 0{\cdot}70$	$0{\cdot}80 > P > 0{\cdot}70$
Significance		Not Significant	Not Significant	Not Significant	Not Significant

Table 9.18 *U.T.A. Newry 1952–1953*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Modified Short*
0	12	11·7	13·5	13·6	13·3
1	26	22·3	22·1	22·0	22·3
2	17	21·3	19·7	19·6	19·8
3	12	13·6	12·6	12·6	12·6
4	8	6·5 } 10·1	6·5 } 11·1	6·5 } 11·2	6·4 } 11·0
$\geqq 5$	4	3·6 }	4·6 }	4·7 }	4·6 }
χ^2		2·035 $\nu = 3$	1·327 $\nu = 2$	1·346 $\nu = 2$	1·257 $\nu = 2$
P		$0{\cdot}70 > P > 0{\cdot}50$	$0{\cdot}70 > P > 0{\cdot}50$	$0{\cdot}70 > P > 0{\cdot}50$	$0{\cdot}70 > P > 0{\cdot}50$
Significance		Not Significant	Not Significant	Not Significant	Not Significant

Table 9.19 *U.T.A. Newry 1954–1955*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Modified Short*
0	17	14·9	16·3	16·3	16·2
1	23	24·8	24·4	24·3	24·5
2	18	20·7	19·5	19·5	19·5
3	16	11·6	11·1	11·1	11·0
$\geqq 4$	5	7·0	7·7	7·8	7·8
χ^2		3·019 $\nu = 3$	3·335 $\nu = 2$	3·383 $\nu = 2$	3·525 $\nu = 2$
P		$0{\cdot}50 > P > 0{\cdot}30$	$0{\cdot}20 > P > 0{\cdot}10$	$0{\cdot}20 > P > 0{\cdot}10$	$0{\cdot}20 > P > 0{\cdot}10$
Significance		Not Significant	Not Significant	Not Significant	Not Significant

Table 9.20 *B.C.T. Bus Drivers 1952–1953*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Modified Short*
0	29	25.9	33.3	34.1	32.6
1	54	50.6	49.7	48.8	50.7
2	48	49.5	43.0	42.6	43.4
3	25	32.3	28.2	28.4	27.9
4	14	15.8	15.5	15.8	15.2
5	6	8.9	7.6	7.7	7.5
≥ 6	7		5.7	5.6	5.7
	χ^2	4.388 $\nu = 4$	2.649 $\nu = 4$	3.339 $\nu = 4$	2.093 $\nu = 4$
	P	$0.50 > P > 0.30$	$0.70 > P > 0.50$	$P \simeq 0.50$	$0.80 > P > 0.70$
	Significance	Not Significant	Not Significant	Not Significant	Not Significant

Table 9.21 *B.C.T. Bus Drivers 1954–1955*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Modified Short*
0	30	23·7	33·4	34·7	32·0
1	55	48·4	47·8	46·2	49·5
2	38	49·5	41·4	40·7	42·2
3	25	33·7	28·0	28·3	27·5
4	21	17·2	16·3	16·8	15·7
5	8	10·5	8·6	8·9	8·3
$\geqq 6$	6		7·5	7·4	7·8
χ^2		9·500 $\nu = 4$	3·728 $\nu = 4$	4·283 $\nu = 4$	3·596 $\nu = 4$
P		$0{\cdot}05 > P > 0{\cdot}01$	$0{\cdot}50 > P > 0{\cdot}30$	$0{\cdot}50 > P > 0{\cdot}30$	$0{\cdot}50 > P > 0{\cdot}30$
Significance		Significant	Not Significant	Not Significant	Not Significant

Table 9.22 *B.C.T. Trolley-Bus Drivers 1952–1953*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Modified Short*
0	40	24·5	41·6	45·1	36·8
1	52	56·3	57·8	53·9	62·2
2	62	64·7	51·7	49·9	55·6
3	36	49·6	37·6	37·8	37·1
4	24	28·5	24·2	25·1	22·1
5	16	13·1	14·4	15·1	13·0
6	8	7·3 (6 and $\geqq 7$ combined)	8·1	8·4	7·6
$\geqq 7$	6		8·6	8·7	9·6
χ^2		21·478, $\nu = 5$	3·731, $\nu = 5$	4·623, $\nu = 5$	4·947, $\nu = 5$
P		$P < 0{\cdot}001$	$0{\cdot}70 > P > 0{\cdot}50$	$0{\cdot}50 > P > 0{\cdot}30$	$0{\cdot}50 > P > 0{\cdot}30$
Significance		Very Highly Significant	Not Significant	Not Significant	Not Significant

Table 9.23 *B.C.T. Trolley-Bus Drivers 1954–1955*

r	*Observed*	*Poisson*	*Neg. Binomial*	*Long = N.T.A.*	*Modified Short*
0	43	28·5	41·2	42·9	38·7
1	55	61·2	61·4	59·3	63·9
2	58	65·7	55·1	54·1	57·0
3	44	47·0	38·6	48·9	38·1
4	21	25·3	23·3	23·9	22·1
5	10	10·9	12·6	13·0	12·0
6	10	5·4	6·4	6·5	6·2
$\geqq 7$	3		5·4	5·4	6·0
χ^2		20·603 $\nu = 5$	5·510 $\nu = 5$	5·079 $\nu = 5$	6·867 $\nu = 5$
P		$P < 0{\cdot}001$	$0{\cdot}50 > P > 0{\cdot}30$	$0{\cdot}50 > P > 0{\cdot}30$	$0{\cdot}30 > P > 0{\cdot}20$
Significance		Very Highly Significant	Not Significant	Not Significant	Not Significant

Bivariate Negative Binomial Marginal Distributions
Observed and Theoretical (Marginal Distribution) Frequencies
for Differing Numbers of Accidents (r)

Table 9.24 *B.C.T. Bus Drivers, 1952–1953 and 1954–1955*

r	*Theoretical*	*Observed* 1952–3	*Observed* 1954–5
0	33·3	29	30
1	48·8	54	55
2	42·3	48	38
3	28·2	25	25
4	16·0	14	21
5	8·1	6	8
$\geqq 6$	6·3	7	6
χ^2		3·112 $\nu = 4$	3·493 $\nu = 4$
P		$P \simeq 0·50$	$P \simeq 0·50$
Significance		Not Significant	Not Significant

Table 9.25 *B.C.T. Trolley-Bus Drivers, 1952–1953 and 1954–1955*

r	*Theoretical*	*Observed* 1952–3	*Observed* 1954–5
0	40·3	40	43
1	59·6	52	55
2	54·1	62	58
3	38·7	36	44
4	24·0	24	21
5	13·6	16	10
6	7·1	8	10
$\geqq 7$	6·6	6	3
χ^2		2·906 $\nu = 5$	6·020 $\nu = 5$
P		$P \simeq 0·70$	$P \simeq 0·30$
Significance		Not Significant	Not Significant

Section 3

Chapter 10 The Causes of Accidents

a Introduction

When the theories of the natural dispensation and the chance allocation of accidents were finally rejected, a period of reaction followed in which investigators tended to dismiss environmental factors as largely impotent *per se*, and to ascribe all accidents to causes *in propria persona*. Thus over much of the last 40 years many have laboured to demonstrate a relationship between personal qualities and accident experience, and have frequently relegated the factors of risk exposure and the environment to subordinate positions. Unquestionably much of this effort was prompted by a genuine enthusiasm to identify those individuals especially liable to accident, but by the Second World War the discipline of accident studies had so disintegrated under this onslaught that Chambers, Yule, Greenwood, Irwin, and others (Chambers and Yule, 1941), and later Greenwood (1950), clearly felt impelled to restate some of the fundamentals especially as regards the Negative Binomial distribution. Arbous and Kerrich (1951) continued this re-education: 'Accidents are no longer regarded as entirely fortuitous events and the inevitable price to be paid for technological advancement. Events which were previously considered to be chance-determined are now regarded as preventable, and causes which were hitherto regarded as beyond the control of the individual are now seen in many cases as intimately related to his psycho-physiological make-up. It is not a question of the blame being shifted from the environment to the individual, but rather an appreciation that what really matters is the degree of adjustment which exists between the two. Our appreciation of the wide range of individual differences which exists in man has led to the natural conclusion that considerable improvement can be effected in human adjustment by a more careful consideration of those aspects of the environment which are man-made, and also the varying degrees of skill, mental ability, physical constitution, temperamental and personality qualities with which individuals are equipped. As a result accidents are to-day more often regarded as problems of human adjustment, or of manifestations of maladjustment'.

Subsequently it has become customary to attempt to allocate accidents depending on their cause into one of two broad categories, viz. those due to 'personal' factors, and those attributable to the *milieu extérieur* in its widest sense. Some authors follow epidemiological convention by grouping road accidents into those due to (1) the driver, (2) the vehicle, and (3) the road and other road users; this represents the orthodox trichotomy of host—intermediary—environment. But such allocation must be, in any particular instance, largely arbitrary, although it is generally claimed that the majority of road accidents can be ascribed to 'personal' factors among road users. If the assumptions underlying the construction of the Short distribution are accepted, then this assertion would appear to be contradicted by the results in Chapter 9, where the 'chance' component of each group's mean was generally larger than the 'personal' one; but it can be argued that in many of the 'environment' (or 'chance') accidents some degree of culpability can be apportioned to other drivers, and thus widening of the 'population' to include *all* drivers would lead to confirmation of the rule.

The present investigation was not specifically designed to enable the degree of culpability of the driver to be assessed in each particular accident. Unquestionably this objective is worth attaining, but, unless the investigator has full powers over the allocation and rotation of drivers, field epidemiological studies are impotent in this context. Also, the individual interrogation of drivers, reliance on insurance company assessors, or reconstruction of each accident situation, must perforce supply data which are of questionable validity. However most writers concede that, quite apart from more fundamental qualities, certain variables of a temporary nature—termed 'temporary attributes of the individual' by Thorndike (1951)—may play a role in accident causation. Much of the evidence is tenuous and will not be reviewed here. (Readers are referred to Thorndike (1951), the many works of R. A. McFarland, e.g. McFarland, Moore and Warren (1955), McFarland and Moore (1957), McFarland (1962), and the admirable précis of Norman (1962)). Instead, the possible role taken by health, temporary emotional disturbance, and fatigue will be briefly discussed. The alleged parts played by subconscious motivation (Adler, 1941; Klein, 1932), by the desire to withdraw from the work situation (Hill and Trist, 1953; Castle, 1956), and other similar theories of accident causation, are outside the scope of this study. The importance of age and driving experience *per se* has already been discussed in Chapter 4.

b 'Temporary Attributes'

Health

Permanent defects of physique, the special senses, neuro-muscular co-ordination or reaction time, quite apart from inadequacies of corporal dexterity or higher conative or cognitive function, have all *inter alia* been incriminated as predisposing drivers to accidents in an unequal fashion. It is axiomatic that sufferers from diseases which are very likely to produce loss of control at the wheel, e.g. epilepsy, or from disorders which are patently incompatible with safe driving, e.g. total blindness or complete disablement, should be excluded from driving. This is the rationale of the private licence declaration, but public-service vehicle drivers are required by law (P.S.V. Regulations, 1934), and usually by their employers, to attain stricter standards of clinical fitness as well as to show technical proficiency. The need for such standards is rigorously defended, and certainly the known prognosis of some conditions might justify the exclusion of certain drivers on pragmatic grounds alone. Frequently, however, the criteria adopted are arbitrary. For example, it is self-evident that a blind man must be a dangerous driver, but at what level does visual acuity *per se* exert an independent influence on accident liability, other things being equal? Also, what is the exact relationship between accident liability and each component of visual acuity over their entire ranges? The same argument can be extended to other physical systems. Since the crucial relationships have never been satisfactorily established, many of the recommendations of the British Medical Association (1954), the World Health Organisation (1956), and the American Medical Association (1959), seem perhaps too arbitrarily chosen. Nor can they be entirely justified on the ground of pragmatism as against that of equity: that, for example, by casting the net widely enough it is hoped that all drivers with, say, a risk of sudden incapacity, will be eliminated. In London Transport nearly 50 drivers lost consciousness at the wheel between 1949 and 1959 (Norman, 1960). If reputable bodies continue to promulgate recommendations based on tenuous evidence then the attainment of their objectives, when offering advice or advising action based on convincing data, must be jeopardised. 'Safe-driver' selection criteria require reappraisal.

Whereas in a driver a permanent or long-standing physical defect may become to some extent compensated, temporary impairment of a function frequently produces no such response and for this reason alone may be potentially more dangerous. Except when obvious, e.g. sudden death, loss of consciousness etc., the influence of such factors on accident liability (as measured by the criterion of accident experience) cannot readily be assessed by epidemiological methods without recourse to reasoning of doubtful logic, and it must be realised that the inadequacies revealed when temporary impairments were induced by alcohol (Drew, Colquhoun and Long, 1959), were on observed simulated tasks and not in the natural driving situation. Nevertheless such inadequacies may well affect the actual accident experience on the road, a fact which the studies of Holcomb (1938), Lucas, Kalow, McColl, Griffith and Smith (1955), and Haddon and Bradess (1959) purported to show. If the existence of a relationship between temporary impairments and accident experience on the road is accepted as likely, then, providing the relevant factors can be identified, the adoption of a medical examination for public transport drivers returning to work after an accident or an illness becomes entirely rational. But as well as being assessed on clinical grounds as unfit to drive (and Norman (1960) so adjudged 23·6 per cent of London Transport drivers on their return to work after illness) there are occasions when drivers who, although clinically 'fit', must perform at reduced efficiency. During such times their liability to accident may *ceteris paribus* increase. This is in the nature of things, and the subclinical or the early stages of disease have *inter alia* been incriminated as causal factors in accidents. At present the importance of their role must be conjectural.

The net result of the influence of health on accident causation seems to be that within certain limits, most of which are obvious, clinically assessed unfitness is an unreliable predictor of increased accident liability as measured by actual accident experience.

Temporary Emotional Disturbances

It is currently unfashionable to deny that fluctuation in a driver's mood, or emotional disquiet, may be associated with variation in his accident liability. Usually the relationships have been inferred from individual case histories of a type which any investigator with an extensive experience of accident studies can easily cite. We believe that such emotional fluctuations may be correlated with 'spells' as conceived in this study, but we are fully aware that all past efforts to establish this relationship (e.g. Hersey, 1936) have been unsuccessful. This may be due to the twin problems of, firstly, retrospectively assessing an individual's exact emotional state at any time, and secondly, if drivers are interviewed soon after an accident, confidently asserting that any identified emotional disturbance precedes the accident. Just as in assessing the effect of temporary 'ill-health' on accident experience, assessing that of temporary emotional disturbance presents technical difficulties of a type not to be easily resolved in practice.

Fatigue

There is no generally accepted definition of this term, but the possible role that fatigue, however defined, may play in accident causation has been repeatedly emphasised. Of the pioneer studies, the results from the British Association Committee Reports (1915) indicated a rapid increase in accident liability during the morning, reaching a peak an hour or more before lunch, and a similar tendency in the afternoon with, however, the peak occurring even earlier in the post-lunch compared to the pre-lunch period. Clearly, if cumulative physical exhaustion *per se* produced fatigue of a type which affected the accident rate, then the number of accidents should increase monotonically in any period. That they did not posed problems for many contemporary investigators wedded to the purely physical theories of fatigue production. Relevant research on industrial groups comprised much of the early work of the Industrial Fatigue Research Board, e.g. Vernon (1919; 1920), Osborne (1919), Osborne, Vernon and Muscio (1922), and many others. Broadly speaking the results crystallized into the concept that under normal working conditions purely physically induced fatigue was not of prime importance in accident causation. The subsequent work of Elton Mayo (Roethlisberger and Dickson, 1949), and others, although difficult to interpret with certainty, suggested that fatigue during working hours could not be equated to purely physical exhaustion unaccompanied by such features as boredom or frustration.

There is little direct evidence as to the problem of fatigue arising from driving a motor vehicle, although it is now fashionable to postulate the prevalence of psychologically induced fatigue producing, in the victim, irrational behaviour patterns. It is further speculated that these can lead to a state where discrimination between relevant and irrelevant stimuli deteriorates. But what may be of more importance to driving are skill-fatigue and vigilance. Bartlett (1943) clearly formulated the bases of the former in his Ferrier Lecture, in which he referred to a type of fatigue arising, not from muscular activity *per se*, but from unrelaxing concentration and the persistent exercise of skill. His observations were based on aviation accidents, but unquestionably road vehicle driving demands similar skills and concentration.

The syndrome he described is characterised by 'fatigue' appearing initially within the first hours of work at which time the individual's reactions to environmental stimuli are basically correct although incorrectly timed; but later incorrect actions predominate. This type of reaction has been incriminated as causal of the bizarre behaviour, known to experienced drivers where, for example, a driver 'halts at an intersection where there is no traffic light and waits patiently for the green; then, "pulling himself together", he dashes on, intent on the clear roadway ahead and deriving no meaning from the headlights he sees approaching from the side' (Lancet, 1957). A conception of the genesis of skill-fatigue must help to elucidate some of the so-called 'personal' factors in accident causation. Considerable relevant research is currently being undertaken in the psychological laboratory.

In certain of its aspects vigilance is a facet of skill-fatigue. When completely absent, i.e. when the driver is asleep, the likelihood of incurring an accident is clearly increased. 'Driver-asleep' accidents do happen; 13·2 per cent of all accidents on the Pennsylvania Turnpike in 1952 and 1953 were so adjudged (Glanville and Moore, 1955), but the association with accident liability of vigilance over its entire range is far from clear. These and parallel findings drew attention to the decrease in vigilance which undoubtedly occurs in a monotonous environment; this is a hazard of trunk-road or long-distance driving but not, one might think, of urban driving. But the suggestions of

McFarland *et al* (1955) that an appreciable number of accidents incurred by long-haul truck drivers were in the first few hours of driving, indicated to some that the nature of the activities before commencing driving could be of crucial importance. Thus, recent studies have attempted to measure a driver's 'spare capacity', i.e. a driver's mental and physical reserves, to see how far it can compensate for factors detrimental to safe driving (Brown, 1961; 1962). What appears to be certain is, that vigilance as measured by experimental tests is not independent of environmental conditions, and varies between individuals (Mackworth, 1950).

In the present investigation it would have been of value to ascertain whether the probability of a driver incurring an accident varied over his driving period independently of external factors. Unfortunately this was impossible because traffic conditions varied markedly throughout the duration of each driving rota, and to design an appropriate field experiment would seem impossible in practice. Only laboratory studies can assess the actual influence of health, temporary emotional disturbance, or fatigue, on accident liability as inferred from performance on simulated tasks; few means seem possible by which to measure accurately the influences of these variables on observed accident experience.

But whether or not certain persons are, irrespective of the environment, more likely than their colleagues at *all* times to incur an accident even though exposed to equal risk, has attracted more attention and controversy. The previous Section compared the merits of this and another hypothesis in a specific environment among a specific experimental group, and did not produce convincing reasons for supposing that such an 'accident prone' class existed. Nevertheless, the concept of 'proneness' as an entity is in wide currency; thus a short rationale seems justified. Before this is attempted one widely held misconception must be dispelled.

The fact, that in any observational period a minority of the individuals at (equal) risk may incur a majority of the total accidents sustained, has all too frequently been interpreted as evidence that accidents cannot be distributed as chance events: 'It has been recognised for many years that some drivers have more mishaps on the road than could be accounted for by chance alone; and up-to-date insurance records suggest that less than 20 per cent of certain groups of drivers report over half the accidents. Unfortunately, growing interest in the *odd distribution* of road accidents . . .' (Lancet, 1961)

Table 10.1 *Theoretical Distribution of 1470 Accidents over 1060 Individuals. (Calculated from Poisson's Limit)*

Number of Accidents	*Number of Individuals*		*Total Number of Accidents Incurred*	
0	266		0	
1	368		368	
2	256		512	
3	119		357	
4	42	40%	168	75%
5	6		30	
≧6	3		35	
Total	1060		1470	

Mean = 1·39

Table 10.2 *Theoretical Distribution of 301 Accidents over 500 Individuals. (Calculated from Poisson's Limit)*

Number of Accidents	*Number of Individuals*		*Total Number of Accidents Incurred*	
0	274		0	
1	165		165	
2	49		98	
3	10	12%	30	45%
≧4	2		8	
Total	500		301	

Mean = 0·60

(Our italics). But such an 'odd distribution' is a fundamental quality of the Poisson (Pure Chance) distribution. This is illustrated in Tables 10.1 and 10.2. In fact the smaller the mean number of accidents—and in accident statistics it is often very small indeed—the greater will this apparent distortion be.

c Accident Proneness

Introduction

The ability of the Distribution of Unequal Liabilities (the Negative Binomial) to graduate frequency distributions compiled from the accident records of women munition workers, prompted Greenwood and Woods (1919) to write: 'These results indicate that varying individual susceptibility to "accident" is an extremely important factor in determining the distribution'. These writers were, of course, fully aware of the necessary qualifications (dealt with in Chapters 5 and 13), and with characteristic circumspection concluded: 'Consequently we have sheltering under the term individual susceptibility, a motley host of motives and factors which will be very difficult indeed to separate and measure'. Thus from the very outset the hypothesis of differentiation being prior to accident experience rather than accident experience itself differentiating the population, became the paramount concept to the field worker, '. . . not because Mr. Yule and I "proved" [it] but for non-mathematical reasons' (Greenwood, 1941). Unquestionably such a conception was attractive to a scientific climate sanguine as to the efficacy of vocational guidance, first for its seeming coherence, and second for the eminently practical reason that it might prove possible to detect 'susceptible' persons *before* they had any accidents at all. Accordingly, the Industrial Fatigue Research Board initiated further investigation along three lines, namely statistical research based on industrial accident records (Newbold, 1926), clinical research based on the examination of persons with many and with few accidents (Farmer and Chambers, 1926), and laboratory research on the factors influencing accuracy of movement (Crowden, 1928; Langdon, 1932). Newbold's conclusions were: 'The average number of accidents is much influenced by a comparatively small number of workers . . . [but] it is not possible in a mass examination of this kind to find how much of this may be due to individual differences in the conditions of work or how much to personal tendency, but there are many indications that *some* part, at any rate, is due to personal tendency'. Farmer and Chambers (1926), when describing the results of their own research, wrote: 'The fact that one of the factors connected with accident liability has been found to be a peculiarity of the individual [as measured by psycho-physical tests] allows us to differentiate between "accident proneness" and "accident liability". "Accident proneness" is a narrower term than "accident liability", and means a personal idiosyncrasy predisposing the individual who possesses it in a marked degree to a relatively high accident rate. "Accident liability" includes all the factors determining accident rate: "accident proneness" refers only to those that are personal'.

This was the first use of the specific term 'accident proneness', although the single word 'prone' in connection with accidents appeared four years earlier in the preface to the Report of Osborne, Vernon and Muscio (1922), '. . . conditions which may reasonably be regarded as analogous to those rendering a worker specially prone to accident'.

At once six questions demanded answers. These were: (1) whether accident proneness (assuming it existed) is a general factor or specific to the occupation from which the statistics were obtained; (2) whether it is stable in the sense that it can be assumed constant through time for each individual; (3) whether the class possessing it is a large or small one; (4) through what faculty or faculties does it manifest its characteristics; (5) whether or not an individual's subsequent accident experience can be predicted; (6) how accurate a measure of accident proneness is in fact the accident record? Some of these points have been considered earlier in this work; the others are now discussed.

The Concept

Arbous and Kerrich (1951) gave equal emphasis to the respective problems of the specificity and stability of accident proneness. To the present writers the former does not seem of fundamental importance in the context of this work because it is the incidence of accidents in a *specific* environment that has been studied, and extension of the conclusions to other occupations or environments is not logically permissible. Moreover there are obstacles in practice, because if it is difficult, even impossible, to obtain an equal risk environment at work, it is naïve to expect to obtain one which operates outside working hours. What is of greater moment is whether accident proneness is stable through time; if it is not then there would seem little advantage in trying to devise means to measure it. This was recognised by the pioneer investigators: 'Unless individual susceptibility to accidents is a stable quality manifesting itself through all periods of exposure, we cannot expect a very definite relationship between psychological tests and accident rate' (Farmer, Chambers and Kirk, 1933). But although not entirely consistent in their writings, Farmer and Chambers clearly conceived accident proneness to be a stable entity: 'Accident proneness is no longer a theory but an established fact, and must be recognised as an important element' (Farmer and Chambers, 1939); 'Summarising briefly what is known about "accident proneness", we may say that it is relatively stable, in the sense that persons with a larger number of accidents than their fellows in one observational period tend to have more accidents in subsequent periods, (although there are numerous exceptions to this generality), and also that persons sustaining a number of one kind of accident tend also to sustain a number of other types' (Chambers and Yule, 1941). As a result of such statements few could cavil with the widespread acceptance of accident proneness as an immutable load to which the unfortunate possessor is chained as inexorably as Ixion to his wheel, with the corollary that its possession can serve as a discriminant by which to segregate the population.

Quite apart from the many whose grasp of accident statistics was limited, such knowledgeable investigators as Adelstein (1952) and Häkkinen (1958) so construed Farmer and Chambers' statements. But some were puzzled into vacillation: 'The accident-proneness of various individuals is not a fixed quality but is liable to be affected by any and every change in their bodily condition' (Vernon, 1936), while three years later the same author wrote: 'Accident liability is influenced by many other personal qualities besides inherent accident proneness. It depends on general health, . . . age and experience, fatigue . . .' (Vernon, 1939). Others were tempted into extravagance: 'These studies suggest that the accident-prone person can be spotted rather easily. Actually he can be spotted with less expense than the person with tuberculosis or heart disease, for whom the expense of roentgenograms is often required' (Dunbar, 1943a). Dante (*Il Paradiso*—Canto XIII) had been more circumspect:

* 'Non sien le genti ancor troppo sicure
A giudicar, sì come quei che stima
Le biade in campo pria che sien mature:
Ch'io ho veduto tutto 'l verno prima
Il prun mostrarsi rigido e feroce
Poscia portar la rosa in su la cima'

* 'Let not the people be too quick to judge;
As one who reckons on the blades in field,
Or e'er the crop be ripe. For I have seen
The thorn frown rudely all the winter long,
And after bear the rose upon its top'.
(H. F. Cary, 1814).

Even Chambers (Chambers and Yule, 1941), one of the originators of the term accident proneness, was not immune to inconsistency: 'We may conclude also that a lengthy period of experience is necessary for an individual's proneness to accidents to manifest itself fully. Accident proneness may be regarded as a latent disposition needing certain circumstances to reveal it, rather than as an active function which is consistently in operation', statements strictly at variance with others of his pronouncements. To add to the confusion the terms 'temporary accident proneness' and 'accident repeater' are gaining increasing currency (Norman, 1962).

When one tries to unravel these skeins the complexities are less formidable than they at first appear. In Greenwood's derivation of the Negative Binomial the assumption was made that the variable (which was later to be called accident proneness) was constant for each individual. Consequently, if proneness was responsible for all or a large part of the non-Poisson character of the observed frequency distributions, then *ceteris paribus* this should be reflected in the

Table 10.3 *Effect of Removing the Men with the Highest Accident Rate in the First Year*

Average Accident Rate for Shunters joining in 1944	*1st Year*	*2nd Year*	*3rd Year*
(a) For all 104 men	0·557	0·355	0·317
(b) If worst 10 for the first year were removed—94 men	0·393	0·361	0·329

Re-cast from ADELSTEIN (1952), 'Accident Proneness: A criticism of the concept based upon an analysis of shunters' accidents', *J. R. statist. Soc.* (series A), **115**, 354–410.

magnitude and behaviour of the correlation coefficients of the number of accidents incurred by individuals in two periods of exposure of reasonable duration. This has already been discussed; but it would also imply, (a) that if those individuals with the worst accident record in any one period were subsequently removed from risk there should be a resultant decrease in the frequency of accidents incurred by the remainder over all subsequent observational periods, and (b) that it should be possible to identify some personal characteristic, within the wide range from corporal dexterity to the psyche, which correlates

Table 10.4 *Mean Accident Rate of the Inter-quartile Groups based on Scores in the Aesthetokinetic Tests*

Year	*Best 25%*	*2nd 25%*	*3rd 25%*	*Worst 25%*
1st	1·50	2·12	1·64	2·17
2nd	1·31	1·50	1·73	2·00
3rd	1·31	1·68	1·85	1·93
4th	1·38	1·26	1·36	2·07
5th	1·38	1·65	1·42	1·79

Compiled from data from FARMER, E. and CHAMBERS, E. G. (1939), *A Study of Accident Proneness amongst Motor Drivers.* Rep. Industr. Hlth. Res. Bd., London, No. 84. H.M. Stationery Office. When the years are pooled some of the differences between the best and worst groups' means are significant.

with, and predicts, accident experience. In fact although the coefficients obtained—when the numbers of accidents incurred by the same men in different time periods are analysed—have frequently been reckoned significant (as measured in various ways), seldom have they been even reasonably stable; and, as Tables 10.3–10.6 suggest, (a) and (b) have not been fulfilled. So, although from time to time significant correlation coefficients (again as measured in various ways) have

Table 10.5 *Effect on Subsequent Accident Rate of Removing Drivers With Many Accidents in their First Year, or Removing Drivers With Poor Aesthetokinetic Co-ordination*

Action	*Percentage of Drivers Removed*	*Percentage Accident Rate*	*Percentage Reduction Effected*
Accident Rate of Whole Group for all years except the first	—	100	—
(1) After removing drivers with 3 or more accidents in the first year	28	91	9
(2) After removing the worst 25% in the Tests	23	93	7
(3) Combining methods (1) and (2)	44	87	13

Reproduced exactly from FARMER, E. and CHAMBERS, E. G. (1939), *A Study of Accident Proneness amongst Motor Drivers.* Rep. Industr. Hlth. Res. Bd., London, No. 84. H.M. Stationery Office.

Table 10.6 *The Mean Percentage Accident Rate over the Whole Period (5 Years) of Groups selected by Different Methods, taking the Accident Rate of the Whole Observed Group as 100 per cent.*

Accident Rate	*Shipwrights*	*Electric Fitters*	*Engine Fitters*
1. Of those left after rejecting the high accident subjects in the first year	87	99	94
2. Of top three inter-quartile groups of the aesthetokinetic tests	80	88	90
3. Combination of Methods 1 and 2	75	88	79
4. Of top inter-quartile group only in the aesthetokinetic tests	61	60	74

Reproduced exactly from FARMER, E., CHAMBERS, E. G. and KIRK, F. J. (1933), *Tests for Accident Proneness.* Rep. Industr. Hlth. Res. Bd., London, No. 68, H.M. Stationery Office.

been recorded, no test or battery of tests has so far been devised which would allow the 'accident prone' to be excluded without also excluding many of their fellows whose subsequent accident experience was unremarkable.

This failure was a serious inconvenience, but it was borne stoically; by the late nineteen-twenties faith in *a priori* selection of individuals suitable for certain occupations was withering. What *was* required was to place a valid construction on these superficially contradictory facts. The construction chosen was to postulate that the *permanently* accident prone comprised only a small proportion of those persons with a 'bad' accident record in any observational period. Most field workers subscribed fairly consistently to this interpretation, and it was Adelstein's (1952) failure to make clear that he understood this fact that prompted Chambers' (1952) criticism. But alternative interpretations are possible. Other coherent hypotheses of accident distribution can be associated with both a Negative Binomial fit *and* positive (and significant) correlation coefficients between the numbers of accidents in different time periods, for example the hypothesis that the risk exposure varies through time in an unequal fashion among the population members. Consequently, if it seems to some unusual that, despite protracted research, inherent differences *in propria persona* between groups of 'high' and 'low' accident individuals have not been demonstrated with more certainty and consistency, it seems to us most disquieting that so many investigators have assumed that such differences *must* be there if only they could be identified. In this work an entire thesis has been constructed, which is in accord with the statistics, without postulating the necessary presence of any inherent 'personal' differences at all.

But supposing that accident proneness *does* exist as a measurable and stable entity, as is usually alleged, then its temporal range must have limits; for example, does it originate in adolescence, in childhood, or at birth; does it terminate at retirement or is it carried to the grave? On this, and other basic properties, its promulgators are silent. But although its concept as a human characteristic becomes less credible the more it is examined, the success of the Negative Binomial to reproduce accident frequency distributions remains. Frequently this success can be clearly and legitimately ascribed to some one of the other hypotheses already considered (Chapter 5), most particularly to that of varying risk exposure, but with some published data considerable efforts have been made to ensure, as far as was possible in practice, that equal risk obtained. In the present study such stringencies were demanded that disparate risk exposure within groups (if it occurred) would, one hopes, be slight. If data, whose heterogeneity was not extreme, could be graduated by a Negative Binomial when in fact the distributions in the *actual* equal risk sub-groups did not diverge significantly from Poisson distributions, then this might further compromise the validity of inferring proneness from an adequate Negative Binomial fit *per se.*

Of relevance is a paper by Amato (1959). If this is translated into the terms of our present thesis, his theoretical problem is as follows. Suppose, for example, that the whole population (here taken to be 100,000 men) actually comprises three equal sub-populations such that over a period of time the mean number of accidents per man is 0·5, 1·5 or 2·5, according to the sub-population considered. Then Amato demonstrated that the theoretical frequencies expected by assuming the distribution of accidents over the whole population to be Poisson with mean 1·5, (referred to below as Simple Poisson), are very different to those arising from the addition of the theoretical Poisson frequencies for the three separate sub-populations (referred to below as Mixed Poisson). In addition a Negative Binomial was fitted to the Mixed Poisson distribution. The results appear in Table 10.7.

Table 10.7 *Theoretical Frequencies of Men Suffering r Accidents over a Period of Time*

r	*Frequency*		
	Mixed Poisson	*Simple Poisson*	*Negative Binomial*
0	30,392	22,314	28,900
1	28,106	33,470	30,027
2	19,446	25,102	20,212
3	11,731	12,550	11,140
4	6,075	4,707	5,461
5	2,702	1,412	2,477
6	1,046	353	1,063
7	357	76	438
8	108	14	175
9	29	2 (for $r = 9$ to ≥ 12)	68
10	7		26
11	1		13 (for $r = 11$ and ≥ 12)
≥ 12	0		
Total	100,000	100,000	100,000

It is clear from inspection that the Simple Poisson is an extremely poor approximation to the Mixed Poisson. Now suppose that the Mixed Poisson frequencies had actually been obtained in practice; then the theoretical Negative Binomial would have provided a poor graduation, with $\chi^2 = 439{\cdot}607$, $\nu = 10$, $P < 0{\cdot}001$. But consider the following. Denote by $E(r)$ the estimated theoretical proportion of a population of nN men expected to incur r accidents each. Then the contribution to χ^2 of the corresponding cell is $nN[\theta(r) — E(r)]^2/E(r)$, where $\theta(r)$ is the proportion observed to have incurred r accidents each. Now suppose that the observed population was much smaller, say N men. Then the contribution to χ^2 (assuming the expected frequency still exceeds 5), drops to $N[\theta(r) - E(r)]^2/E(r)$, giving (approximately) the contribution to χ^2 to be around $1/n$ of its previous value. In the present instance, if the population was 1,000

Table 10.8 *Observed and Theoretical Frequencies of Days with a Varying Number (r) of Infant Deaths in Catania over 1948–1953*

r	*Males*			*Females*		
	Observed	*Poisson*	*Negative Binomial*	*Observed*	*Poisson*	*Negative Binomial*
0	845	801·6	845·9	916	861·5	903·7
1	765	806·4	762·8	731	804·5	760·5
2	380	405·6	383·6	378	375·7	357·6
3	148	136·0	141·9	119	116·9	123·9
4	38	34·2	43·0	38	27·3	35·2
5	12	8·2	14·8	9	6·1	11·1
6	3			1		
7	1					
χ^2		14·986 $\nu = 4$	1·000 $\nu = 3$		17·041 $\nu = 4$	3·004 $\nu = 3$
Probability		$0{\cdot}01 > P > 0{\cdot}001$	$0{\cdot}90 > P > 0{\cdot}80$		$0{\cdot}01 > P > 0{\cdot}001$	$0{\cdot}50 > P > 0{\cdot}30$
Significance		Highly Significant	Not Significant		Highly Significant	Not Significant

Compiled from data available in Amato, V. (1959), 'L'esponenziale di Poisson e la distribuzione del numero dei morti per giorno', *Statistica*, **19**, 20.

men and not 100,000 men, then $\chi^2 = 3{\cdot}805$, $\nu = 5$, $0{\cdot}70 > P > 0{\cdot}50$, and the fit would be reckoned highly satisfactory.

This is disconcerting since it allows the speculation that the satisfactory concordance with the observations, usually obtained with the Negative Binomial in accident studies, could well be due to its ability to 'smooth' the data arising from a heterogeneous population, and that this agreement could possibly be overthrown provided the population was sufficiently large. In fact few populations selected for

Table 10.9 *Mean Number of Infant Deaths per Day, for each Month of the Year in Catania over 1948–1953*

Month	*Male*	*Female*
January	0·96	0·92
February	0·75	0·70
March	0·68	0·61
April	0·54	0·44
May	0·80	0·67
June	1·33	1·17
July	1·37	1·28
August	1·20	1·25
September	1·23	1·22
October	1·25	1·10
November	1·13	0·99
December	0·83	0·83
Mean	1·01	0·93

Compiled from data available in AMATO, V. (1959), 'L'esponenziale di Poisson e la distribuzione del numero dei morti per giorno', *Statistica*, **19**, 20.

study in the present field comprise as many as 1,000 individuals. This speculation can be confirmed by the data actually presented by Amato, which are the distribution of the number of days on which a varying number of infant deaths (children who died within one year of birth) were observed in Catania over the period 1948–1953. Poisson and Negative Binomial distributions were compared with those observed for either sex (Table 10.8), and in both cases the Poisson proved inadequate but the Negative Binomial provided an excellent fit. If, now, the mean number of infant deaths per day over the months of the year over the entire period are calculated, as in Table 10.9, and the square root of these rates used as the variate in an

Table 10.10 *Analysis of Variance using the Square Root of the Variate in Table 10.9*

Source	*D.F.*	*Sums of Squares*	*Mean Squares*	*Variance Ratio*
Between Months	11	0·479 741	0·043 613	76·94 ***
Between Sexes	1	0·009 239	0·009 239	16·29 *
Residual	11	0·006 235	0·000 567	
Total	23	0·495 215		

*** Significant on the 0·1 per cent level.
* Significant on the 1 per cent level.

Table 10.11 *Values of χ^2 (and Degrees of Freedom) for Poisson Distribution Fits to Monthly Data*

Month	*Male*	*Female*
January	3·367 (2)	0·107 (2)
February	1·260 (2)	1·116 (2)
March	2·912 (2)	0·052 (1)
April	0·032 (1)	3·107 (1)
May	0·919 (2)	0·612 (2)
June	2·619 (3)	3·933 (3)
July	1·837 (3)	4·179 (3)
August	7·296 (3)	1·437 (3)
September	0·891 (3)	3·889 (3)
October	0·612 (3)	4·483 (3)
November	3·054 (3)	7·001 (3)
December	2·036 (2)	2·069 (2)

Reproduced directly from AMATO, V. (1959), 'L'esponenziale di Poisson e la distribuzione del numero dei morti per giorno', *Statistica*, **19,** 20.

analysis of variance (Table 10.10), the conclusion can be drawn that infant mortality (as defined) varied appreciably according to both month and sex. When Poisson distributions were fitted to the observed frequencies of days for each month separately for either sex they described the data well, none of the discrepancies being significant on the 5 per cent level. This can be seen from Table 10.11 (constructed by Amato).

This serves as a practical example of the Negative Binomial distribution reproducing the statistics from a demonstrably heterogeneous population. It supports the speculation that a satisfactory Negative Binomial fit may only conceal the fact that the population selected may not be completely homogeneous for exposure to risk, a situation which almost invariably must obtain in studies of accident distribution.

d The Inference of Accident Proneness from the Accident Record

There are two fundamental problems inherent in adopting the accident record as a criterion for accident proneness. The first is the logical one that it commits the *post hoc ergo propter hoc* fallacy: 'Care must be taken not to make accident incidence *per se* a measure of accident proneness, for this is to adopt the position of those who say that accidents are due to carelessness and when asked to define carelessness do so in such a way as to leave little doubt that by carelessness they mean having an undue number of accidents' (Farmer and Chambers, 1926). The second is more subtle and has been charmingly put by Greenwood (1941) in a passage that so rewards study that it is quoted here in full.*

'The human and unscientific habit of making dichotomies—so and so is either A or B—must be firmly resisted. It is one of the curses of medical literature. Think of the history of opinion on tuberculosis. In the days of Hitler's forerunner Bonaparte, the vast majority of physicians held that—to use Karl Pearson's nomenclature—soil not seed was of fundamental, almost exclusive, importance, and took a very Calvinistic view of tuberculosis. In 1815 a physician who was also a mathematician, Thomas Young, wrote:

> "There is a very general prejudice respecting the transmission of a tendency to scrofula which is often the source of much unnecessary uneasiness; it is supposed by many to constitute a marked and decided character, incapable of being increased or diminished, and which must in all probability produce at some time or other the most melancholy effects in the individual and in

*Taken verbatim from Greenwood, M. (1941), 'Discussion on Chambers and Yule's paper', *J. R. statist. Soc., Supplement* (Series B) Vol. 7, pps. 108–109.

> his descendants. In fact, however, no man was ever born incapable of becoming scrofulous, and in this sense every person may be said to possess more or less of a scrofulous taint, which may become mischievous or fatal to all, under improper management, but which in other circumstances may easily remain latent throughout life".

'Young had no effect on his contemporaries; two generations passed, and, with the coming of bacteriology, medical opinion veered to the direct opposite of that fashionable in Young's day; it was left to Karl Pearson to advocate soil in opposition to seed. Now, I suppose, most students agree that the question is not of soil *versus* seed, but of their co-operation and how to make it as ineffective as possible.

Mr. Chambers has shown that a necessary condition for acceptance of the proneness hypothesis as a complete explanation of the facts is not fulfilled. The explanation he suggests, that λ changes with time, commends itself to me. I know that *comparaison n'est pas raison*, but analogy is always tempting. We used to be taught that one of the charms of alcohol as compared with other narcotics was that tolerance was never established, that the sensitiveness of individuals varied, but did not change for each individual. A aged 20 and B aged 20 had danger limits of respectively one and two double whiskies, and at the age of 40 their limits would be exactly the same. The difference between the beginner and the seasoned toper was not that the latter was any less "drunk", but that experience enabled him to carry his liquor more prudently; at 20 he might cheerfully attempt to say Royal Statistical Society, at 40 he would not mention the Society at all. Experience plays its part in preventing an overt consequence. Statistically we infer proneness *ex post facto*, so the situation is similar. That is what Young meant in the passage I quoted; the diathesis or predisposition could not be modified, but its practical consequences could'.

Nevertheless it is necessary to examine from the statistics how accurate a guide the accident record is to accident liability. Since some would have accident proneness an even narrower term than accident liability, then, unless accident liability bears a close association to the accident record *in the circumstances of the particular study*, a driver's actual accident experience must be adjudged a poor criterion of his underlying accident proneness.

If the Negative Binomial distribution (as derived by Greenwood) and the meaning of the parameters are accepted as forming the model, then, as is shown in Section 4, the function

$$v = 2[(p/\alpha) + 2]\lambda$$

where λ is the accident liability
p is a parameter of the Negative Binomial distribution
α is the average number of accidents per driver over either sub-period

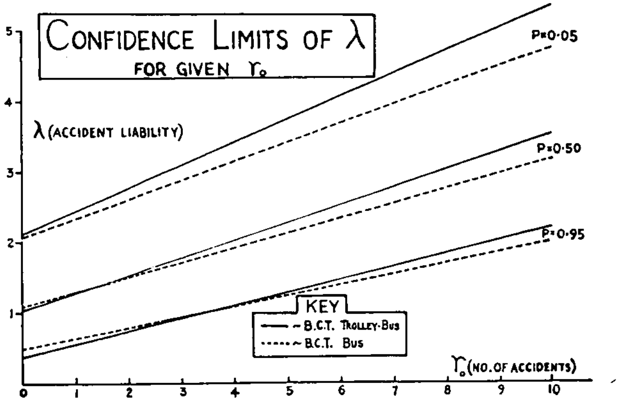
has a χ^2-distribution with $2(p + r_0)$ degrees of freedom. The distributions of accidents derived from the B.C.T. driver populations satisfied the initial condition, namely that the average number of accidents over each sub-period could be regarded as nearly constant. Consequently, Table 10.12 and Graph 10.1 could be constructed relating λ to r_0 (the total number of accidents incurred over the entire period).

Table 10.12 *90% Confidence Limits for λ, given that a Driver suffers r_0 Accidents during the period 1952–1955*

r_0	λ	
	B.C.T. Bus Driver	*B.C.T. Trolley-Bus Driver*
0	0·482–2·075	0·417–2·123
1	0·621–2·358	0·574–2·469
2	0·766–2·636	0·739–2·806
3	0·914–2·909	0·911–3·136
4	1·067–3·178	1·088–3·461
5	1·222–3·445	1·269–3·782
6	1·380–3·709	1·454–4·099
7	1·541–3·970	1·643–4·413
8	1·703–4·230	1·833–4·724
9	1·867–4·487	2·026–5·033
10		2·222–5·340

As was to be expected the greater the number of accidents incurred the greater the value of λ as calculated; but the 90 per cent confidence limits of the estimates show considerable overlapping through the range of r_0. Consequently, it would be less than prudent to assert that, for example, in the circumstances of the present study a driver sustaining nine accidents over the period is certainly more 'liable' to accident than a driver incurring only one. The further steps of

Graph 10.1



designating the nine-accident driver as 'accident prone', or as 'more accident prone', are clearly even less justified. Reference may be made to a similar conclusion by Arbous and Kerrich (1951): 'Admittedly, the methods applied to other data *may* on occasions give much more clear cut results than are obtained for these shunters'. This hope is unrealised in the present instance.

Chapter 11 Further Research, Summary, Conclusions, Bibliography

Introduction

This investigation was planned as a piece of purely academic research—in the sense that the possible application of the findings to the practical problem of accident reduction was not a primary consideration—rather than as an Operational Research project where the suggestion of beneficial action and its implementation by the executive is the direct objective. Nonetheless few, who have examined any relevant aspect, can be wholly indifferent to the immediacy of the road accident problem. Thus we consider it obligatory to suggest such further lines of research concerning the vehicle driver as appear to afford genuine scope for action designed to reduce the human toll exacted on the roads.

The ideas presented here emerged naturally during the course of the present enquiry and consequently they do not amount to a fully comprehensive research programme. Further, some of the projected lines of study may prove technically difficult and time-consuming (and expensive) to execute. This is acknowledged; however it remains for others to decide what should be done along the lines indicated.

General Considerations

It must be at once re-emphasised that the findings obtained during the course of the present investigation may not be truly basic. Public transport drivers were chosen to form the population for study simply to ensure both an adequate ascertainment of accidents and an accurate computation of exposure to risk. However such drivers do not comprise a representative sample of the general driving population. For example, the bus driver is of lower social class (and all that this implies regarding housing, education, etc.), he drives full-time, he may have a genuine wish to drive, he must satisfy certain stringent medical and technical requirements, he is more heavily selected by his accident record, he drives a very special type of vehicle, he must retire at a definite age, and so on. To draw conclusions as to all drivers from the findings in this group is illogical. Thus it is mandatory to investigate a more representative sample of the driving population. But there are some obvious difficulties. In a retrospective study attention could be directed to such strata as commercial travellers (who sample approximately equal driving conditions) since their mileage and accidents might be reliably ascertained. Such individuals are more representative of all drivers than are bus drivers, but to proceed still more generally in a retrospective study would, in our opinion, be certain to invite too much heterogeneity in the data relating to essential variables. Also, no matter how carefully they are conducted, retrospective studies must present difficulties in interpreting the results. Thus a carefully planned prospective study of an appropriate sample of the driving population appears unavoidable. To secure strict compliance with methodological requirements sufficient control would be required over the subjects to facilitate an experiment to be designed and executed along the lines of, say, a Latin Square. Even then the effect of the observer on the observed would be difficult to eliminate or discount. But elaboration of the theoretical niceties of such an experiment is unnecessary because, as far as can be foreseen, the requisite powers are unlikely to be available in practice. Consequently less ambitious objectives should be first sought. Some of these are now discussed.

Experience

It has been repeatedly demonstrated among groups of professional drivers (e.g. Farmer and Chambers, 1939; Häkkinen, 1958; Norman, 1960; Cornwall, 1962) that in different age groups the least experienced drivers had the worst accident record, and that this was especially so for drivers with less than about two years' experience of the job. To judge for how long the experience component exerts its effect, a prospective cohort study would be desirable. Although it seems reasonable to postulate a similar phenomenon to obtain in the general driving population, this hypothesis should be tested if practicable. Assuming this effect of experience to be a general finding then a special effort should be directed towards the inexperienced driver, the problem being to decide the form that this should take. Norman (1960) suggests that private licence holders should receive additional training, by way of lectures and demonstrations for perhaps two years after a licence is first obtained, and the efficacy of this approach has been championed by some investigators (e.g. DeSilva, 1939a) but not by all (e.g. Johnson and Cobb, 1938; Johnson, 1938). But there is no sound evidence to suggest that this approach would be beneficial—and exactly what should one teach? Accidents are seldom enacted as single episodes, and it may be that the qualities required to avoid an accident situation are very different from those facilitating escape from such a situation once it has arisen. Norman (1960) himself states: 'It is assumed—but the assumption may not be correct—that these qualities [required in safe driving] can be taught in their just proportions, and that the work of the psychological laboratory can be applied to the driving school'. So far these qualities have not been identified. Until they have been identified it is premature to apply psychological laboratory research to driver-training methods.

From the purely pragmatic viewpoint, the objective of training methods must be to confer on the novice driver, as quickly as possible and under conditions of safety, the benefits of 'experience' customarily acquired during the passage of time in charge of a vehicle on the road. Once permitted on the road the beginner should attain—if he has not already reached it—the nadir of his 'learning curve' (see Chapter 4, Graph 4.1) in the shortest possible time. These objectives point clearly to the use of a laboratory simulator. Such a simulator must be capable of reproducing the same kind of problems encountered, and of teaching the same kind of skills developed, while actually driving on the road. It must produce 'simulation in real time', and performance on the instrument and in the real life driving situation must be highly correlated. To design and validate such an instrument is a formidable undertaking, but the dividends are potentially considerable.

Age

The finding in the present work—which is similar to that of Häkkinen (1958)—that the accident rate tends to increase among bus drivers over about 50 years of age, should, in strict logic, be tested in other populations. As before, there would be formidable technical problems involved, but, recognising the selection processes operating among groups of bus drivers, the likelihood must be that the finding is truly a basic one. If so then it presents a most serious public health problem. Whereas a bus driver's career is usually summarily terminated at age 65, a member of the public may, for the most part, drive to whatever age he so wishes. And—although little is known about this except from Spratling's (1961) and Cornwall's (1962) data—the deterioration of the accident rate with age may in fact accelerate after about 60 or 65 years of age, i.e. the relationship between age and accident rate may not be a linear one. But before any executive action is recommended certain problems demand answers.

The most urgent problems are to ascertain the age at which the 'age component' starts to exert its deleterious effect, and to establish the form of the relationship between age (over all its range) and accident experience. If (as may be suspected) the form of this relationship varies between individuals then *reliable* predictors must be identified. All studies which compare accident rates between drivers in different age groups are impotent in this context, firstly because no matter how carefully conducted they can be legitimately criticised on the ground that the accident experiences being compared are those of different men, and secondly because they afford little information as to *why* the accident rates do in fact differ. Consequently there is no adequate alternative to a prospective cohort study of a group of, say, bus drivers. Since available information indicates that the zenith of an experienced public transport driver's capabilities (as measured by his accident record) occurs in his forties, the chosen cohort should be of men in the 40–44 or 40–49 year age group, and their subsequent record should be followed until retirement. Also, the study of this cohort should be so designed as to allow an opinion as to *why* the accident rate should vary. If—as is suspected—the accident rate increases, then, reasoning *a priori*, this could be due to a deterioration of the accident record either of a few men or alternatively in a substantial proportion of the population under observation. It is tempting to suggest that pathological or environmental factors may be responsible for the first, and some facet of physiological ageing for the second.

In either instance—but more particularly in the first—it is vital to identify the 'bad risk' driver *in posse* before he becomes one *in esse*. This is a fundamental problem if any policy for accident reduction is to be both effective and equitable. There is only one sound approach to its solution. In this, drivers who are adjudged potentially bad risks on whatever criteria are adopted, are identified and their future accident experience until retirement compared with that of the remainder of the age-specific cohort. Strict attention should be paid to ensure that any unequal risk is adequately discounted, either by rotation of drivers over routes or by an accurate computation of a 'risk coefficient' for each route; and if possible the drivers should be unaware that they are under observation. If the accident rates in the sub-groups of the cohort behave similarly then the criteria (as a group) adopted were ineffectual; if not, then some or all can be assumed valid predictors. We must emphasise that such 'predictors' should subsequently be tested by their ability to make accurate predictions in advance. This might seem obvious but it has not always been accepted as an integral part of a thorough study.

The above approach is rigorous and, some would argue, impracticable. But there seems to us little to justify in principle the currently fashionable expedient of removing professional drivers who either suffer from conditions which, *a priori* reasoning suggests, could produce sudden loss of control at the wheel, or who are adjudged 'unfit' on returning to duty after illness. Except when the known prognosis of the condition *clearly* warrants it, such arbitrary action is generally to be deprecated, and for two good reasons. Firstly, it could be inequitable in that, for all anyone knows, some (or many) of the men so excluded would have driven subsequently with no less safety than before. Secondly, it is unscientific because the adequacy of the criteria used have not been established. Most investigators are aware of these strictures, but they assume that the vital nature of the problem justifies expediency and, they argue, the validity of these procedures could be established *after* action has been taken. For example, since 1958 in Belfast Corporation Transport and the London Transport Executive, drivers have been examined periodically from 50 years of age onwards, and some men barred from driving on medical grounds. (These medical criteria are listed by Norman (1958; 1960)). If the subsequent accident experience of the remainder of the drivers compared favourably with that of drivers in similar age groups *before* such examinations were inaugurated, i.e. prior to 1958, then the procedure could be claimed to have been efficacious. But apart altogether from the obvious imperfections of this method there are more subtle criticisms, for example it could be argued that their colleagues' dismissal acted simply *pour encourager les autres.* In fact this method, besides having little scientifically to commend it, might necessitate as extensive a delay in obtaining the requisite information as would a prospective cohort study which is, of course, superior.

If, on the other hand, a sizeable proportion of the 'healthy' members are responsible for the increased accident rate in the age-specific group, then some general factor of ageing could be suspected. It is known that many skills deteriorate with age but so far this decline in skills has not been successfully linked with an increased accident experience under normal driving conditions. Until it is, the logical sequence is incomplete. Once more the solution is to be sought in a prospective cohort study. Deterioration with age in skills *and* accident record of the cohort should be demonstrated, and, as well, successful prediction should be made of the accident experience of the members of a succeeding cohort.

Other Qualities

Many social and biological variables have been alleged to play a role in accident causation. Some of these were referred to in previous chapters; others are specified by Norman (1960; 1962) and McFarland (1962). While much of the evidence lacks convincing statistics, professional bodies, e.g. the British Medical Association (1954), the World Health Organisation (1956), and the American Medical Association (1959), have published recommendations for 'safe-driver' selection which include criteria relating to many of these qualities. Because of the disparate nature of the qualities incriminated—ranging from minor defects of the eyesight to the activities of the driver before commencing duty—a prospective cohort study should be planned to investigate most facets of the driver, his environment and activities. The magnitude of the task and the diverse disciplines necessarily involved indicate that this should be a team project. Its success would require *inter alia* considerable co-operation on the part of the drivers and their families. Further, the population for study should be selected in an area where conditions are such that excessive labour turnover would be unlikely to ruin the framework of the experiment. Such an undertaking, although onerous, is inevitable if real progress is to be achieved.

The alternative—and it is at best a poor alternative—is to conduct further retrospective studies. These are likely to confuse the picture even further. It is not a question of more care being required, it is simply that the technical and logical problems posed by such studies cannot be overcome. Perhaps to find answers to some of these problems other disciplines would be more suitable than epidemiology; certainly the psychological and engineering laboratories have an important role to play. But, whatever the approach, all one would ask is, that before recommending 'safe-driver' standards official bodies should ensure that the criteria on which such recommendations are based have been validated and have not been either arbitrarily or emotively chosen, as many now seem to be.

SUMMARY OF RESULTS

1 The population studied comprised all Ulster Transport Authority (U.T.A.) and Belfast Corporation Transport (B.C.T.) bus and trolley-bus drivers who were in continuous employment in the respective Authorities throughout the period 1952–1955, and who had not more than ten weeks' certified sickness absence during either 1952–1953 or 1954–1955. Some necessary restriction on this population was imposed for some of the analyses.

2 All accidents recorded on the central record sheets were included, other than those exclusively to a passenger, conductor or an untended bus.

3 All accidents were pooled, this being justified by the significant correlation coefficients obtained between the numbers of different types of accidents incurred.

4 Over parts of their ranges, driving experience (as defined) and age, considered as group properties, independently influenced the accident rate, as follows: (a) for experienced drivers, those over about 50 years of age had a higher average accident rate than the younger age groups tested, and (b) increasing experience appeared to be an important factor in lowering the accident rate, certainly in the first few years of driving.

5 The Poisson, Negative Binomial, 'Single-Biassed', and Bivariate Negative Binomial distributions, are discussed. Two additional theoretical distributions (termed the 'Long' and the 'Short') were derived from first principles from stated hypotheses of accident causation. The mathematical similarity between the Long and the Neyman Type A is demonstrated.

6 The abilities of these distributions (except the Single-Biassed) to reproduce the observed frequency distributions of accidents to drivers compiled from the present data, are contrasted. Generally they all adequately graduate the observations with the exception of the Poisson distribution.

7 Estimation of the parameters of the Short distribution allows 'personal' and 'chance' components (as defined) to be calculated. In the main the 'personal' components as estimated from each of the sets of data in this and parallel reported studies, were similar; the 'chance' component appeared to vary with the mean number of accidents.

8 Two hypotheses of accident distribution are compared using other aspects of the data. The hypotheses are: (1) 'accident proneness', i.e. that certain individuals are more likely at all times than other individuals to incur an accident even though exposed to equal risk, and (2) that on which the Short model was constructed, i.e. that accidents occur to individuals in 'spells', that within each spell accidents are randomly distributed, that spells themselves are randomly distributed in the population, and that some accidents occur at random independently of both spells and 'spell' accidents. The other aspects of the data are: (a) the association between the numbers of accidents incurred in different (and equal) periods of one or two years each, (b) the time-intervals between successive accidents, and (c) the values of certain social and biological variables between two matched groups of drivers. The composition of these two groups is described.

9 It is concluded that the present data do not support the contention that there were (comparatively) many, if indeed any, bus or trolley-bus drivers in the population studied over 1952–1955 who were 'accident prone'.

10 Current theories of accident causation are reviewed. Some further lines of research are suggested.

CONCLUSIONS

Having isolated a population of men working in an equal risk environment, the main problem is to construct a model to explain the incidence of accidents among this population. This contains many of the elements of detective fiction: 'We are only considering possibilities. It is like trying on the clothes. Does this fit? No, it wrinkles on the shoulder. This one? Yes, that is better—but not quite large enough. The other one is too small. So on and so on—until we reach the perfect fit—the truth' (Christie, 1933). However it is obvious that no one model could exhaustively explain the complete data emerging from such a complex situation as that under review. It is conceivable that after sustaining an accident one driver may become more liable to incur another accident in the immediate future whereas the reverse may easily hold for a second driver, whilst a third driver may be unaffected by the experience. Again, the effect of an accident on a driver's subsequent accident liability may depend on the seriousness of the accident and perhaps on the extent to which the driver himself was endangered. The most that any model can do is to smooth the data and possibly afford some insight into the mechanism by which the distribution was built up. But one can be too defeatist about the statistical contribution. The following passage from Arbous and Kerrich (1951) is surely unjustifiably pessimistic: '. . . our attempts to over-simplify the accident-causing situation by seeking to sub-divide it into "personal causes" and "environmental causes" tends to lead us nowhere. Surely the essence of accident causation is the rather intricate inter-relationship which exists between the individual and the environment and the influence of one cannot be appreciated without considering its interaction with the other, and to attempt to separate the two is about as profitable as attempting to unravel the respective influences in the heredity vs. environment controversy'. Not all biologists would agree with these opinions.

It is essential to realise the exact assumptions made in each proposed model. A theoretical distribution, even if the data agree with it, is not necessarily the only one possible, and because of logical problems of inverse probability deductions can only be drawn subject to reservation. In fact the scientific investigator must not attempt to reason from observed events to the probabilities of the hypotheses which may explain them; rather he must consider only problems in direct probability, reasoning deductively from given probabilities to the probabilities of contingent events. This is why Greenwood (Greenwood and Woods, 1919) said merely that it was practicable to *form a judgement* as to the nature of the operating causes when a theoretical distribution was in accordance with the observations: 'Knowing the form of the ultimate distribution of pigeon holes with various numbers of balls, it is evidently practicable to form a judgement as to the nature of the causes which have operated in the distribution, since these will completely determine the result. We say advisedly *form a judgement as to* and not *prove what was* because an inverse problem of this kind presents certain difficulties which we have no space to discuss'. Some thirty years later, Greenwood (1949) re-emphasised the problem: 'A negative binomial could arise in a great many ways, and if we had a negative binomial and it was a good fit, accident proneness may be involved or it may not'. Unfortunately not all investigators have heeded this warning.

The sole reason for assuming that liability was a continuous variable adequately represented by a Pearson Type III curve was that it led to the requisitely skew shape. The Normal distribution was

Table 11.1 *Accidents incurred by Women working on 6-in. H.E. Shell production. (Compiled by David (1949) from Greenwood and Yule's (1920) data)*

No. of Accidents	*Observed Frequency*	*Negative Binomial*	*Neyman Type A*
0	447	442	448
1	132	140	128
2	42	45	49
3	21	14	16
4	3	5	5
5	2	2	1

For Neyman Type A $\chi^2 = 2{\cdot}857$, $\nu = 2$, $0{\cdot}30 > P > 0{\cdot}20$.

Re-cast from DAVID, F. N. (1949), *Probability Theory for Statistical Method*. Cambridge: University Press.

briefly considered (Greenwood and Yule, 1920) but summarily dismissed. Clearly the Neyman Type A distribution will emerge if it is assumed that the individual's liability to accident is determined by Poisson parameter, say λ, and λ itself is distributed among the population in another Poisson distribution. And the Neyman Type A adequately graduated the data in this study. If the success of the Neyman Type A (or Long) distribution is general in accident studies —and there is some reason to think so from Table 11.1 of industrial accidents—then the whole elaborate superstructure of the section purporting to show a relationship between the accident record and accident liability (including accident proneness) must collapse, because the parameters of the Negative Binomial no longer have an inherently unique meaning. David (1949) remarked: 'It is, however, difficult to see what the parameters of either distribution [Negative Binomial and Neyman Type A] mean'. In view of the work contained in this book this objection would no longer appear valid.

The theoretical distributions admitted in the literature are essentially 'inhuman' models in that pigeon-holes being bombarded with billiard balls formed the basis of their construction. It should be clearly recognised that Greenwood never claimed otherwise: 'These examples, although the analogy to the subject we are engaged upon is but imperfect, start a train of thought' (Greenwood and Woods, 1919). Men were assumed to be *ab ovo* fixed in their capacity to sustain accidents, although not all men equally so. The only exception to this is the hypothesis underlying the original Biassed Distribution (Greenwood and Yule, 1920), although in its 'single-bias' form—i.e. that after one accident an individual's liability to further accidents changes irrevocably to another level and no further alteration is admitted as possible no matter how many more accidents that individual experiences—it too is mechanistic in concept. The acceptance of these ideas were at least partly responsible for the conception of an innate fixed 'accident proneness', to be hung like the albatross around each person's neck.

However the Short distribution was constructed on a much more flexible basis and is an essentially 'human' model; also it makes some provision for 'chance' accidents, events which must occur especially on the roads: '*Any* statistics of accidents must contain a number of events which have no connection with the personal qualities of the exposed to risk' (Greenwood, 1950). This is not to say that all men are to be assumed equal in their liability to accidents, because, as may be seen from the present work, each man's liability to accident varies according to whether he is in a 'spell' or not. Thus the re-introduction of 'accident proneness' as a temporary and not a permanent quality may be considered as meaningful. The following extract from Smiley's (1955) paper shows that the concept of a 'spell' has some practical justification. In discussing his findings (using Culpin's (1930) grouping), Smiley stated: 'On a number of occasions individuals who had been rated as in classification 3, 4, or 5 [i.e. with more than one symptom of 'nervousness'] when seen subsequently, after their particular anxieties had been resolved, would have been down graded by two grades [i.e. into Groups 0, 1 or 2—symptoms absent or mild]. As an example, the case history of a fitter aged 29 is typical. Five years previously his fiancée died. His father, mother, one sister, and two brothers were killed in an air raid on Belfast in 1941. He went to live elsewhere and became engaged to the daughter of his host. His second fiancée died suddenly on March 16, 1944, and at first inexplicably. The inquest was adjourned and police inquiries followed. He had six accidents in the first week after this catastrophe. On interview he was restless, agitated, showed marked tremor and stammer. He had some agoraphobia, headache, and slept little. He was disturbed by dreams, the most frequently recurring being that he was sitting near the centre of a huge revolving gramophone disc, the centrifugal force of which was driving him nearer and nearer the circumference until, eventually, when he was flung into space, he awakened trembling, bathed in perspiration. The following week he had five more accidents in three days immediately before the adjourned inquest. He was classified in Group 4. He took ten days' holiday and during the remainder of the year had no more accidents. Later he was classified in Group 2'.

Now perhaps a reason can be advanced for the conspicuous failure of the attempts to isolate the 'accident prone' by psychological tests, in that when examined after the period of exposure to the risk of accident the spell may have 'worn off'. Since there has been in this work no need to reckon men as differing permanently in their liability to spells, this suggests that the 'accident prone' group (in the classical 'permanent' sense) is liable to be a very small one, at least in the populations studied. This is not to say that there is no such group at all; the fact that the correlation coefficient between the numbers of accidents incurred in different periods of time is far from zero precludes anything like so categorical a statement. But the suspected instability of the correlation coefficient suggests that the 'accident prone' group (if it exists) is likely to be one whose members change as time goes on. Of relevance is the work of Schulzinger (1956) who analysed a series of some 35,000 injuries in general and industrial practice over a period of 25 years. His findings indicated that the group which was responsible for most of the accidents in one observational period in the main comprised different individuals to the group which was responsible for most of the accidents in any other observational period.

The justification in practice of the assumptions involved in the construction of the Short model would seem difficult to establish, but a paper by Moffie and Alexander (1953) is relevant. These writers

Table 11.2 *Observed and Theoretical Frequencies for Differing Numbers of Accidents* (r)
582 Prague Tram Drivers (*Křivohlavý* (*1958*))

r	*Observed*	*Poisson*	*Negative Binomial*	*Short*
0	81	48	85·6	73·7
1	137	121	128·9	129·9
2	124	142	122·4	136·0
3	88	128	93·9	93·6
4	68	80	63·4	54·9
5	34	40	39·3	31·9
6	18	16	22·7	19·8
7	17		12·4	12·7
8	7		6·6	8·0
9	4			
10	1	7		
11	1 } 8		6·5	11·5
14	1			
16	1			
χ^2		131·817 $\nu = 6$	5·242 $\nu = 7$	8·251 $\nu = 6$
P		$P < 0{\cdot}001$	$0{\cdot}70 > P > 0{\cdot}50$	$0{\cdot}30 > P > 0{\cdot}20$
Significance		Very Highly Significant	Not Significant	Not Significant

Compiled from data presented by KŘIVOHLAVÝ, J. (1958), *Accident Activity in Situations with a Different Level of Risk.* Prague: Industrial Safety Research Institute.

investigated the incidence of 'preventable' and 'non-preventable' traffic accidents separately over a year, and found that the distribution of 'non-preventable' accidents was closer to a Poisson form than was that of the 'preventable' ones: the correlation coefficient between the two classes was $-0{\cdot}12$. On a more practical basis data from

Table 11.3 *Observed and Theoretical Frequencies for Differing Numbers of Accidents (r)*
363 Helsinki Tram Drivers (Häkkinen (1958))

r	*Observed*	*Poisson*	*Negative Binomial*	*Short*
0	136	122·3	135·7	135·3
1	117	133·1	121·1	121·9
2	75	72·4	64·9	64·7
3	20	26·3	27·1	26·9
4	8 } 15	} 8·9	} 14·2	} 14·2
5	6			
6	1			
χ^2		9·274 $\nu = 3$	3·623 $\nu = 2$	3·656 $\nu = 1$
P		$0·05 > P > 0·02$	$0·20 > P > 0·10$	$0·10 > P > 0·05$
Significance		Significant	Not Significant	Not Significant

Compiled from data presented by Häkkinen, S. (1958), *Traffic Accidents and Driver Characteristics. A Statistical and Psychological Study.* Helsinki: Finland's Institute of Technology, Scientific Researches, No. 13.

tram-drivers in Prague (Křivohlavý, 1958) and Helsinki (Häkkinen, 1958) show that the utility of the Short distribution is not confined to results from Irish drivers (Tables 11.2 and 11.3).

If the term 'accident proneness' is dropped, what, if anything, should replace it? 'Temporary accident proneness' may appear more satisfactory, but Mephistopheles' retort seems pertinent: 'Den Bösen sind Sie los, die Bösen sind geblieben' ('You get rid of the evil one, but evil still remains') (Goethe, 1831). Also, it is probable that the inflexible connotation of 'prone' would denote to many an inherent characteristic. Greenwood and Woods did not use the term 'accident proneness', but talked of 'individual susceptibility to accident', which they envisaged as having a wide connotation: 'Consequently we have sheltering under the term individual susceptibility, a motley host of motives or factors which will be very difficult to separate and measure' (Greenwood and Woods, 1919). In the preface to Newbold's (1926) Report the term receives a more specific meaning: 'An investigation carried out by Greenwood and Woods on data collected in munition factories during the war indicates that the distribution of accidents is largely influenced by a special personal susceptibility inherent in the individual and differing from one individual to another'. An even less fortunate term is 'accident liability'. This has been used indiscriminately by many authors, although more specifically by some, e.g. by Farmer (1938): 'We regard accident proneness as an individual quality of relative permanence, and use accident-liability as the sum total of all the factors determining accident causation'. The terms 'individual tendency to accident', and 'personal tendency', appear in the summary of Newbold's (1926) Report, but they were not elaborated, and, so far as we are aware, these terms have never been clearly defined by any investigator. Consequently, if it is considered desirable for any reason to replace the term 'accident proneness' by one of equivalent quality but which may more accurately, and perhaps less ambiguously, reflect the observed findings, the term 'variable accident tendency' is suggested.

Any action taken as a result of the introduction of the concept of accident proneness has failed to lead to a decrease in accident rates comparable to that achieved by reduction in environmental risk. It can, in fact, be argued that the existence of this concept may actually have dissuaded organisations from implementing safety programmes. De Reamer (1958) expressed this view succinctly: 'If a supervisor believes that a worker is accident prone, he is likely to assume that the case is out of his hands'. Newbold's (1926) warning is worth repeating: 'In dealing with the human factor we do not intend in the least to minimise the importance of the mechanical side of accident cause and prevention, or to show any sympathy with the neglect of the first and most clearly necessary duty of any employer to make all machinery and working conditions as free from risk and as foolproof as possible'.

Lastly, it is of interest to remember in what circumstances the modern investigation into accident statistics was initiated, namely in connection with women munitions workers during the First World War. This was a *milieu* in which 'spells' could be easily imagined. Very likely many of these women had brothers, husbands and fathers in France, and this could produce a degree of strain apart altogether from the difficulties of increased work pressure and life on the home front. Possibly sociological research—as partly touched on by Biesheuvel (1949)—would prove a more fruitful line of enquiry into accident causation than those already tried. That at least two other contemporary invesitgators—one in the field of industrial accidents, the other concerned with road accidents—may be of like opinion is shown by the following quotations from their work: 'But the most common story was of the shortage of housing, of getting married and "living with the wife's people", of quarrels with parents-in-law, and most usually the "mother-in-law" ("the old man—he's decent, he understands, but the old woman, she's —!") was a constantly recurring theme' (Smiley, 1955). 'Skilled activities, such as driving, tend to become disorganised under emotional stress. Emotional states also influence what is perceived in a situation, and inadequate or inappropriate reactions may be made by emotionally disturbed drivers, leading to a condition of temporary accident proneness' (Norman, 1960).

Tendency to accident is a hazard of living.

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Section 4

Chapter 12 The Incidence of Accidents among a Population at Risk

a Introduction

This and the following chapter present a review of the existing theory, followed by the derivation, from first principles, of new models to explain the frequency distributions observed in the field of accident statistics. The review is brief because of the comprehensive article by Arbous and Kerrich (1951), although the theory is here reformulated from a slightly different viewpoint to that taken hitherto.

Generally, in a statistical investigation, a theoretical model to explain a measurable phenomenon associated with a physical system is constructed and then tested against actual data. If the test is successful, then, from the model, deductions can be made as to the underlying properties of the physical system, which deductions should be in turn tested, if possible. The physical system under immediate consideration is that of a population of transport drivers working in a given environment in which, as far as can be judged, the risk of an accident is equal for each driver. The measurable phenomenon is the incidence of accidents among the population at risk. The several existing models will now be briefly examined in turn.

b The Poisson Distribution

Historically, the first model considered to explain such a system was the Poisson distribution. Although discovered in 1837, the initial and by now classical instance of its use in the field of accident statistics was by von Bortkiewicz (1898). The data are worth repeating for a reason which will be apparent later; they concern the number of men killed by horse-kicks in 10 Prussian Army Corps over a period of twenty years (1875–1894) (Table 12.1).

Table 12.1 *The Number of Deaths in 10 Corps per Army Corps per Annum over 20 Years*

No. of Deaths	*Frequency*	
	Observed	*Expected*
0	109	108·7
1	65	66·3
2	22 } 26	20·2 } 25.0
3	3	4·1
4	1	0·7
Mean = 0·61; Variance = 0·6079	$\chi^2 = 0{\cdot}066$; $\nu = 1$; $0{\cdot}80 > P > 0{\cdot}70$	

The frequencies expected on the assumption of the Poisson model are clearly very close to those actually observed. Nevertheless it is interesting to note that the Poisson distribution only really came into prominence when Student (1907) showed that this distribution seemed to afford an appropriate model in a class of haemocytometer counts.

Formally the Poisson distribution may be derived as follows. Consider a time interval $t = 0$ to $t = T$, divided into k non-overlapping sub-intervals, t_0 to t_1, t_1 to t_2, and so on, where

$$t_0 = 0, \qquad t_k = T$$

and

$$\delta t_i = t_{i+1} - t_i, \qquad i = 0, 1, \ldots (k-1). \tag{1}$$

Let r_i be the number of accidents an individual suffers during time interval δt_i, and assume r_i refers to a rare event with distribution law $p_i(r_i)$,

where

$$\left.\begin{aligned} p_i(0) &= 1 - f(t_i).\delta t_i - o(\delta t_i), \\ p_i(1) &= \quad f(t_i).\delta t_i + o(\delta t_i), \\ p_i(r_i) &= o(\delta t_i)^{r_i - 1}, \qquad r_i > 1. \end{aligned}\right\} \tag{2}$$

and

It is further assumed that accidents occur by 'pure chance', i.e. that the number of accidents suffered in any period is independent of the number suffered in any other period, or more precisely

$$p(r_0, r_1, \ldots r_{k-1}) = p_0(r_0)p_1(r_1) \ldots p_{k-1}(r_{k-1}) \quad \text{for} \quad k > 1. \tag{3}$$

A population where (2) and (3) held was termed by Arbous and Kerrich, 'homogeneous within the time interval $0 < t < T$'.

If r is the number of accidents suffered by an individual over the whole period 0 to T, it follows immediately that

$$p(r) = e^{-\lambda}.\frac{\lambda^r}{r!}, \tag{4}$$

where

$$\lambda = \int_0^T f(t)\,dt,$$

which is the Poisson distribution with parameter λ. It is to be observed that λ is categorically assumed the same for every individual.

This derivation of the Poisson distribution, due to Arbous and Kerrich, is a much more general result than Greenwood's (Greenwood and Woods, 1919) original model, where λ was a constant, independent of time.

However the converse is not true, i.e. if the observed distribution is adequately fitted by a Poisson, then the population need not be homogeneous as defined above.

c The Negative Binomial Distribution

Upon analysing accident data garnered during the First World War, Greenwood observed that the Poisson distribution did not generally provide a suitable model to explain the incidence of accidents among the populations studied, which were mainly composed of munition workers. The difficulty was that the variance of the observed distribution in most instances appreciably exceeded the mean instead of being equal to it as required by the Poisson distribution, (see for example von Bortkiewicz's data, given previously). Consequently he sought ways of relaxing the stringent conditions embodied in the notion of a homogeneous population. Greenwood conceived the idea, while still retaining

$$p(r|\lambda) = e^{-\lambda}.\frac{\lambda^r}{r!} \qquad , \tag{5}$$

that λ itself might vary according to the individual. The resulting model he termed the 'Distribution of Unequal Liabilities'. From the practical consideration that such a distribution must be skew, it was arbitrarily assumed that λ was distributed among the population at risk in a Pearson Type III curve. Formally, the distribution of λ is given by

$$dF = \frac{c^p}{\Gamma(p)} . e^{-c\lambda} . \lambda^{p-1}\, d\lambda, \qquad 0 \leqq \lambda \leqq \infty \tag{6}$$

It follows immediately that the probability of an individual suffering r accidents is given by

$$p(r) = \left(\frac{c}{c+1}\right)^p . \frac{\Gamma(p+r)}{r!.\Gamma(p).(c+1)^r} \tag{7}$$

The first two moments, being

$$\mu_1' = \frac{p}{c}$$

and

$$\mu_2 = \frac{p}{c} + \frac{p}{c^2} \quad ,$$

yield momental estimators, which enable a Negative Binomial distribution to be fitted to an observed distribution whose variance exceeds its mean.

Historically, a binomial with negative index was no novelty since Yule (1910) had already shown that such a distribution was necessary when considering a population subjected to recurring attacks of a disease. Newbold (1927) consolidated this line of attack and her results gave no reason to doubt that the Negative Binomial provided, generally speaking, an adequate fit to accident data.

Once again the converse to the theorem is not necessarily true, i.e. although equation (7) inevitably follows if equations (5) and (6) hold, the fact that the distribution of accidents among the population may be represented by a Negative Binomial does not necessarily imply that the accident distribution is a mixture of Poisson distributions. Actually, if it is assumed that a person's having had an accident affects the probability of his having another, then, under certain conditions, the Negative Binomial again emerges. Such a distribution is termed in the literature a 'Contagious Distribution'.

Formally, it is assumed that

by time $t = 0$, no individual has had an accident. (8)

Letting $p(r, t)$ be the probability that an individual has had r

accidents by time t, assume that, during the time interval t to $t + dt$, an individual can have (apart from infinitesimals of higher order in dt)

$$0 \text{ accidents, with probability } 1 - f(r, t) \,.\, dt$$

or

$$1 \text{ accident, with probability } f(r, t) \,.\, dt \tag{9}$$

In other words, the more accidents the individual has had the more likely he is to have another one.

Further it is assumed that

$$f(r, t) = \beta + \gamma r, \text{ where } \beta \text{ and } \gamma \text{ are positive} \tag{10}$$

Then it can readily be established that

$$p(r, t) = \frac{\Gamma\{(\beta/\gamma) + r\}}{r!\,\Gamma(\beta/\gamma)} .(1 - e^{-\gamma t})^r . e^{-\beta t} \tag{11}$$

This is clearly of the same form as equation (7) with

$$p = \beta/\gamma$$

and

$$c = (e^{\gamma t} - 1)^{-1}$$

In other words, a very different set of assumptions leads to exactly the same mathematical model.

d The Biassed Distribution

Greenwood and Yule in their original paper advanced a further model which they called the Biassed distribution. Assumptions (8) and (9), given previously, are made with the further assumptions

$$f(0, t) = \delta,$$

$$f(r, t) = \varepsilon, \qquad \text{for} \quad r \geqq 1, \tag{12}$$

where

$$\delta > \varepsilon > 0.$$

This model, it will be observed, postulates that until the first accident the driver's probability of having an accident within a short interval of time dt is $\delta . dt$, and immediately after the first accident the probability of his having a further one immediately decreases to $\varepsilon . dt$ and no further reduction can take place. In other words, all 'learning' occurs simultaneously with the occurrence of the first accident and no further experience will ever alter the chance of his having another accident.

The above assumptions led to what Arbous and Kerrich later termed the 'Burnt Fingers' distribution, which, apart from being awkward to fit in practice, cannot be logically entertained with regard to most distributions actually encountered in this field. The only merit of the Biassed distribution is that it can provide a theoretical fit in the unusual case where the observed mean exceeds the variance.

However the assumption (8), required for both the Contagious and Biassed distributions, is simply not true for the populations analysed in this work and consequently these distributions will not be considered further. In passing, the results regarding ex-B.C.T. tram drivers (given in Chapter 4) indicate that the Biassed distribution might appear to be based on a much too unsophisticated model.

e The Bivariate Negative Binomial Distribution

In Chapter 6, the sample correlation coefficients of the various bivariate frequency distributions arising from the data were calculated and shown to differ from zero to such an extent that it would appear reasonable to assume the population correlation coefficients were greater than zero. This affords the tentative conclusion that, over the whole period of time in question, some drivers tended to have more accidents than their fellows. Thus the suggestion, made by Arbous and Kerrich, arises that a bivariate analysis may enable more information to be gleaned with the object of high-lighting those particular individuals. A simple form of Bivariate Negative Binomial is derived as follows.

Consider a complete time interval $\delta_0 = 0$ to T divided into two equal sub-intervals δ_1 and δ_2. As before, let r_0, r_1 and r_2 be the numbers of accidents a driver incurs during time intervals δ_0, δ_1 and δ_2. Assume for each driver,

$$p(r_i, \lambda) = \mathrm{e}^{-\lambda\delta_i} . \frac{(\lambda\delta_i)^{r_i}}{r_i!}, \quad i = 0, 1, 2 \tag{13}$$

Now make the simplifying assumptions that each sub-interval is of unit length and that the average number of accidents per driver over either sub-interval is α. It is to be carefully noted that λ is fixed for the whole period, not varying through time.

Once more, the further assumption is made that λ is distributed in a Pearson Type III, or formally

$$dF(\lambda) = (p/\alpha)^p . \frac{\lambda^{p-1} . e^{-p\lambda/\alpha}}{\Gamma(p)} . d\lambda \tag{14}$$

Whence it can be deduced that the 'marginal' distribution for r_i, $i = 1, 2$, is Negative Binomial with

$$p(r_i) = \left(\frac{p}{p+\alpha}\right)^p . \frac{\Gamma(p + r_i)}{r_i!\,\Gamma(p)} . \left(\frac{\alpha}{p+\alpha}\right)^{r_i} \tag{15}$$

The expression for r_0 is similar, except that α must be replaced by 2α.

The general term of the Bivariate Negative Binomial distribution is given by

$$p(r_1, r_2) = \frac{p^p \alpha^{r_0} \Gamma(p + r_0)}{(p + 2\alpha)^{p+r_0} . \Gamma(p) r_1!\, r_2!} \tag{16}$$

An important property of this distribution, due to Lundberg (1940), is

$$\rho(r_1, r_2) = \frac{1}{1 + (p/\alpha)} \tag{17}$$

The distribution of individual liabilities can be examined in detail since

$$\nu = 2[(p/\alpha) + 2]\lambda \text{ has a } \chi^2\text{-distribution}$$

with $\qquad 2(p + r_0)$ degrees of freedom.

It is worth noting that Equation (17) is actually formally equivalent to Newbold's formula, (c.f. Maritz (1950)).

Substitution of

$$\alpha = \frac{\mu_i'}{2} = \frac{p}{2c}$$

into (17) gives

$$\rho = \frac{1}{1 + 2c},$$

which is in fact identical with Newbold's formula.

Chapter 13 The Long and Short Distributions

a Introduction

New models to explain the frequency distributions observed in the field of accident studies are derived from first principles in this chapter; *ab initio* they will be so constructed as to have parameters with readily interpretable meanings.

In the first model considered the average driver is assumed to be liable to 'spells', and it is supposed that an accident can only happen during such a spell and that spells themselves occur at random among the population. This theoretical distribution (the Long) is shown to be formally equivalent to the Neyman Type A.

In the second model considered the above severe restriction is removed; more specifically it is assumed that a driver can incur an accident outside a spell. The resultant distribution (the Short) provides a theoretical basis for the division of the total number of accidents into those due to factors *in propria persona*, and those due to pure chance.

The statistician may be surprised that the Long distribution is not derived in more elegant fashion in this chapter by employing, *inter alia*, the moment generating function. The reason is as follows. Kendall (1946) wrote: 'The idea of the characteristic function can be traced back as far as Laplace, but its introduction into the theory of statistics, through the theory of probability, is mainly due to Poincaré and Lévy (1925)'. Further, although the mathematical development could have been expedited by using the fact that $\begin{bmatrix} r \\ k \end{bmatrix}$ is the number of ways of placing r balls into k different cells, so that no cell is unoccupied, such sophistication in combinatorial analysis —as displayed by, for example, Riordan (1958) in showing the solution of this occupancy problem to involve Stirling numbers of the second kind—was not general among statisticians in 1920. In fact the 'differences of zero' were apparently re-discovered and first specifically introduced into statistics by Stevens (1937) when he showed them to afford exact solutions to some important sampling problems. Therefore these methods were not in currency when

Greenwood and Yule investigated the problem of accident distribution, and we have decided to derive the following theoretical distributions using the same statistical tools as were then available. This is certainly not to imply that Greenwood and Yule *should* have devised other distributions; nor is it for the purpose of making a theoretical point only. It is for the following very practical reason. We have mentioned earlier (Chapter 5) that Greenwood's selection of the Pearson Type III curve was largely for practical convenience, that the Negative Binomial was available in 1919 and 1920 since Yule (1910) had already derived it for use in quite a different context (Chapter 12), and that the subsequent interpretation of this distribution's parameters by Farmer and Chambers (1926) led to their advancing the hypothesis of accident proneness. Consequently, the main reason for the somewhat lengthy treatment in this chapter is to demonstrate that the use of the Negative Binomial and the concomitant evolution of the concept of accident proneness have been to some considerable extent fortuitous.

Before commencing the construction of the distributions it is convenient to establish a few lemmas.

b Lemmas

LEMMA 1

$$\frac{S^{r-1}}{1!(r-1)!} + \frac{S^{r-2}}{2!(r-2)!} + \cdots\cdots + \frac{S^1}{(r-1)!1!} = \frac{(S+1)^r - S^r - 1}{r!}$$

Proof

$$(S+1)^r = S^r + \binom{r}{1}S^{r-1} + \binom{r}{2}S^{r-2} + \cdots\cdots + \binom{r}{r-1}S^1 + 1$$

$$= S^r + 1 + r!\left\{\frac{S^{r-1}}{1!(r-1)!} + \frac{S^{r-2}}{2!(r-2)!} + \cdots \right.$$

$$\left. \cdots + \frac{S^1}{(r-1)!1!}\right\}$$

$$= S^r + 1 + r!.(\text{LHS})$$

$$\therefore \text{LHS} = \frac{(S+1)^r - S^r - 1}{r!}$$

[q.e.d

LEMMA 2

$$(e^\theta - 1)^k = \sum_{r=0}^{\infty} \begin{bmatrix} r \\ k \end{bmatrix} \frac{\theta^r}{r!},$$

for k finite, positive and integral, where

$$\begin{bmatrix} r \\ k \end{bmatrix} = k^r - \binom{k}{1}(k-1)^r + \binom{k}{2}(k-2)^r - \cdots$$

$$\cdots + (-1)^{k-1}\binom{k}{k-1}.1^r + (-1)^k.0^r$$

Proof

$$(e^\theta - 1)^k = e^{k\theta} - \binom{k}{1}e^{(k-1)\theta} + \binom{k}{2}e^{(k-2)\theta} - \cdots$$

$$\cdots + (-1)^{k-1}\binom{k}{k-1}e^\theta + (-1)^k$$

$$= \sum_{r=0}^{\infty} \frac{\theta^r}{r!}\left[k^r - \binom{k}{1}(k-1)^r + \binom{k}{2}(k-2)^r - \cdots \right.$$

$$\left. \cdots + (-1)^{k-1}\binom{k}{k-1}1^r + (-1)^k.0^r\right]$$

(defining $0^r = 0$, $(r \neq 0)$, $= 1$, $(r = 0)$)

$$= \sum_{r=0}^{\infty} \begin{bmatrix} r \\ k \end{bmatrix} \frac{\theta^r}{r!}$$

[q.e.d

As corollaries, it may be observed that

$$\begin{bmatrix} r \\ k \end{bmatrix} = 0 \qquad \text{for } 0 \leqq r \leqq k-1,$$

and

$$\begin{bmatrix} k \\ k \end{bmatrix} = k!$$

Clearly

$$\begin{bmatrix} r \\ 1 \end{bmatrix} = 1, \qquad \text{for } 1 \leqq r \leqq \infty.$$

The system is logically completed by defining

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} = 1 \quad \text{and} \quad \begin{bmatrix} r \\ 0 \end{bmatrix} = 0 \qquad \text{for } 1 \leqq r \leqq \infty.$$

$$(\mathrm{e}^\theta - 1)^k = \begin{bmatrix} k \\ k \end{bmatrix} \frac{\theta^k}{k!} + \begin{bmatrix} k+1 \\ k \end{bmatrix} \frac{\theta^{k+1}}{(k+1)!} + \begin{bmatrix} k+2 \\ k \end{bmatrix} \frac{\theta^{k+2}}{(k+2)!} + \dots$$

Differentiation, with respect to θ, yields

$$k(\mathrm{e}^\theta - 1)^{k-1}.\mathrm{e}^\theta = \begin{bmatrix} k \\ k \end{bmatrix} \frac{\theta^{k-1}}{(k-1)!} + \begin{bmatrix} k+1 \\ k \end{bmatrix} \frac{\theta^k}{k!} + \begin{bmatrix} k+2 \\ k \end{bmatrix} \frac{\theta^{k+1}}{(k+1)!} + \dots$$

This result will be referred to as Lemma 3.

Differentiation once again, with respect to θ, yields

$$\{k(k-1)(\mathrm{e}^\theta - 1)^{k-2}.\mathrm{e}^{2\theta}\} + \{k(\mathrm{e}^\theta - 1)^{k-1}.\mathrm{e}^\theta\}$$
$$= \begin{bmatrix} k \\ k \end{bmatrix} \frac{\theta^{k-2}}{(k-2)!} + \begin{bmatrix} k+1 \\ k \end{bmatrix} \frac{\theta^{k-1}}{(k-1)!} + \begin{bmatrix} k+2 \\ k \end{bmatrix} \frac{\theta^k}{k!} + \dots$$

This result will be referred to as Lemma 4.

Differentiation once more, with respect to θ, yields

$$\{k(k-1)(k-2)(\mathrm{e}^\theta - 1)^{k-3}.\mathrm{e}^{3\theta}\} + \{3k(k-1)(\mathrm{e}^\theta - 1)^{k-2}.\mathrm{e}^{2\theta}\} + \{k(\mathrm{e}^\theta - 1)^{k-1}.\mathrm{e}^\theta\}$$
$$= \begin{bmatrix} k \\ k \end{bmatrix} \frac{\theta^{k-3}}{(k-3)!} + \begin{bmatrix} k+1 \\ k \end{bmatrix} \frac{\theta^{k-2}}{(k-2)!} + \begin{bmatrix} k+2 \\ k \end{bmatrix} \frac{\theta^{k-1}}{(k-1)!} + \begin{bmatrix} k+3 \\ k \end{bmatrix} \frac{\theta^k}{k!} + \dots$$

The result will be referred to as Lemma 5.

The Differences of Zero and $\begin{bmatrix} r \\ k \end{bmatrix}$

The Leading Differences of Zero are

$$1^r - 0^r,\ 2^r - 2.1^r + 0^r,\ 3^r - 3.2^r + 3.1^r - 0^r, \dots$$

the next differences being

$$2^r - 1^r,\ 3^r - 2.2^r + 1^r,\ 4^r - 3.3^r + 3.2^r - 1^r, \dots$$

It is required to prove that

$$\Delta^k(0)^r = \begin{bmatrix} r \\ k \end{bmatrix}$$

Proof by Mathematical Induction

Let

$$\Delta^k(0)^r = \begin{bmatrix} r \\ k \end{bmatrix}$$
$$= k^r - \binom{k}{1}(k-1)^r + \cdots\ldots + (-1)^{k-1}\binom{k}{k-1}1^r + (-1)^k.0^r,$$

for all $k \leqq k$, (of course, similar expansions hold for the next differences). Then

$$\Delta^{k+1}(0)^r = -\left[k^r - \binom{k}{1}(k-1)^r + \cdots\ldots + (-1)^{k-1}\binom{k}{k-1}1^r + (-1)^k.0^r\right]$$
$$+ \left[(k+1)^r - \binom{k}{1}k^r + \cdots\ldots + (-1)^{k-1}\binom{k}{k-1}2^r + (-1)^k.1^r\right]$$
$$= \sum_{t=-1}^{k} \{(-1)^{t+1}.C_t(k-t)^r\},$$

where

$$C_t = \binom{k}{t+1} + \binom{k}{t}$$
$$= \binom{k+1}{t+1}$$

Thus

$$\Delta^{k+1}(0)^r = (k+1)^r - \binom{k+1}{1}k^r + \cdots\ldots + (-1)^k\binom{k+1}{k} + (-1)^{k+1}.0^r.$$
$$= \begin{bmatrix} r \\ k+1 \end{bmatrix}$$

The proposition is clearly true for $k = 1$ and the proof by induction is complete.
Hence

$$\Delta^k(0)^r = \begin{bmatrix} r \\ k \end{bmatrix}$$

[q.e.d

(For the sake of compactness, the notation introduced previously in this work will be retained in the sequel.)

c The Long Distribution

Suppose a man is subject to 'spells', during which he is liable to accident, and assume it is impossible for an accident to occur except during a spell. It is further assumed that pure chance alone governs the occurrence of spells and also of accidents within a spell, and that both are rare events. Hence both can be regarded as Poisson distributed, although clearly both parameters need not be identical.

Let the probabilities of a man suffering a spell and of his incurring an accident within a spell be determined by the Poisson parameters λ and θ respectively over a given period of time.

It is easily seen that the probability of a man having no accidents over the whole period is given by

$$\begin{aligned} P(0) &= e^{-\lambda} + e^{-\lambda}\frac{\lambda}{1!}.e^{-\theta} + e^{-\lambda}\frac{\lambda^2}{2!}.e^{-2\theta} + \ldots \\ &= e^{-\lambda}\left[1 + \frac{\lambda\, e^{-\theta}}{1!} + \frac{(\lambda\, e^{-\theta})^2}{2!} + \ldots\right] \\ &= e^{\lambda(e^{-\theta}-1)}. \end{aligned}$$

A spell is subsequently termed 'fruitful' if at least one accident occurs within it; alternatively, 'abortive', if no accident results.

The probability of a man incurring r accidents, (where $r \geqq 1$), over the whole period of time is now considered.

The r accidents may occur in r, and only r, distinct ways—

(1) in one single fruitful spell,

(2) in two separate fruitful spells,
(3) in three separate fruitful spells,
.
.
.
.
.
.
(r) in r separate fruitful spells.

In each case, all further spells suffered (if any) are abortive.

We may write the probability of a man suffering r accidents as

$$P(r) = \sum_{k=1}^{r} P(r, k) \tag{1}$$

where $P(r, k)$ is the probability of suffering r accidents in k separate and fruitful spells.

Let $p(k)$ be the probability of suffering exactly k 'basic' spells, i.e. at least k spells are incurred, any beyond k being abortive.

Now

$$p(k) = \mathrm{e}^{-\lambda}\frac{\lambda^k}{k!} + \mathrm{e}^{-\lambda}\frac{\lambda^{k+1}}{(k+1)!}\binom{k+1}{1}\mathrm{e}^{-\theta} + \mathrm{e}^{-\lambda}\frac{\lambda^{k+2}}{(k+2)!}\binom{k+2}{2}\mathrm{e}^{-2\theta} + \cdots$$

$$= \mathrm{e}^{-\lambda}\sum_{n=0}^{\infty}\left\{\lambda^{k+n}.\mathrm{e}^{-n\theta}.\frac{1}{(k+n)!}\binom{k+n}{n}\right\}$$

$$= \mathrm{e}^{-\lambda}\sum_{n=0}^{\infty}\frac{\lambda^{k+n}.\mathrm{e}^{-n\theta}}{n!k!}$$

$$= \mathrm{e}^{-\lambda}\frac{\lambda^k}{k!}\sum_{n=0}^{\infty}\frac{(\lambda\,\mathrm{e}^{-\theta})^n}{n!}$$

$$= \mathrm{e}^{\lambda(\mathrm{e}^{-\theta}-1)}.\frac{\lambda^k}{k!}$$

An immediate corollary is that the probability of all spells (if any) beyond the k 'basic' ones being abortive is

$$e^{\lambda e^{-\theta}}$$

Let $P[r, k]$ be the probability of incurring r accidents, having suffered k 'basic' spells, so that all 'basic' spells are fruitful.

Then, the probability of incurring r accidents in k fruitful spells,

$$P(r, k) = p(k).P[r, k]$$

Thus

$$\frac{P(r, k)}{e^{\lambda(e^{-\theta}-1)}.\lambda^k/k!} = P[r, k] \tag{2}$$

Substitution of $k = 1$ into (2) immediately yields

$$P(r, 1) = e^{\lambda(e^{-\theta}-1)}.(\lambda\, e^{-\theta})\frac{\theta^r}{r!}$$

It is instructive to consider the cases $k = 2$ and $k = 3$ in some detail.

$$P[r, 2] = e^{-\theta}\frac{\theta^{r-1}}{(r-1)!}.e^{-\theta}\frac{\theta}{1!} + e^{-\theta}\frac{\theta^{r-2}}{(r-2)!}.e^{-\theta}\frac{\theta^2}{2!} + \cdots$$

$$\cdots + e^{-\theta}\frac{\theta}{1!}.e^{-\theta}\frac{\theta^{r-1}}{(r-1)!}$$

Thus

$$\frac{P[r, 2]}{e^{-2\theta}.\theta^r} = \frac{1}{(r-1)!1!} + \frac{1}{(r-2)!2!} + \cdots\cdots + \frac{1}{1!(r-1)!}$$

$$= \frac{1}{r!}[2^r - 1^r - 1] \qquad \text{(By Lemma 1, with } S = 1)$$

$$= \frac{\begin{bmatrix} r \\ 2 \end{bmatrix}}{r!}$$

Hence

$$P(r, 2) = e^{\lambda(e^{-\theta}-1)}.\frac{\theta^r}{r!}.\begin{bmatrix} r \\ 2 \end{bmatrix}\frac{(\lambda\, e^{-\theta})^2}{2!}$$

Similarly,

$$\frac{P[r,3]}{e^{-3\theta}} = \frac{\theta}{1!}\left[\frac{\theta^{r-2}}{(r-2)!}\cdot\frac{\theta}{1!} + \frac{\theta^{r-3}}{(r-3)!}\cdot\frac{\theta^2}{2!} + \cdots\cdots + \frac{\theta}{1!}\cdot\frac{\theta^{r-2}}{(r-2)!}\right]$$

$$+ \frac{\theta^2}{2!}\left[\frac{\theta^{r-3}}{(r-3)!}\cdot\frac{\theta}{1!} + \frac{\theta^{r-4}}{(r-4)!}\cdot\frac{\theta^2}{2!} + \cdots\cdots + \frac{\theta}{1!}\cdot\frac{\theta^{r-3}}{(r-3)!}\right]$$

$$+ \vdots$$

$$\vdots$$

$$+ \frac{\theta^{r-2}}{(r-2)!}\left[\frac{\theta}{1!}\cdot\frac{\theta}{1!}\right]$$

Thus,

$$\frac{P[r,3]}{e^{-3\theta}.\theta^r} = \frac{1}{1!}\left[\frac{1}{(r-2)!1!} + \frac{1}{(r-3)!2!} + \cdots\cdots + \frac{1}{1!(r-2)!}\right]$$

$$+ \frac{1}{2!}\left[\frac{1}{(r-3)!1!} + \frac{1}{(r-4)!2!} + \cdots\cdots + \frac{1}{1!(r-3)!}\right]$$

$$+ \vdots$$

$$\vdots$$

$$+ \frac{1}{(r-2)!}\left[\frac{1}{1!}\cdot\frac{1}{1!}\right]$$

$$= \frac{1}{1!}\cdot\frac{2^{r-1}-2}{(r-1)!} + \frac{1}{2!}\cdot\frac{2^{r-2}-2}{(r-2)!} + \cdots\cdots + \frac{2^2-2}{(r-2)!2!}$$

(By Lemma 1, with $S = 1$)

$$= \left[\frac{2^{r-1}}{1!(r-1)!} + \frac{2^{r-2}}{2!(r-2)!} + \cdots \right.$$

$$\left. \cdots + \frac{2^2}{(r-2)!2!} + \frac{2}{(r-1)!1!}\right]$$

$$-2\left[\frac{1}{1!(r-1)!} + \frac{1}{2!(r-2)!} + \cdots \right.$$

$$\left. \cdots + \frac{1}{(r-2)!2!} + \frac{1}{(r-1)!1!}\right]$$

$$= \frac{3^r - 2^r - 1}{r!} - \frac{2(2^r - 2)}{r!}$$

(By Lemma 1, with $S = 2$ and 1 in succession)

$$= \frac{1}{r!}[3^r - 3.2^r + 3]$$

$$= \frac{\begin{bmatrix} r \\ 3 \end{bmatrix}}{r!}.$$

Hence

$$P(r, 3) = e^{\lambda(e^{-\theta}-1)}.\frac{\theta^r}{r!}.\begin{bmatrix} r \\ 3 \end{bmatrix}.\frac{(\lambda\, e^{-\theta})^3}{3!}.$$

Similarly, it can be shown that

$$P[r, 4] = e^{-4\theta}.\frac{\theta^r}{r!}.\begin{bmatrix} r \\ 4 \end{bmatrix}.$$

and hence

$$P(r, 4) = e^{\lambda(e^{-\theta}-1)}.\frac{\theta^r}{r!}.\begin{bmatrix} r \\ 4 \end{bmatrix}.\frac{(\lambda\, e^{-\theta})^4}{4!}.$$

Now is postulated the following

Theorem

$$P(r, k) = e^{\lambda(e^{-\theta}-1)}.\frac{\theta^r}{r!}.\begin{bmatrix} r \\ k \end{bmatrix}\frac{(\lambda\, e^{-\theta})^k}{k!},$$

where $1 \leqq k \leqq r$ (3)

It is clearly sufficient to establish that

$$P[r, k] = e^{-k\theta}.\frac{\theta^r}{r!}.\begin{bmatrix} r \\ k \end{bmatrix} \tag{4}$$

Proof by Mathematical Induction

Equation (4) is assumed to hold for all $r \leqq r$ and all $k \leqq k - 1$, i.e. in particular, the following is assumed.

$$P[s, k-1] = e^{-(k-1)\theta}.\frac{\theta^s}{s!}\begin{bmatrix} s \\ k-1 \end{bmatrix} \qquad \text{for } s \leqq r - 1 \tag{5}$$

Now clearly

$$P[r, k] = e^{-\theta}\frac{\theta}{1!}.P[r-1, k-1] + e^{-\theta}\frac{\theta^2}{2!}.P[r-2, k-1] + \cdots$$

$$\cdots + \frac{e^{-\theta}\theta^{r-k+1}}{(r-k+1)!}.P[k-1, k-1]$$

$$= e^{-k\theta}.\theta^r\left\{\frac{1}{1!(r-1)!}\begin{bmatrix} r-1 \\ k-1 \end{bmatrix} + \frac{1}{2!(r-2)!}\begin{bmatrix} r-2 \\ k-1 \end{bmatrix} + \cdots\right.$$

$$\left.\cdots + \frac{1}{(r-k+1)!(k-1)!}\begin{bmatrix} k-1 \\ k-1 \end{bmatrix}\right\}$$

(using equation (5) above)

Thus by expansion,

$$\frac{P[r, k]}{e^{-k\theta}.\theta^r} = \frac{1}{1!(r-1)!}\left[(k-1)^{r-1} - \binom{k-1}{1}(k-2)^{r-1}\right.$$

$$\left. + \binom{k-1}{2}(k-3)^{r-1} - \cdots\ldots + (-1)^{k-2}\binom{k-1}{k-2}1^{r-1}\right]$$

$$+ \frac{1}{2!(r-2)!}\left[(k-1)^{r-2} - \binom{k-1}{1}(k-2)^{r-2}\right.$$

$$\left. + \binom{k-1}{2}(k-3)^{r-2} - \cdots\ldots + (-1)^{k-2}\binom{k-1}{k-2}1^{r-2}\right]$$

$$+ \vdots$$

$$+ \frac{1}{(r-k+1)!(k-1)!}\left[(k-1)^{k-1} - \binom{k-1}{1}(k-2)^{k-1}\right.$$

$$\left. + \binom{k-1}{2}(k-3)^{k-1} - \cdots\ldots + (-1)^{k-2}\binom{k-1}{k-2}1^{k-1}\right]$$

$$= \frac{(k-1)^{r-1}}{1!(r-1)!} + \frac{(k-1)^{r-2}}{2!(r-2)!} + \cdots\ldots + \frac{(k-1)^{k-1}}{(r-k+1)!(k-1)!}$$

$$- \binom{k-1}{1}\left[\frac{(k-2)^{r-1}}{1!(r-1)!} + \frac{(k-2)^{r-2}}{2!(r-2)!} + \cdots \right.$$

$$\left. \cdots + \frac{(k-2)^{k-1}}{(r-k+1)!(k-1)!}\right]$$

$$+$$

$$\vdots$$

$$+ (-1)^{k-2}\binom{k-1}{k-2}\left[\frac{1}{1!(r-1)!} + \frac{1}{2!(r-2)!} + \cdots \right.$$

$$\left. \cdots + \frac{1}{(r-k+1)!(k-1)!}\right]$$

$$= \left\{\frac{k^r - (k-1)^r - 1}{r!}\right\} - \binom{k-1}{1}\left\{\frac{(k-1)^r - (k-2)^r - 1}{r!}\right\}$$

$$+ \cdots \ldots + (-1)^{k-2}\binom{k-1}{k-2}\left\{\frac{2^r - 1^r - 1}{r!}\right\}$$

(By Lemma 1 and the corollaries contained in Lemma 2).

Therefore

$$\frac{P[r,k]}{e^{-k\theta}.\theta^r}.r! =$$

$$= k^r - (k-1)^r\left[\binom{k-1}{0} + \binom{k-1}{1}\right]$$

$$+ (k-2)^r\left[\binom{k-1}{1} + \binom{k-1}{2}\right] - \cdots$$

$$\cdots + (-1)^{k-1}.1^r\left[\binom{k-1}{k-2} + \binom{k-1}{k-1}\right]$$

$$= k^r - \binom{k}{1}(k-1)^r + \binom{k}{2}(k-2)^r - \cdots$$

$$\cdots + (-1)^{k-1}\binom{k}{k-1}1^r$$

$$= \begin{bmatrix} r \\ k \end{bmatrix}$$ (By the expansion contained in Lemma 2).

Hence, equation (4) is true for $r = r$ and $k = k$ if true for $r = r$ and $k = k - 1$. The result has been established for $r = r$ and for $k = 1$ and so the Theorem is proved. [q.e.d

Now may be written immediately from (1) and (3), the probability of a man suffering r accidents

$$P(r) = e^{\lambda(e^{-\theta}-1)} \frac{\theta^r}{r!} \sum_{k=0}^{r} \left\{ \begin{bmatrix} r \\ k \end{bmatrix} \frac{(\lambda\, e^{-\theta})^k}{k!} \right\} \tag{6}$$

Inspection shows (6) to be valid also for $r = 0$, so this formula is correct for all r.

As a check it is necessary to show that

$$\sum_{r=0}^{\infty} P(r) = 1.$$

$$\begin{aligned}
\sum_{r=0}^{\infty} P(r) &= e^{\lambda(e^{-\theta}-1)} \sum_{r=0}^{\infty} \left\{ \frac{\theta^r}{r!} \left(\sum_{k=0}^{r} \begin{bmatrix} r \\ k \end{bmatrix} \frac{(\lambda\, e^{-\theta})^k}{k!} \right) \right\} \\
&= e^{\lambda(e^{-\theta}-1)} \sum_{k=0}^{\infty} \left\{ \left(\sum_{r=0}^{\infty} \begin{bmatrix} r \\ k \end{bmatrix} \frac{\theta^r}{r!} \right) \frac{(\lambda\, e^{-\theta})^k}{k!} \right\} \\
&= e^{\lambda(e^{-\theta}-1)} \sum_{k=0}^{\infty} \left\{ (e^{\theta} - 1)^k \frac{(\lambda\, e^{-\theta})^k}{k!} \right\}
\end{aligned}$$

(By Lemma 2)

$$\begin{aligned}
&= e^{\lambda(e^{-\theta}-1)} . e^{\lambda(1-e^{-\theta})} \\
&= 1.
\end{aligned}$$

[q.e.d

For illustration, the first five terms of the probability distribution are supplied as follows.

$$P(0) = e^{\lambda(e^{-\theta}-1)}$$

$$P(1) = e^{\lambda(e^{-\theta}-1)} . \theta\{(\lambda\, e^{-\theta})\}$$

$$P(2) = e^{\lambda(e^{-\theta}-1)} . \frac{\theta^2}{2!} \{(\lambda\, e^{-\theta}) + (\lambda\, e^{-\theta})^2\}$$

$$P(3) = e^{\lambda(e^{-\theta}-1)} . \frac{\theta^3}{3!} \left\{ (\lambda\, e^{-\theta}) + \begin{bmatrix} 3 \\ 2 \end{bmatrix} \frac{(\lambda\, e^{-\theta})^2}{2!} + (\lambda\, e^{-\theta})^3 \right\}$$

$$\begin{aligned}
P(4) = e^{\lambda(e^{-\theta}-1)} . \frac{\theta^4}{4!} \Bigg\{ (\lambda\, e^{-\theta}) &+ \begin{bmatrix} 4 \\ 2 \end{bmatrix} \frac{(\lambda\, e^{-\theta})^2}{2!} \\
&+ \begin{bmatrix} 4 \\ 3 \end{bmatrix} \frac{(\lambda\, e^{-\theta})^3}{3!} + (\lambda\, e^{-\theta})^4 \Bigg\}.
\end{aligned}$$

d Determination of the Moments of the Long Distribution from First Principles

Determination of the First Moment about the Origin, i.e. the Mean μ_1'.

$$\mu_1' = E(r)$$

$$= \sum_{r=0}^{\infty} \{r.\, P(r)\}$$

$$= e^{\lambda(e^{-\theta}-1)}\left\{\frac{\theta}{1!}.1.\frac{(\lambda\, e^{-\theta})}{1!}\right.$$

$$+\frac{\theta^2}{2!}.2.\left[\frac{(\lambda\, e^{-\theta})}{1!}+\begin{bmatrix}2\\2\end{bmatrix}\frac{(\lambda\, e^{-\theta})^2}{2!}\right]$$

$$+\frac{\theta^3}{3!}.3.\left[\frac{(\lambda\, e^{-\theta})}{1!}+\begin{bmatrix}3\\2\end{bmatrix}\frac{(\lambda\, e^{-\theta})^2}{2!}+\begin{bmatrix}3\\3\end{bmatrix}\frac{(\lambda\, e^{-\theta})^3}{3!}\right]$$

$$+\frac{\theta^4}{4!}.4.\left[\frac{(\lambda\, e^{-\theta})}{1!}+\begin{bmatrix}4\\2\end{bmatrix}\frac{(\lambda\, e^{-\theta})^2}{2!}+\begin{bmatrix}4\\3\end{bmatrix}\frac{(\lambda\, e^{-\theta})^3}{3!}\right.$$

$$\left.\left.+\begin{bmatrix}4\\4\end{bmatrix}\frac{(\lambda\, e^{-\theta})^4}{4!}\right]+\cdots\quad\ldots\right\}$$

$$= e^{\lambda(e^{-\theta}-1)}\left\{\theta.\frac{(\lambda\, e^{-\theta})}{1!}+\frac{\theta^2}{1!}.\frac{(\lambda\, e^{-\theta})}{1!}+\frac{\theta^3}{2!}.\frac{(\lambda\, e^{-\theta})}{1!}+\frac{\theta^4}{3!}.\frac{(\lambda\, e^{-\theta})}{1!}+\ldots\right.$$

$$+\frac{\theta^2}{1!}\begin{bmatrix}2\\2\end{bmatrix}\frac{(\lambda\, e^{-\theta})^2}{2!}+\frac{\theta^3}{2!}\begin{bmatrix}3\\2\end{bmatrix}\frac{(\lambda\, e^{-\theta})^2}{2!}+\frac{\theta^4}{3!}\begin{bmatrix}4\\2\end{bmatrix}\frac{(\lambda\, e^{-\theta})^2}{2!}+\ldots$$

$$+\frac{\theta^3}{2!}\begin{bmatrix}3\\3\end{bmatrix}\frac{(\lambda\, e^{-\theta})^3}{3!}+\frac{\theta^4}{3!}\begin{bmatrix}4\\3\end{bmatrix}\frac{(\lambda\, e^{-\theta})^3}{3!}+\frac{\theta^5}{4!}\begin{bmatrix}5\\3\end{bmatrix}\frac{(\lambda\, e^{-\theta})^3}{3!}+\ldots$$

$$\left.+\cdots\quad\ldots\right\}$$

$$= e^{\lambda(e^{-\theta}-1)}\left\{\frac{(\lambda\, e^{-\theta})}{1!}\theta\left[1+\frac{\theta}{1!}+\frac{\theta^2}{2!}+\frac{\theta^3}{3!}+\ldots\right]\right.$$

$$+\frac{(\lambda\, e^{-\theta})^2}{2!}\theta\left[\begin{bmatrix}2\\2\end{bmatrix}\frac{\theta}{1!}+\begin{bmatrix}3\\2\end{bmatrix}\frac{\theta^2}{2!}+\begin{bmatrix}4\\2\end{bmatrix}\frac{\theta^3}{3!}+\ldots\right]$$

$$+\frac{(\lambda\, e^{-\theta})^3}{3!}\theta\left[\begin{bmatrix}3\\3\end{bmatrix}\frac{\theta^2}{2!}+\begin{bmatrix}4\\3\end{bmatrix}\frac{\theta^3}{3!}+\begin{bmatrix}5\\3\end{bmatrix}\frac{\theta^4}{4!}+\ldots\right]$$

$$\left.+\cdots\quad\ldots\right\}$$

$$= e^{\lambda(e^{-\theta}-1)}.\theta\left\{\frac{(\lambda\, e^{-\theta})}{1!}.e^{\theta} + \frac{(\lambda\, e^{-\theta})^2}{2!}.2(e^{\theta}-1)\,e^{\theta} + \frac{(\lambda\, e^{-\theta})^3}{3!}.3(e^{\theta}-1)^2\,e^{\theta} + \ldots\right\}$$

(By Lemma 3)

$$= e^{\lambda(e^{-\theta}-1)}.\theta.(\lambda\, e^{-\theta}).e^{\theta}\left\{1 + \frac{(\lambda\, e^{-\theta})(e^{\theta}-1)}{1!} + \frac{(\lambda\, e^{-\theta})^2(e^{\theta}-1)^2}{2!} + \ldots\right\}$$

$$= e^{\lambda(e^{-\theta}-1)}.\lambda\theta.e^{\lambda(1-e^{-\theta})}$$

$$= \lambda\theta$$

Thus the mean $\mu_1' = \lambda\theta$

Determination of the Second Moment about the Mean, i.e. the Variance μ_2

$E\{r(r-1)\} =$

$$= \sum_{r=0}^{\infty}\{r(r-1)P(r)\}$$

$$= e^{\lambda(e^{-\theta}-1)}\left\{\frac{\theta^2}{2!}.2.1\left[\frac{(\lambda\, e^{-\theta})}{1!} + \begin{bmatrix}2\\2\end{bmatrix}\frac{(\lambda\, e^{-\theta})^2}{2!}\right]\right.$$

$$+ \frac{\theta^3}{3!}.3.2\left[\frac{(\lambda\, e^{-\theta})}{1!} + \begin{bmatrix}3\\2\end{bmatrix}\frac{(\lambda\, e^{-\theta})^2}{2!} + \begin{bmatrix}3\\3\end{bmatrix}\frac{(\lambda\, e^{-\theta})^3}{3!}\right]$$

$$+ \frac{\theta^4}{4!}.4.3\left[\frac{(\lambda\, e^{-\theta})}{1!} + \begin{bmatrix}4\\2\end{bmatrix}\frac{(\lambda\, e^{-\theta})^2}{2!} + \begin{bmatrix}4\\3\end{bmatrix}\frac{(\lambda\, e^{-\theta})^3}{3!} + \begin{bmatrix}4\\4\end{bmatrix}\frac{(\lambda\, e^{-\theta})^4}{4!}\right]$$

$$+ \frac{\theta^5}{5!}.5.4\left[\frac{(\lambda\, e^{-\theta})}{1!} + \begin{bmatrix}5\\2\end{bmatrix}\frac{(\lambda\, e^{-\theta})^2}{2!} + \begin{bmatrix}5\\3\end{bmatrix}\frac{(\lambda\, e^{-\theta})^3}{3!} + \begin{bmatrix}5\\4\end{bmatrix}\frac{(\lambda\, e^{-\theta})^4}{4!} + \begin{bmatrix}5\\5\end{bmatrix}\frac{(\lambda\, e^{-\theta})^5}{5!}\right]$$

$$\left. + \cdots \quad \ldots\right\}$$

$$= e^{\lambda(e^{-\theta}-1)}\left\{\theta^2 \frac{(\lambda e^{-\theta})}{1!} + \frac{\theta^3}{1!}\frac{(\lambda e^{-\theta})}{1!} + \frac{\theta^4}{2!}\frac{(\lambda e^{-\theta})}{1!} + \frac{\theta^5}{3!}\frac{(\lambda e^{-\theta})}{1!} + \cdots\right.$$

$$+ \theta^2 \begin{bmatrix}2\\2\end{bmatrix}\frac{(\lambda e^{-\theta})^2}{2!} + \frac{\theta^3}{1!}\begin{bmatrix}3\\2\end{bmatrix}\frac{(\lambda e^{-\theta})^2}{2!} + \frac{\theta^4}{2!}\begin{bmatrix}4\\2\end{bmatrix}\frac{(\lambda e^{-\theta})^2}{2!}$$

$$+ \frac{\theta^5}{3!}\begin{bmatrix}5\\2\end{bmatrix}\frac{(\lambda e^{-\theta})^2}{2!} + \ldots$$

$$+ \frac{\theta^3}{1!}\begin{bmatrix}3\\3\end{bmatrix}\frac{(\lambda e^{-\theta})^3}{3!} + \frac{\theta^4}{2!}\begin{bmatrix}4\\3\end{bmatrix}\frac{(\lambda e^{-\theta})^3}{3!} + \frac{\theta^5}{3!}\begin{bmatrix}5\\3\end{bmatrix}\frac{(\lambda e^{-\theta})^3}{3!} + \ldots$$

$$+ \frac{\theta^4}{2!}\begin{bmatrix}4\\4\end{bmatrix}\frac{(\lambda e^{-\theta})^4}{4!} + \frac{\theta^5}{3!}\begin{bmatrix}5\\4\end{bmatrix}\frac{(\lambda e^{-\theta})^4}{4!} + \ldots$$

$$\left. + \cdots \quad \ldots\right\}$$

$$= e^{\lambda(e^{-\theta}-1)}\left\{\frac{(\lambda e^{-\theta})}{1!}.\theta^2\left[1 + \frac{\theta}{1!} + \frac{\theta^2}{2!} + \frac{\theta^3}{3!} + \ldots\right]\right.$$

$$+ \frac{(\lambda e^{-\theta})^2}{2!}.\theta^2\left[\begin{bmatrix}2\\2\end{bmatrix} + \begin{bmatrix}3\\2\end{bmatrix}\frac{\theta}{1!} + \begin{bmatrix}4\\2\end{bmatrix}\frac{\theta^2}{2!} + \begin{bmatrix}5\\2\end{bmatrix}\frac{\theta^3}{3!} + \ldots\right]$$

$$+ \frac{(\lambda e^{-\theta})^3}{3!}.\theta^2\left[\begin{bmatrix}3\\3\end{bmatrix}\frac{\theta}{1!} + \begin{bmatrix}4\\3\end{bmatrix}\frac{\theta^2}{2!} + \begin{bmatrix}5\\3\end{bmatrix}\frac{\theta^3}{3!} + \ldots\right]$$

$$+ \frac{(\lambda e^{-\theta})^4}{4!}.\theta^2\left[\begin{bmatrix}4\\4\end{bmatrix}\frac{\theta^2}{2!} + \begin{bmatrix}5\\4\end{bmatrix}\frac{\theta^3}{3!} + \ldots\right]$$

$$\left. + \cdots \quad \ldots\right\}$$

$$= e^{\lambda(e^{-\theta}-1)}\left\{\frac{(\lambda e^{-\theta})}{1!}.\theta^2[\qquad e^{\theta}]\right.$$

$$+ \frac{(\lambda e^{-\theta})^2}{2!}.\theta^2[2(2-1).1. \qquad e^{2\theta} + 2(e^{\theta}-1) \quad e^{\theta}]$$

$$+ \frac{(\lambda e^{-\theta})^3}{3!}.\theta^2[3(3-1)(e^{\theta}-1)\, e^{2\theta} + 3(e^{\theta}-1)^2 \; e^{\theta}]$$

$$+ \frac{(\lambda e^{-\theta})^4}{4!}.\theta^2[4(4-1)(e^{\theta}-1)^2\, e^{2\theta} + 4(e^{\theta}-1)^3\, e^{\theta}]$$

$$+\frac{(\lambda\,e^{-\theta})^5}{5!}.\theta^2[5(5-1)(e^\theta-1)^3\,e^{2\theta}+5(e^\theta-1)^4\,e^\theta]$$

$$+\cdots\quad\ldots\Big\}$$

(By Lemma 4)

$$=e^{\lambda(e^{-\theta}-1)}.\theta^2\Big\{(\lambda\,e^{-\theta})^2\,e^{2\theta}+\frac{(\lambda\,e^{-\theta})^3}{1!}(e^\theta-1)\,e^{2\theta}$$

$$+\frac{(\lambda\,e^{-\theta})^4}{2!}(e^\theta-1)^2\,e^{2\theta}+\frac{(\lambda\,e^{-\theta})^5}{3!}(e^\theta-1)^3\,e^{2\theta}+\ldots$$

$$+(\lambda\,e^{-\theta})\,e^\theta+\frac{(\lambda\,e^{-\theta})^2}{1!}(e^\theta-1)\,e^\theta+\frac{(\lambda\,e^{-\theta})^3}{2!}(e^\theta-1)^2\,e^\theta$$

$$+\frac{(\lambda\,e^{-\theta})^4}{3!}(e^\theta-1)^3\,e^\theta+\ldots\Big\}$$

$$=e^{\lambda(e^{-\theta}-1)}.\theta^2\Big\{(\lambda\,e^{-\theta})^2\,e^{2\theta}\Big[1+\frac{(\lambda\,e^{-\theta})(e^\theta-1)}{1!}$$

$$+\frac{(\lambda\,e^{-\theta})^2(e^\theta-1)^2}{2!}+\frac{(\lambda\,e^{-\theta})^3(e^\theta-1)^3}{3!}+\ldots\Big]$$

$$+(\lambda\,e^{-\theta})\,e^\theta\Big[1+\frac{(\lambda\,e^{-\theta})(e^\theta-1)}{1!}+\frac{(\lambda\,e^{-\theta})^2(e^\theta-1)^2}{2!}$$

$$+\frac{(\lambda\,e^{-\theta})^3(e^\theta-1)^3}{3!}+\ldots\Big]\Big\}$$

$$=e^{\lambda(e^{-\theta}-1)}.\theta^2\{\lambda^2+\lambda\}.\{e^{\lambda(1-e^{-\theta})}\}$$

$$=\lambda(\lambda+1)\theta^2.$$

Now $E(r^2)=E\{r\,(r-1)+r\}$

$$=E\{r\,(r-1)\}+E(r)$$

$$=\lambda(\lambda+1)\theta^2+\lambda\theta$$

But the Variance, $\mu_2=E(r^2)-\{E(r)\}^2$

$$=\lambda(\lambda+1)\theta^2+\lambda\theta-\lambda^2\theta^2$$

$$=\lambda\theta(1+\theta)$$

Thus the Variance $\mu_2=\lambda\theta(1+\theta)$

Determination of the Third Moment about the Mean, μ_3

$E\{r(r-1)(r-2)\}$

$$= \sum_{r=0}^{\infty} \{r(r-1)(r-2)P(r)\}$$

$$= e^{\lambda(e^{-\theta}-1)}\left\{\frac{\theta^3}{3!}.3.2.1\left[\frac{(\lambda e^{-\theta})}{1!} + \begin{bmatrix}3\\2\end{bmatrix}\frac{(\lambda e^{-\theta})^2}{2!} + \begin{bmatrix}3\\3\end{bmatrix}\frac{(\lambda e^{-\theta})^3}{3!}\right]\right.$$

$$+ \frac{\theta^4}{4!}.4.3.2\left[\frac{(\lambda e^{-\theta})}{1!} + \begin{bmatrix}4\\2\end{bmatrix}\frac{(\lambda e^{-\theta})^2}{2!} + \begin{bmatrix}4\\3\end{bmatrix}\frac{(\lambda e^{-\theta})^3}{3!} + \begin{bmatrix}4\\4\end{bmatrix}\frac{(\lambda e^{-\theta})^4}{4!}\right]$$

$$+ \frac{\theta^5}{5!}.5.4.3\left[\frac{(\lambda e^{-\theta})}{1!} + \begin{bmatrix}5\\2\end{bmatrix}\frac{(\lambda e^{-\theta})^2}{2!} + \begin{bmatrix}5\\3\end{bmatrix}\frac{(\lambda e^{-\theta})^3}{3!} + \begin{bmatrix}5\\4\end{bmatrix}\frac{(\lambda e^{-\theta})^4}{4!} + \begin{bmatrix}5\\5\end{bmatrix}\frac{(\lambda e^{-\theta})^5}{5!}\right]$$

$$\left. + \cdots \quad \ldots\right\}$$

$$= e^{\lambda(e^{-\theta}-1)}\left\{\theta^3\frac{(\lambda e^{-\theta})}{1!} + \frac{\theta^4}{1!}\frac{(\lambda e^{-\theta})}{1!} + \frac{\theta^5}{2!}\frac{(\lambda e^{-\theta})}{1!} + \ldots\right.$$

$$+ \theta^3\begin{bmatrix}3\\2\end{bmatrix}\frac{(\lambda e^{-\theta})^2}{2!} + \frac{\theta^4}{1!}\begin{bmatrix}4\\2\end{bmatrix}\frac{(\lambda e^{-\theta})^2}{2!} + \frac{\theta^5}{2!}\begin{bmatrix}5\\2\end{bmatrix}\frac{(\lambda e^{-\theta})^2}{2!} + \ldots$$

$$+ \theta^3\begin{bmatrix}3\\3\end{bmatrix}\frac{(\lambda e^{-\theta})^3}{3!} + \frac{\theta^4}{1!}\begin{bmatrix}4\\3\end{bmatrix}\frac{(\lambda e^{-\theta})^3}{3!} + \frac{\theta^5}{2!}\begin{bmatrix}5\\3\end{bmatrix}\frac{(\lambda e^{-\theta})^3}{3!} + \ldots$$

$$+ \frac{\theta^4}{1!}\begin{bmatrix}4\\4\end{bmatrix}\frac{(\lambda e^{-\theta})^4}{4!} + \frac{\theta^5}{2!}\begin{bmatrix}5\\4\end{bmatrix}\frac{(\lambda e^{-\theta})^4}{4!} + \frac{\theta^6}{3!}\begin{bmatrix}6\\4\end{bmatrix}\frac{(\lambda e^{-\theta})^4}{4!} + \ldots$$

$$\left. + \cdots \quad \ldots\right\}$$

$$= \theta^3.e^{\lambda(e^{-\theta}-1)}\left\{\frac{(\lambda e^{-\theta})}{1!}\left[1 + \frac{\theta}{1!} + \frac{\theta^2}{2!} + \ldots\right]\right.$$

$$+ \frac{(\lambda e^{-\theta})^2}{2!}\left[\begin{bmatrix}3\\2\end{bmatrix} + \begin{bmatrix}4\\2\end{bmatrix}\frac{\theta}{1!} + \begin{bmatrix}5\\2\end{bmatrix}\frac{\theta^2}{2!} + \ldots\right]$$

$$+\frac{(\lambda\,e^{-\theta})^3}{3!}\left[\begin{bmatrix}3\\3\end{bmatrix}+\begin{bmatrix}4\\3\end{bmatrix}\frac{\theta}{1!}+\begin{bmatrix}5\\3\end{bmatrix}\frac{\theta^2}{2!}+\dots\right]$$

$$+\frac{(\lambda\,e^{-\theta})^4}{4!}\left[\begin{bmatrix}4\\4\end{bmatrix}\frac{\theta}{1!}+\begin{bmatrix}5\\4\end{bmatrix}\frac{\theta^2}{2!}+\begin{bmatrix}6\\4\end{bmatrix}\frac{\theta^3}{3!}+\dots\right]$$

$$+\cdots\quad\dots\Big\}$$

$$=\theta^3.e^{\lambda(e^{-\theta}-1)}\left\{\frac{(\lambda\,e^{-\theta})}{1!}\,[\qquad e^{\theta}]\right.$$

$$+\frac{(\lambda\,e^{-\theta})^2}{2!}\,[\qquad 3.2.1.e^{2\theta}+2(e^{\theta}-1)^1\,e^{\theta}]$$

$$+\frac{(\lambda\,e^{-\theta})^3}{3!}\,[\quad 3.2.1\,e^{3\theta}+3.3.2(e^{\theta}-1)^1\,e^{2\theta}+3(e^{\theta}-1)^2\,e^{\theta}]$$

$$+\frac{(\lambda\,e^{-\theta})^4}{4!}\,[4.3.2(e^{\theta}-1)^1\,e^{3\theta}+3.4.3(e^{\theta}-1)^2\,e^{2\theta}+4(e^{\theta}-1)^3\,e^{\theta}]$$

$$\left.+\cdots\quad\dots\right\}$$

(By Lemma 5)

$$=\theta^3.e^{\lambda(e^{-\theta}-1)}\left\{(\lambda e^{-\theta})^3.e^{3\theta}\left[1+\frac{(\lambda.\overline{1-e^{-\theta}})^1}{1!}+\frac{(\lambda.\overline{1-e^{-\theta}})^2}{2!}+\dots\right]\right.$$

$$+(\lambda\,e^{-\theta})^2.e^{2\theta}.3\left[1+\frac{(\lambda.\overline{1-e^{-\theta}})^1}{1!}+\frac{(\lambda.\overline{1-e^{-\theta}})^2}{2!}+\dots\right]$$

$$\left.+(\lambda\,e^{-\theta}).e^{\theta}\left[1+\frac{(\lambda.\overline{1-e^{-\theta}})^1}{1!}+\frac{(\lambda.\overline{1-e^{-\theta}})^2}{2!}\right]+\dots\right\}$$

$$=\theta^3.e^{\lambda(e^{-\theta}-1)}\{e^{\lambda(1-e^{-\theta})}[\lambda^3+3\lambda^2+\lambda]\}$$

$$=[\lambda^3+3\lambda^2+\lambda]\theta^3$$

Now, $E(r^3)=E[r.(r-1)(r-2)+3r(r-1)+r]$

$$=E[r(r-1)(r-2)]+3E[r(r-1)]+E(r)$$

$$=[\lambda^3+3\lambda^2+\lambda]\theta^3+3\lambda(\lambda+1)\theta^2+\lambda\theta$$

But the Third Moment,

$$\begin{aligned}\mu_3 &= E(r-\bar{r})^3\\ &= E(r^3) - 3\bar{r}E(r^2) + 3\bar{r}^3 - \bar{r}^3\\ &= [\lambda^3 + 3\lambda^2 + \lambda]\theta^3 + 3\lambda(\lambda+1)\theta^2 + \lambda\theta - 3\lambda\theta[\lambda(\lambda+1)\theta^2 + \lambda\theta]\\ &\qquad + 2\lambda^3\theta^3\\ &= \lambda\theta(1 + 3\theta + \theta^2)\end{aligned}$$

Thus, the Third Moment about the Mean,

$$\mu_3 = \lambda\theta(1 + 3\theta + \theta^2)$$

Fitting the Long Distribution

From the first and second moments, the parameters satisfy the following equations

$$\theta = \frac{\mu_2 - \mu_1'}{\mu_1'}$$

and

$$\lambda = \frac{\mu_1'}{\theta}$$

For a sample of reasonable size, substitution of the sample mean and variance into the above equations provides estimates of the two parameters.

Upon the completion of this distribution, it appeared to have a marked affinity to the Neyman Type A, and after investigation these two distributions proved to be identical. A formal proof to this effect follows.

e The Equivalence of the Neyman Type A (N.T.A.) and the Long Distributions

The N.T.A. distribution gives the probability of an individual suffering an event n times as

$$\Pi_n = e^{-\lambda}\frac{c^n}{n!}\sum_{k=0}^{\infty}\left\{\frac{k^n}{k!}(e^{-c}\lambda)^k\right\}$$

(See, for example, Feller (1943) formula (2.7).)

It will be recalled that the Long distribution gives the corresponding probability, (see formula (6) previously), as

$$P(r) = e^{\lambda(e^{-\theta}-1)} \frac{\theta^r}{r!} \sum_{k=0}^{r} \left\{ \begin{bmatrix} r \\ k \end{bmatrix} \frac{(\lambda e^{-\theta})^k}{k!} \right\}$$

$$= e^{-\lambda} \frac{\theta^r}{r!} . e^{\lambda e^{-\theta}} \sum_{k=0}^{r} \left\{ \begin{bmatrix} r \\ k \end{bmatrix} \frac{(\lambda e^{-\theta})^k}{k!} \right\}$$

In similar notation, the N.T.A. probability reduces to the form

$$P(r) = e^{-\lambda} \frac{\theta^r}{r!} \sum_{k=0}^{\infty} \left\{ \frac{k^r}{k!} (e^{-\theta}\lambda)^k \right\}$$

Thus, in order to establish equivalence, it is necessary to prove

$$e^{\lambda e^{-\theta}} \sum_{k=0}^{r} \left\{ \begin{bmatrix} r \\ k \end{bmatrix} \frac{(\lambda e^{-\theta})^k}{k!} \right\} = \sum_{k=0}^{\infty} \left\{ \frac{k^r}{k!} (\lambda e^{-\theta})^k \right\}$$

The above may be simplified to

R.T.P. $$e^{\chi} \sum_{k=0}^{r} \left\{ \begin{bmatrix} r \\ k \end{bmatrix} \frac{\chi^k}{k!} \right\} = \sum_{k=0}^{\infty} \left\{ \frac{k^r}{k!} . \chi^k \right\}$$

Proof Upon expansion,

$$\text{L.H.S.} = \left(1 + \frac{\chi}{1!} + \frac{\chi^2}{2!} + \dots\right)\left(\begin{bmatrix} r \\ 0 \end{bmatrix} + \begin{bmatrix} r \\ 1 \end{bmatrix} \frac{\chi}{1!} + \begin{bmatrix} r \\ 2 \end{bmatrix} \frac{\chi^2}{2!} + \cdots \right.$$
$$\left. \dots + \begin{bmatrix} r \\ r \end{bmatrix} \frac{\chi^r}{r!}\right)$$

$$= \begin{bmatrix} r \\ 0 \end{bmatrix} + \left\{ \frac{\begin{bmatrix} r \\ 1 \end{bmatrix}}{1!} + \frac{\begin{bmatrix} r \\ 0 \end{bmatrix}}{1!} \right\} \chi + \left\{ \frac{\begin{bmatrix} r \\ 2 \end{bmatrix}}{2!} + \frac{\begin{bmatrix} r \\ 1 \end{bmatrix}}{1!1!} + \frac{\begin{bmatrix} r \\ 0 \end{bmatrix}}{2!} \right\} \chi^2$$
$$+ \left\{ \frac{\begin{bmatrix} r \\ 3 \end{bmatrix}}{3!} + \frac{\begin{bmatrix} r \\ 2 \end{bmatrix}}{2!1!} + \frac{\begin{bmatrix} r \\ 1 \end{bmatrix}}{1!2!} + \frac{\begin{bmatrix} r \\ 0 \end{bmatrix}}{3!} \right\} \chi^3 + \dots$$

$$= \sum_{k=0}^{\infty} C_k \chi^k, \qquad \text{where}$$

$$C_k = \frac{\begin{bmatrix} r \\ k \end{bmatrix}}{k!} + \frac{\begin{bmatrix} r \\ k-1 \end{bmatrix}}{(k-1)!\,1!} + \frac{\begin{bmatrix} r \\ k-2 \end{bmatrix}}{(k-2)!\,2!} + \cdots \dots + \frac{\begin{bmatrix} r \\ 0 \end{bmatrix}}{k!}$$

$$= \frac{k^r - \binom{k}{1}(k-1)^r + \cdots \ldots + (-1)^{k-1}\binom{k}{k-1}.1^r}{\mathrm{k}!}$$

$$+ \frac{(k-1)^r - \binom{k-1}{1}(k-2)^r + \cdots\cdots + (-1)^{k-2}\binom{k-1}{k-2}.1^r}{(k-1)!\,1!}$$

$$+ \frac{(k-2)^r - \binom{k-2}{1}(k-3)^r + \cdots\cdots + (-1)^{k-3}\binom{k-2}{k-3}.1^r}{(k-2)!\,2!}$$

$$+ \cdots\cdots$$

$$= \frac{k^r}{k!} - (k-1)^r\left\{\frac{\binom{k}{1}}{k!} - \frac{1}{(k-1)!\,1!}\right\}$$

$$+ (k-2)^r\left\{\frac{\binom{k}{2}}{k!} - \frac{\binom{k-1}{1}}{(k-1)!1!} + \frac{1}{(k-2)!\,2!}\right\} - \cdots$$

$$= \frac{k^r}{k!} + \sum_{j=1}^{k-1}\{(-1)^j D_j (k-j)^r\}, \qquad \text{where}$$

$$D_j = \frac{\binom{k}{j}}{k!} - \frac{\binom{k-1}{j-1}}{(k-1)!\,1!} + \frac{\binom{k-2}{j-2}}{(k-2)!\,2!} - \cdots + (-1)^j . \frac{1}{(k-j)!\,j!}$$

$$= \frac{1}{j!\,(k-j)!} - \frac{1}{(j-1)!\,(k-j)!\,1!}$$

$$+ \frac{1}{(k-j)!\,(j-2)!\,2!} - \cdots\cdots + (-1)^j . \frac{1}{(k-j)!\,j!}$$

$$= \frac{1}{(k-j)!}\left[\frac{1}{j!\,0!} - \frac{1}{(j-1)!\,1!} + \frac{1}{(j-2)!\,2!} - \cdots \right.$$

$$\left. \cdots + (-1)^j . \frac{1}{0!\,j!}\right]$$

$$= \frac{1}{(k-j)!\,j!}(1-1)^j$$

$$= 0$$

Thus

$$C_k^r = \frac{k^r}{r!}$$

and the L.H.S. = R.H.S., establishing the equivalence.

[q.e.d

Incidentally the following Lemma has been established,

$$k^r = \binom{k}{0}\begin{bmatrix} r \\ k \end{bmatrix} + \binom{k}{1}\begin{bmatrix} r \\ k-1 \end{bmatrix} + \binom{k}{2}\begin{bmatrix} r \\ k-2 \end{bmatrix} + \cdots\cdots + \binom{k}{k}\begin{bmatrix} r \\ 0 \end{bmatrix}$$

for all integral $r \geqq 0$.

f The Short Distribution

It will be recalled that the previously considered model, which led to the Long distribution, (and this being equivalent to the Neyman Type A), precluded the possibility of an accident occurring except during a spell. This restriction is now removed and it is now specifically assumed that accidents *can* happen outside a spell. It is further assumed that such 'pure chance' accidents are Poisson distributed with parameter ϕ, and occur independently of 'spell' accidents.

Then, for the new model,

$$P(0) = e^{-\phi} . e^{\lambda(e^{-\theta}-1)}$$

$$= \exp[\lambda(e^{-\theta} - 1) - \phi]$$

$$P(1) = e^{-\phi}\frac{\phi}{1!}. e^{\lambda(e^{-\theta}-1)} + e^{-\phi}. e^{\lambda(e^{-\theta}-1)}.\frac{\theta}{1!}\frac{(\lambda e^{-\theta})}{1!}$$

$$= \exp[\lambda(e^{-\theta} - 1) - \phi]\cdot\left[\frac{\phi}{1!} + \frac{\theta}{1!}\frac{(\lambda e^{-\theta})}{1!}\right]$$

$$P(2) = e^{-\phi}\frac{\phi^2}{2!}. e^{\lambda(e^{-\theta}-1)} + e^{-\phi}.\frac{\phi}{1!}. e^{\lambda(e^{-\theta}-1)}.\frac{\theta}{1!}\frac{(\lambda e^{-\theta})}{1!}$$

$$+ e^{-\phi}. e^{\lambda(e^{-\theta}-1)}.\frac{\theta^2}{2!}\left\{\frac{(\lambda e^{-\theta})}{1!} + \begin{bmatrix} 2 \\ 2 \end{bmatrix}\frac{(\lambda e^{-\theta})}{2!}\right.$$

$$= \exp[\lambda(e^{-\theta} - 1) - \phi]\cdot\left[\frac{\phi^2}{2!} + \frac{\phi}{1!}\cdot\frac{\theta}{1!}\,\frac{(\lambda\,e^{-\theta})}{1!}\right.$$

$$\left. + \frac{\theta^2}{2!}\left\{\frac{(\lambda\,e^{-\theta})}{1!} + \begin{bmatrix}2\\2\end{bmatrix}\frac{(\lambda\,e^{-\theta})^2}{2!}\right\}\right]$$

In general,

$$P(r) = \exp[\lambda(e^{-\theta} - 1) - \phi]\cdot\left[\frac{\phi^r}{r!} + \frac{\phi^{r-1}}{(r-1)!}\cdot\frac{\theta}{1!}\,\frac{(\lambda\,e^{-\theta})}{1!}\right.$$

$$+ \frac{\phi^{r-2}}{(r-2)!}\cdot\frac{\theta^2}{2!}\left\{\frac{(\lambda\,e^{-\theta})}{1!} + \begin{bmatrix}2\\2\end{bmatrix}\frac{(\lambda\,e^{-\theta})^2}{2!}\right\} + \cdot$$

$$\left. \ldots + \frac{\theta^r}{r!}\left\{\sum_{k=0}^{r}\begin{bmatrix}r\\k\end{bmatrix}\frac{(\lambda\,e^{-\theta})^k}{k!}\right\}\right]$$

It is easily seen that $\sum_{r=0}^{\infty} P(r) = 1$, as is necessary.

Now write μ_1', μ_2 and μ_3 for the first three moments of the Short distribution. Further denote by p, accidents occurring during spells, and by c, accidents occurring outside spells; p' and c' being the deviations from their respective means.

Then,

$$\mu_1' = E(c + p)$$
$$= \phi + \lambda\theta$$
$$\mu_2 = E(c' + p')^2$$
$$= E(c'^2) + 2E(c').E(p') + E(p'^2)$$
$$= \phi + \lambda\theta(1 + \theta)$$
$$\mu_3 = E(c' + p')^3$$
$$= E(c'^3) + 3E(c'^2)E(p') + 3E(c')E(p'^2) + E(p'^3)$$
$$= \phi + \lambda\theta(1 + 3\theta + \theta^2)$$

The above three equations supply the following solutions,

$$\theta = \frac{\mu_3 - \mu_2}{\mu_2 - \mu_1'} - 2$$

$$\lambda = \frac{(\mu_2 - \mu_1')^3}{(\mu_3 - 3\mu_2 + 2\mu_1')^2} = \frac{\mu_2 - \mu_1'}{\theta^2}$$

and

$$\phi = \mu_1' - \frac{(\mu_2 - \mu_1')^2}{(\mu_3 - 3\mu_2 + 2\mu_1')} = \mu_1' - \lambda\theta$$

For a reasonably large sample, substitution of the sample values for the population moments provides estimates of the three parameters θ, λ and ϕ, from which the theoretical distribution can be derived.

The Modified Short Distribution

It is realised that with small samples, the instability of the third moment could lead to very inaccurate estimates for the parameters. In this case it is assumed that it is known that

$$\phi = q\mu_1' \qquad \text{where } 0 \leqq q \leqq 1.$$

This provides solutions for θ and λ as follows.

$$\theta = \frac{\mu_2 - \mu_1'}{\mu_1'(1 - q)}$$

and

$$\lambda = \frac{\mu_1'(1 - q)}{\theta}$$

The ensuing distribution is subsequently termed the Modified Short distribution.

g The Cumulants and Moments of the Long and Short Distributions

Consider the Moment Generating Function for the Long distribution,

$$M_0(t) = \sum_{r=0}^{\infty} e^{tr}.P(r),$$

where

$$P(r) = e^{\lambda(e^{-\theta}-1)} \cdot \frac{\theta^r}{r!} \sum_{k=0}^{r} \left\{ \begin{bmatrix} r \\ k \end{bmatrix} \frac{(\lambda\, e^{-\theta})^k}{k!} \right\} \tag{6}$$

Expansion yields

$$\begin{aligned} M_0(t) = e^{\lambda(e^{-\theta}-1)} \cdot \Big[& e^{0t} + e^t . \theta\{\lambda\, e^{-\theta}\} + e^{2t} . \frac{\theta^2}{2!} \{(\lambda\, e^{-\theta}) + (\lambda\, e^{-\theta})^2\} \\ & + e^{3t} . \frac{\theta^3}{3!} \left\{ (\lambda\, e^{-\theta}) + \begin{bmatrix} 3 \\ 2 \end{bmatrix} \frac{(\lambda\, e^{-\theta})^2}{2!} + (\lambda\, e^{-\theta})^3 \right\} \\ & + e^{4t} . \frac{\theta^4}{4!} \left\{ (\lambda\, e^{-\theta}) + \begin{bmatrix} 4 \\ 2 \end{bmatrix} \frac{(\lambda\, e^{-\theta})^2}{2!} + \begin{bmatrix} 4 \\ 3 \end{bmatrix} \frac{(\lambda\, e^{-\theta})^3}{3!} + (\lambda\, e^{-\theta})^4 \right\} \\ & + \cdots \qquad \ldots \Big] \end{aligned}$$

$$\begin{aligned} = e^{\lambda(e^{-\theta}-1)} \Big[& 1 + (\lambda\, e^{-\theta}) \left\{ (\theta\, e^t) + \frac{(\theta\, e^t)^2}{2!} + \frac{(\theta\, e^t)^3}{3!} + \ldots \right\} \\ & + \frac{(\lambda\, e^{-\theta})^2}{2!} \left\{ (\theta\, e^t)^2 + \begin{bmatrix} 3 \\ 2 \end{bmatrix} \frac{(\theta\, e^t)^3}{3!} + \begin{bmatrix} 4 \\ 2 \end{bmatrix} \frac{(\theta\, e^t)^4}{4!} + \ldots \right\} \\ & + \frac{(\lambda\, e^{-\theta})^3}{3!} \left\{ (\theta\, e^t)^3 + \begin{bmatrix} 4 \\ 3 \end{bmatrix} \frac{(\theta\, e^t)^4}{4!} + \begin{bmatrix} 5 \\ 3 \end{bmatrix} \frac{(\theta\, e^t)^5}{5!} + \ldots \right\} \\ & + \cdots \qquad \ldots \Big] \end{aligned}$$

$$\begin{aligned} = e^{\lambda(e^{-\theta}-1)} . \Big[& 1 + \frac{(\lambda\, e^{-\theta})(e^{\theta e^t} - 1)}{1!} + \frac{(\lambda\, e^{-\theta})^2 (e^{\theta e^t} - 1)^2}{2!} \\ & + \frac{(\lambda\, e^{-\theta})^3 (e^{\theta e^t} - 1)^3}{3!} + \ldots \Big] \end{aligned}$$

(By Lemma 2)

$$= \exp[\lambda(e^{-\theta} - 1)] . \exp[(\lambda\, e^{-\theta})(e^{\theta e^t} - 1)]$$

$$= \exp \lambda[e^{\theta(e^t - 1)} - 1] \tag{7}$$

It is seen immediately for the Long distribution that the cumulative function is

$$K(t) = \lambda\{e^{\theta(e^t - 1)} - 1\}.$$

Further, since in the Short distribution pure chance accidents are assumed to be independent of 'personal' accidents, the cumulative function for the Short distribution is

$$K(t) = \lambda\{e^{\theta(e^t - 1)} - 1\} + \phi(e^t - 1) \, .$$

Taking logarithms in Equation (7), we obtain

$$\begin{aligned}
K(t) &= \log M(t) \\
&= \lambda\{e^{\theta(e^t-1)} - 1\} \\
&= \lambda\left\{\theta(e^t - 1) + \frac{\theta^2}{2!}(e^t - 1)^2 + \frac{\theta^3}{3!}(e^t - 1)^3 + \frac{\theta^4}{4!}(e^t - 1)^4 + \ldots\right\} \\
&= \lambda\Bigg\{\theta\left(\frac{t}{1!} + \frac{t^2}{2!} + \frac{t^3}{3!} + \frac{t^4}{4!} + \ldots\right) \\
&\qquad + \frac{\theta^2}{2!}\left(t^2 + \begin{bmatrix}3\\2\end{bmatrix}\frac{t^3}{3!} + \begin{bmatrix}4\\2\end{bmatrix}\frac{t^4}{4!} + \ldots\right) \\
&\qquad\qquad + \frac{\theta^3}{3!}\left(t^3 + \begin{bmatrix}4\\3\end{bmatrix}\frac{t^4}{4!} + \ldots\right) \\
&\qquad\qquad\qquad + \frac{\theta^4}{4!}\left(t^4 + \ldots\right) \\
&\qquad\qquad\qquad + \cdots \qquad \ldots \Bigg\}
\end{aligned}$$

(By Lemma 2)

$$\begin{aligned}
&= \lambda\Bigg\{\frac{t}{1!}\theta + \frac{t^2}{2!}(\theta + \theta^2) + \frac{t^3}{3!}\left(\theta + \frac{\theta^2}{2!}\begin{bmatrix}3\\2\end{bmatrix} + \theta^3\right) \\
&\qquad + \frac{t^4}{4!}\left(\theta + \frac{\theta^2}{2!}\begin{bmatrix}4\\2\end{bmatrix} + \frac{\theta^3}{3!}\begin{bmatrix}4\\3\end{bmatrix} + \theta^4\right) + \ldots\Bigg\} \\
&= \sum_{r=1}^{\infty} \kappa_r . \frac{t^r}{r!} \, .
\end{aligned}$$

Thus the r^{th} cumulant of the Long distribution is

$$\kappa_r = \lambda\theta \sum_{i=1}^{r} \left\{\frac{\theta^{i-1}}{i!}\begin{bmatrix}r\\i\end{bmatrix}\right\} \tag{8}$$

In passing, it is clear that the cumulants of the Short distribution are as follows—

$$\kappa_r = \lambda\theta \sum_{i=1}^{r} \left\{ \frac{\theta^{i-1}}{i!} \begin{bmatrix} r \\ i \end{bmatrix} \right\} + \phi \tag{9}$$

The first six cumulants of the Long distribution are—

$$\begin{aligned}
\kappa_1 &= \lambda\theta \\
\kappa_2 &= \lambda\theta(1+\theta) \\
\kappa_3 &= \lambda\theta(1+3\theta+\theta^2) \\
\kappa_4 &= \lambda\theta(1+7\theta+6\theta^2+\theta^3) \\
\kappa_5 &= \lambda\theta(1+15\theta+25\theta^2+10\theta^3+\theta^4) \\
\kappa_6 &= \lambda\theta(1+31\theta+90\theta^2+65\theta^3+15\theta^4+\theta^5)
\end{aligned} \tag{10}$$

In computation of higher moments of either distribution, it is more convenient to evaluate the cumulants first and then utilise the well-known relationships,

$$\begin{aligned}
\mu_1' &= \kappa_1' \\
\mu_2 &= \kappa_2 \\
\mu_3 &= \kappa_3 \\
\mu_4 &= \kappa_4 + 3\kappa_2^2 \\
\mu_5 &= \kappa_5 + 10\kappa_2\kappa_3 \\
\mu_6 &= \kappa_6 + 10\kappa_3^2 + 15\kappa_2(\kappa_4+\kappa_2^2)
\end{aligned} \tag{11}$$

It is immediately seen that the first three moments of the Long and Short distributions are as obtained before.

Because of the complexity of the moments, it seems better to refrain from any attempt to express the (Long and) Short distribution moments in terms of the parameters (beyond the first three already given) and to utilise in computation the relationships 8–11 above.

h Standard Errors of the Moment Estimators of the Short Distribution Parameters for a Large Sample

Suppose ξ is the moment estimator of parameter ξ.
Formally, if m_1', m_2 and m_3 are the moments, let

$$\xi = \xi(m_1', m_2, m_3).$$

Then for a large sample, approximately

$$\operatorname{Var}(\xi) = \left(\frac{\partial \xi}{\partial m_1'}\right)^2 \operatorname{Var}(m_1') + \left(\frac{\partial \xi}{\partial m_2}\right)^2 \operatorname{Var}(m_2)$$

$$+ \left(\frac{\partial \xi}{\partial m_3}\right)^2 \operatorname{Var}(m_3) + 2\left(\frac{\partial \xi}{\partial m_1'}\right)\left(\frac{\partial \xi}{\partial m_2}\right) \operatorname{Cov}(m_1', m_2)$$

$$+ 2\left(\frac{\partial \xi}{\partial m_1'}\right)\left(\frac{\partial \xi}{\partial m_3}\right)\operatorname{Cov}(m_1', m_3) + 2\left(\frac{\partial \xi}{\partial m_2}\right)\left(\frac{\partial \xi}{\partial m_3}\right)\operatorname{Cov}(m_2, m_3) \quad (12)$$

The following expressions for the variances and covariances of the first three sample moments may be readily deduced for a large sample of size n,

$$\operatorname{Var}(m_1') = \frac{\mu_2}{n}$$

$$\operatorname{Var}(m_2) = \frac{(\mu_4 - \mu_2^2)}{n}$$

$$\operatorname{Var}(m_3) = \frac{(\mu_6 - \mu_3^2 + 9\mu_2^3 - 6\mu_2\mu_4)}{n}$$

$$\operatorname{Cov}(m_1', m_2) = \frac{\mu_3}{n}$$

$$\operatorname{Cov}(m_1', m_3) = \frac{(\mu_4 - 3\mu_2^2)}{n}$$

and

$$\operatorname{Cov}(m_2, m_3) = \frac{(\mu_5 - 4\mu_2\mu_3)}{n} \quad (13)$$

The moment estimators of the Short distribution parameters are

$$\bar{\theta} = \frac{m_3 - m_2}{m_2 - m_1'} - 2$$

$$\bar{\lambda} = \frac{(m_2 - m_1')^3}{(m_3 - 3m_2 + 2m_1')^2}$$

and

$$\bar{\Phi} = m_1' - \left\{\frac{(m_2 - m_1')^2}{(m_3 - 3m_2 + 2m_1')}\right\}$$

Partial differentiation with respect to m_1', m_2 and m_3 in succession yields

$$\frac{\partial\bar{\theta}}{\partial m_1'} = \frac{(m_3 - m_2)}{(m_2 - m_1')^2}$$

$$\frac{\partial\bar{\theta}}{\partial m_2} = \frac{(m_1' - m_3)}{(m_2 - m_1')^2} \qquad 14(\bar{\theta})$$

$$\frac{\partial\bar{\theta}}{\partial m_3} = \frac{1}{(m_2 - m_1')}$$

$$\frac{\partial\bar{\lambda}}{\partial m_1'} = -\frac{(m_2 - m_1')^2(3m_3 - 5m_2 + 2m_1')}{(m_3 - 3m_2 + 2m_1')^3}$$

$$\frac{\partial\bar{\lambda}}{\partial m_2} = \frac{3(m_2 - m_1')^2(m_3 - m_2)}{(m_3 - 3m_2 + 2m_1')^3} \qquad 14(\bar{\lambda})$$

$$\frac{\partial\bar{\lambda}}{\partial m_3} = -2\left\{\frac{m_2 - m_1'}{m_3 - 3m_2 + 2m_1'}\right\}^3$$

$$\frac{\partial\bar{\phi}}{\partial m_1'} = 1 + 2\frac{(m_2 - m_1')(m_3 - 2m_2 + m_1')}{(m_3 - 3m_2 + 2m_1')^2}$$

$$\frac{\partial\bar{\phi}}{\partial m_2} = -\frac{(m_2 - m_1')(2m_3 - 3m_2 + m_1')}{(m_3 - 3m_2 + 2m_1')^2} \qquad 14(\bar{\phi})$$

$$\frac{\partial\bar{\phi}}{\partial m_3} = \left\{\frac{m_2 - m_1'}{m_3 - 3m_2 + 2m_1'}\right\}^2$$

The substitution of information from equations (13) and (14) into equation (12), with $\xi = \theta$, λ and ϕ in succession, leads to estimates of the standard errors required.

Table 13.1 $\dfrac{\begin{bmatrix} r \\ k \end{bmatrix}}{k!}$

r \ k	1	2	3	4	5	6	7	8	9	10	11	12
1	1											
2	1	1										
3	1	3	1									
4	1	7	6	1								
5	1	15	25	10	1							
6	1	31	90	65	15	1						
7	1	63	301	350	140	21	1					
8	1	127	966	1701	1 050	266	28	1				
9	1	255	3 025	7 770	6 951	2 646	462	36	1			
10	1	511	9 330	34 105	42 525	22 827	5 880	750	45	1		
11	1	1 023	28 501	145 750	246 730	179 487	63 987	11 880	1 155	55	1	
12	1	2 047	86 526	611 501	1 379 400	1 323 652	627 396	159 027	22 275	1 705	66	1

Table 13.1 is abridged from Table XXII of FISHER & YATES: "*Statistical Tables for Biological, Agricultural and Medical Research*" published by Oliver & Boyd Ltd., Edinburgh, and by permission of the authors and publishers.

Table 13.2 *Distribution Parameters and their Standard Errors*

Population	*Distribution*									
	Negative Binomial				*Short*					
	p	σ_p	c	σ_c	λ	σ_λ	θ	σ_θ	ϕ	σ_ϕ
U.T.A. (Excluding Ballymena, Derry and Newry) Bus Drivers	4·574	0·804	1·995	0·356	1·393	2·109	0·908	0·719	1·027	0·924
U.T.A. Ballymena Bus Drivers	8·143	5·557	3·689	2·532	0·055	0·125	3·304	3·704	2·026	0·262
U.T.A. Derry Bus Drivers	4·523	1·760	1·658	0·656	1·215	3·617	1·164	1·827	1·314	2·021
U.T.A. Newry Bus Drivers	5·753	2·584	1·606	0·732	0·454	1·028	2·217	2·686	2·576	1·110
B.C.T. Omnibus Drivers	5·484	1·478	1·371	0·375	0·634	0·939	2·146	1·704	2·640	0·968
B.C.T. Trolley-Bus Drivers	4·413	0·881	0·992	0·203	0·394	0·345	3·372	1·625	3·118	0·552

Table 13.3 *The Parameters of the Various Theoretical Distributions*

Distribution and Parameters		*U.T.A. (Excluding Ballymena, Derry and Newry)*			*U.T.A. Derry*			*B.C.T. Omnibus*			*B.C.T. Trolley-Bus*		
		1952–3	*1954–5*	*1952–5*	*1952–3*	*1954–5*	*1952–5*	*1952–3*	*1954–5*	*1952–5*	*1952–3*	*1954–5*	*1952–5*
Poisson	m	1·291	1·001	2·292	1·509	1·219	2·728	1·956	2·044	4·000	2·299	2·148	4·447
Negative	p	5·461	5·221	4·574	4·024	6·391	4·523	6·273	4·791	5·484	3·523	4·878	4·413
Binomial	c	4·230	5·213	1·995	2·667	5·242	1·658	3·207	2·344	1·371	1·532	2·271	0·992
Long =	θ	0·236	0·192	0·501	0·375	0·191	0·603	0·312	0·427	0·730	0·653	0·440	1·008
N.T.A.	λ	5·461	5·221	4·574	4·024	6·391	4·523	6·273	4·788	5·483	3·523	4·878	4·413
Short and	ϕ	0·578	0·449	1·027	0·724	0·585	1·314	1·291	1·349	2·640	1·609	1·503	3·118
Modified	θ	0·428	0·347	0·908	0·721	0·367	1·164	0·917	1·256	2·146	2·176	1·467	3·372
Short	λ	1·664	1·591	1·393	1·088	1·728	1·215	0·725	0·553	0·634	0·317	0·439	0·394
$\frac{\phi}{m}\%$		Modified Short		45%	Modified Short		48%	Modified Short		66%	Modified Short		70%

Table 13.4 *The Parameters of the Various Theoretical U.T.A. Distributions*

Distribution and Parameters		*U.T.A. (Excluding Ballymena, Derry and Newry)*			*U.T.A. Ballymena*			*U.T.A. Derry*			*U.T.A. Newry*		
		1952–3	*1954–5*	*1952–5*	*1952–3*	*1954–5*	*1952–5*	*1952–3*	*1954–5*	*1952–5*	*1952–3*	*1954–5*	*1952–5*
Poisson	m	1·291	1·001	2·292	1·387	0·821	2·208	1·509	1·219	2·728	1·911	1·671	3·582
Negative	p	5·461	5·221	4·574	1 439·515	8·308	8·143	4·024	6·391	4·523	11·372	14·282	5·753
Binomial	c	4·230	5·213	1·995	1 038·018	10·123	3·689	2·667	5·242	1·658	5·950	8·548	1·606
Long =	θ	0·236	0·192	0·501	0·001	0·099	0·271	0·375	0·191	0·603	0·168	0·117	0·623
N.T.A.	λ	5·461	5·221	4·574	1 440·075	8·308	8·143	4·024	6·391	4·523	11·372	14·282	5·753
Short and	ϕ	0·578	0·449	1·027	1·273	0·753	2·026	0·724	0·585	1·314	1·374	1·201	2·576
Modified	θ	0·428	0·347	0·908	0·012	1·205	3·304	0·721	0·367	1·164	0·598	0·416	2·217
Short	λ	1·664	1·591	1·393	9·680	0·056	0·055	1·088	1·728	1·215	0·898	1·128	0·454
$\frac{\phi}{m}\%$		Modified Short		45%	Modified Short		92%	Modified Short		48%	Modified Short		72%

Section 5

Appendix

Data comparable to those of the present study have seldom become available. Consequently we decided to publish as much of the raw data as practicable to allow other workers to subject them to alternative methods of analysis, or to use them for comparison with their own findings. Also, some readers may find it convenient to have readily available the details of how to fit the various distributions in practice.

In some instances the figures may seem to have been carried to an excessive number of decimal places. Since these were 'working' figures and the final results depended on somewhat complicated manipulation, it was decided that it might confuse the reader, endeavouring to retrace the steps in the calculation, if premature rounding were introduced.

Frequently, lengthy calculations were involved. In these instances Ferranti 'Pegasus' Autocode programmes were written to obtain the presented results.

INDEX TO THE APPENDIX

U.T.A. Route Analysis

Table A.1 *Accidents on U.T.A. Omnibus Routes (1954–1955)* Numbers of Accidents, Mileages and Accident Rates (per million miles)

Group of Rotas (Area)	*1954*			*1955*		
	No.	*Mileage*	*A/R.*	*No.*	*Mileage*	*A/R.*
Urban Derry	42	244 857	171·5	42	304 773	137·8
Rest of Derry City	29	1 146 237	25·3	33	1 166 363	28·3
All Derry City	71	1 391 093	51·0	75	1 471 136	51·0
Rest of Co. Derry	73	2 605 643	28·0	57	2 607 927	21·9
Ballymena	16	1 088 648	14·7	12	1 072 907	11·2
Rest of Ballymena	31	2 254 764	13·7	42	2 270 558	18·5
Ballynahinch	36	1 937 104	18·6	48	1 946 546	24·7
Bangor	18	1 073 848	16·8	28	988 164	28·3
Coleraine	55	1 787 864	30·8	55	1 793 636	30·7
Downpatrick	56	2 039 136	27·5	60	2 022 567	29·7
Dungannon	46	1 913 383	24·0	52	1 917 037	27·1
Lisburn	33	1 556 727	21·2	30	1 555 659	19·3
Rest of Lisburn	25	1 427 776	17·5	32	1 419 819	22·5
Lurgan	55	1 320 298	41·7	34	1 329 051	25·6
Newry	67	1 702 202	39·4	68	1 709 235	39·8
Newtownards	15	847 305	17·7	16	830 056	19·3
Rest of Newtownards	53	2 106 199	25·2	39	2 083 600	18·7
Portadown	27	943 021	28·6	46	936 578	49·1
Smithfield No. 1	62	2 087 510	29·7	46	2 031 798	22·6
Smithfield No. 2	61	2 678 311	22·8	66	2 739 575	24·1
Total	800	30 760 832	26·0	806	30 725 849	26·2

N.B. Any apparent discrepancies in total mileages are due to rounding-off.

Table A.2 *Square Root Accident Rate*

Group of Rotas (Area)	*1954*	*1955*	*Total*	*Area Mean*
Ballymena	3·834 1	3·346 6	7·180 7	3·590 4
Rest of Ballymena	3·701 4	4·301 2	8·002 6	4·001 3
Ballynahinch	4·312 8	4·969 9	9·282 7	4·641 4
Bangor	4·098 8	5·319 8	9·418 6	4·709 3
Coleraine	5·549 8	5·540 8	11·090 6	5·545 3
Derry City	7·141 4	7·141 4	14·282 8	7·141 4
Rest of Co. Derry	5·291 5	4·679 7	9·971 2	4·985 6
Downpatrick	5·244 0	5·449 8	10·693 8	5·346 9
Dungannon	4·899 0	5·205 8	10·104 8	5·052 4
Lisburn	4·604 3	4·393 2	8·997 5	4·498 8
Rest of Lisburn	4·183 3	4·743 4	8·926 7	4·463 4
Lurgan	6·457 6	5·059 6	11·517 2	5·758 6
Newry	6·276 9	6·308 7	12·585 6	6·292 8
Newtownards	4·207 1	4·393 2	8·600 3	4·300 2
Rest of Newtownards	5·020 0	4·324 3	9·344 3	4·672 2
Portadown	5·347 9	7·007 1	12·355 0	6·177 5
Smithfield No. 1	5·449 8	4·753 9	10·203 7	5·101 9
Smithfield No. 2	4·774 9	4·909 2	9·684 1	4·842 1
Total	90·394 6	91·847 6	182·242 2	
Mean	5·021 9	5·102 6	10·124 6	5·062 3

Sums of Squares

1. $\sum$ individuals^2 = 952·999 327
2. $\sum$ Area totals^2/2 = 948·440 088
3. $\sum$ Year totals^2/18 = 922·620 296
4. Grand total^2/36 = 922·561 651

Table A.3 *Analysis of Variance*

Source	*Sums of Squares*	*D.F.*	*Mean Squares*	*V.R.*
Between Areas	25·878 437	17	1·522 261	5·75***
Between Years	0·058 645	1		
Residual	4·500 594	17	0·264 741	
Total	30·437 676	35		

The variance ratio of 5·75 was very highly significant on the 0·1 per cent level, so it was concluded that there was a significant difference between Areas (and no difference between the two years). The next question was, what Areas could not be regarded as having the same accident rate as the rest?

Where e referred to the Residual,

$$\frac{(\sigma_e)^2}{2} = 0{\cdot}132\ 37$$

and $$\frac{\sigma_e}{\sqrt{2}} = 0{\cdot}363\ 85$$

Thus the 99 per cent control limits for Area means were:

lower limit = 4·007 9, and upper limit = 6·116 7.

This suggested that Ballymena, Rest of Ballymena Area, Derry City, Newry and Portadown had accident rates different from the rest.

Seeing that Derry City was so very different from the rest, the analysis was repeated, omitting Derry City.

U.T.A. Areas (Omitting Derry City)

Table A.4 *Analysis of Variance*

Source	*Sums of Squares*	*D.F.*	*Mean Squares*	*V.R.*
Between Areas	16·724 428	16	1·045 277	3·72**
Between Years	0·062 094	1		
Residual	4·497 145	16	0·281 072	
Total	21·283 667	33		

The variance ratio of 3·72 was highly significant on the 1 per cent level. Hence there was still a difference between Areas.

The 99 per cent control limits for Area means of 3·827 7 and 6·052 3 showed Ballymena, Portadown and Newry to be different from the rest.

Seeing that the mean had now been reduced, a fresh analysis was made, this time omitting Portadown and Newry as well as Derry City. (Table A.5)

The variance ratio of 2·86 was significant on the 5 per cent level. Hence there was again a difference between Areas.

The 99 per cent control limits for Area means of 3·763 9 and 5·770 7 showed Ballymena to be still different from the rest.

The further omission of Ballymena would clearly have the effect of

U.T.A. Areas (Omitting Derry City, Portadown and Newry)

Table A.5 *Analysis of Variance*

Source	*Sums of Squares*	*D.F.*	*Mean Squares*	*V.R.*
Between Areas	9·106 653	14	0·650 475	2·86*
Between Years	0·001 889	1		
Residual	3·180 372	14	0·227 169	
Total	12·288 914	29		

raising the mean and consequently the analysis was again repeated, this time omitting both Ballymena and the Rest of Ballymena, in addition to those already omitted.

U.T.A. Areas (Omitting Derry City, Portadown, Newry, Ballymena, and Rest of Ballymena Area)

Table A.6 *Analysis of Variance*

Source	*Sums of Squares*	*D.F.*	*Mean Squares*	*V.R.*
Between Areas	4·581 999	12	0·381 833	1·59
Between Years	0·004 719	1		
Residual	2·878 834	12	0·239 903	
Total	7·465 552	25		

The variance ratio of 1·59 was now not significant. Hence there was no reason to doubt that the remaining Areas might be regarded as offering equal risks to a driver.

The 99 per cent control limits for Area means of 3·858 5 and 5·975 1 embraced all of the remaining Area means. Furthermore, the 95 per cent control limits of 4·162 0 and 5·671 6 were such that Lurgan was only just excluded. Seeing that 13 Areas were analysed, this seemed reasonable.

Thus the U.T.A. drivers fell naturally into four separate 'equal risk' populations, viz.

(1) Ballymena (and the Rest of Ballymena)
(2) Newry (and Portadown)
(3) Derry
and (4) the Rest, (wherever subsequently U.T.A. is mentioned, this population is meant).

Table A.7 *Accidents on U.T.A. Double-Deck and Single-Deck Bus Routes* (1954–1955). Numbers of Accidents, Mileages and Accident Rate (per million miles)

	Double-Deck Buses			*Single-Deck Buses*		
Rota Group	*No. of Accidents*	*Mileage*	*Accident Rate*	*No. of Accidents*	*Mileage*	*Accident Rate*
Portadown	6	288 715	26·2	48	1 496 155	32·1
Ballymoney	6	136 200	44·1	13	258 623	50·3
Portrush	6	242 528	24·7	13	383 280	33·9
Coleraine	12	448 574	26·8	28	700 403	40·0
Ballyclare	10	374 247	26·7	23	1 181 700	19·5
Total	40	1 430 264	28·0	125	4 020 160	31·1

Table A.8 *Analysis of Variance*

Source of Variance	*Sums of Squares*	*D.F.*	*Mean Squares*	*V.R.*
Between Rota Groups	653·40	4	163·35	5·59
Between Bus-Types	74·53	1	74·53	2·55
Residual	116·92	4	29·23	
Total	844·85	9		

Both variance ratios of 5·59 and 2·55 were not significant, so it was concluded that the accident rate was irrespective of whether double- or single-deck buses were employed on any particular Rota.

B.C.T. Omnibus Route Analysis

Table A.9 *Accidents on B.C.T. Omnibus Routes (1954–1955)*
Numbers of Accidents, Mileages (1954) and Accident Rates (per million miles)

Route Group	*1954*			*1955*	
	No.	*Mileage*	*A/R*	*No.*	*A/R*
Aircraft, Queen's Road. & R.N.A.S.	72	871 116	82·7	92	105·6
Ardoyne & Springfield	41	778 798	52·7	35	44·9
Ballygomartin	21	353 479	59·4	21	59·4
Cavehill	17	522 154	32·6	17	32·6
Cherryvalley	31	508 049	61·0	42	82·7
Crumlin	38	702 470	54·1	44	62·6
Donegall Road	34	579 267	58·7	28	48·3
Downview	13	246 424	52·8	16	64·9
Gas Works	30	551 038	54·4	30	54·4
Lisburn Road	62	1 009 242	61·4	57	56·5
L.M.S., Duncrue Street & Cross-Channel Boats	10	112 670	88·8	4	35·5
Oldpark & Carr's Glen	32	658 434	48·6	39	59·2
Ormeau	36	692 601	52·0	30	43·3
Ravenhill	17	332 144	51·2	22	66·2
Shankill	32	762 118	42·0	45	59·1
Stranmillis & Malone	25	844 037	29·6	30	35·5
Sydenham & Stormont	16	355 509	45·0	37	104·1
Total	527	9 879 550	53·3	589	59·6

An Analysis of Variance was employed in the sequel to analyse the above data, which were first transformed to the square root.

Table A.10 *Square Root Accident Rate*

Route Group	*1954*	*1955*	*Total*
Aircraft, Queen's Road, & R.N.A.S.	9·091 3	10·276 0	19·367 3
Ardoyne & Springfield	7·256 0	6·703 7	13·959 7
Ballygomartin	7·707 7	7·707 7	15·415 4
Cavehill	5·706 1	5·706 1	11·412 2
Cherryvalley	7·811 5	9·092 4	16·903 9
Crumlin	7·355 3	7·914 5	15·269 8
Donegall Road	7·661 6	6·952 7	14·614 3
Downview	7·263 6	8·058 0	15·321 6
Gas Works	7·378 3	7·378 3	14·756 6
Lisburn Road	7·836 7	7·515 3	15·352 0
L.M.S., Duncrue Street & Cross-Channel Boats	9·421 3	5·958 2	15·379 5
Oldpark & Carr's Glen	6·971 4	7·696 1	14·667 5
Ormeau	7·209 7	6·581 1	13·790 8
Ravenhill	7·154 0	8·138 8	15·292 8
Shankill	6·479 9	7·684 3	14·164 2
Stranmillis & Malone	5·442 4	5·961 6	11·404 0
Sydenham & Stormont	6·708 9	10·203 0	16·911 9
Total	124·455 7	129·527 8	253·983 5

Table A.11 *Analysis of Variance*

Source	*Sums of Squares*	*D.F.*	*Mean Squares*	*V.R.*
Between Groups	28·180 098	16	1·761 256	1·81
Between Years	0·756 653	1		
Residual	15·598 833	16	0·974 927	
Total	44·535 584	33		

The variance ratio of 1·81 was not significant on the 5 per cent level, hence it might be concluded that there was no difference between Groups of Routes, or between Years, for B.C.T. omnibus routes.

The 95 per cent control limits for (two year) totals were 11·979 8 and 17·900 6. Cavehill and Stanmillis lay just below the lower limit, whereas the Aircraft route was well over the upper limit. In fact, the latter exceeded the appropriate 99 per cent control limit

(19·019 1), but since journeys on this route only occurred at peak periods and all drivers were liable to drive there, it could be concluded that all drivers faced approximately equal hazards.

B.C.T. Trolley-Bus Route Analysis

Table A.12 *Accidents on B.C.T. Trolley-Bus Routes (1954–1955)* Numbers of Accidents, Mileage (1954) and Accident Rates (per million miles)

Route Group	*1954*			*1955*	
	No.	*Mileage*	*A/R*	*No.*	*A/R*
Bloomfield	17	343 717	49·5	24	69·8
Carr's Glen	31	613 761	50·5	48	78·2
Castlereagh	49	647 327	75·7	61	94·2
Cregagh	49	740 655	66·2	52	70·2
Dundonald	56	1 003 005	55·8	55	54·8
Falls	61	1 050 280	58·1	74	70·5
Glengormley	55	1 363 606	40·3	61	44·7
Greencastle	43	1 077 912	39·9	54	50·1
Ormeau	33	551 201	59·9	18	32·7
Stormont	67	1 066 850	62·8	71	66·6
Total	461	8 458 314	54·5	518	61·2

An Analysis of Variance was employed in the sequel to analyse the above data, which were first transformed to the square root.

Table A.13 *Square Root Accident Rate*

Route Group	*1954*	*1955*	*Total*
Bloomfield	7·032 8	8·355 8	15·388 6
Carr's Glen	7·107 0	8·843 7	15·950 7
Castlereagh	8·700 6	9·707 2	18·407 8
Cregagh	8·133 8	8·379 1	16·512 9
Dundonald	7·471 9	7·405 4	14·877 3
Falls	7·621 0	8·394 0	16·015 0
Glengormley	6·350 6	6·688 0	13·038 6
Greencastle	6·315 8	7·078 1	13·393 9
Ormeau	7·737 6	5·714 9	13·452 5
Stormont	7·924 6	8·157 9	16·082 5
Total	74·395 7	78·724 1	153·119 8

Table A.14 *Analysis of Variance*

Source	*Sums of Squares*	*D.F.*	*Mean Squares*	*V.R.*
Between Groups	12·510 991	9	1·390 110	2·66
Between Years	0·936 752	1		
Residual	4·704 501	9	0·522 722	
Total	18·152 245	19		

The variance ratio of 2·66 was not significant on the 5 per cent level, hence it might be concluded that there was no difference between Groups of Routes, or between Years, for B.C.T. trolley-bus routes.

The 95 per cent control limits for (two year) totals were 12·999 0 and 17·625 0. Only Castlereagh exceeded the upper limit but it lay well inside the appropriate 99 per cent control limit (18·635 3), so it could be taken that trolley-bus drivers faced roughly equal hazards, whatever the route.

Accidents of Different Types—B.C.T. Bus Drivers (1951–1955)
The Correlation between 'Collision' Accidents and All Other Accidents

The correlation coefficient (r) = 0·813, and to test its significance an analysis of variance was employed, as follows.

Let x denote the total number of 'Collision' accidents corresponding to y, the total number of all other accidents, summed over all drivers in a cell. Then, summing over all cells:

$$\sum x = 125 \qquad \sum x^2 = 1\,755$$

$$\sum y = 611 \qquad \sum y^2 = 43\,117$$

$$\sum xy = 7\,964$$

Then of the total variance, $(\sigma_y)^2 = \sum y^2 - (1/16)(\sum y)^2$, the regression accounted for

$$\frac{(\sigma_{xy})^4}{(\sigma_x)^2} = \frac{[\sum xy - (1/16)\sum x \sum y]^2}{\sum x^2 - (1/16)(\sum x)^2}$$

Table A.15 *Analysis of Variance*

Source	*D.F.*	*Sums of Squares*	*Mean Squares*	*V.R*
Regression	1	13 077·080		27·29***
Residual	14	6 707·358	479·097	
Total	15	19 784·438		

The variance ratio of 27·29 is very highly significant on the 0·1 per cent level and hence the correlation was established.

Accidents of Different Types—B.C.T. Trolley-Bus Drivers

(a) *The Correlation between 'Collision' Accidents and All Other Accidents*

The correlation coefficient (r) = 0·927, and to test its significance an Analysis of Variance was employed as before.

Table A.16 *Analysis of Variance*

Source	*D.F.*	*Sums of Squares*	*Mean Squares*	*V.R.*
Regression	1	39 538·355		92·16***
Residual	15	6 435·410	429·027	
Total	16	45 973·765		

The variance ratio of 92·16 is easily very highly significant on the 0·1 per cent level and hence the correlation was established.

(b) *The Correlation between Pedestrian Accidents and All Other Accidents*

The correlation coefficient (r) = 0·358, and to test its significance a similar Analysis of Variance was employed.

Table A.17 *Analysis of Variance*

Source	*D.F.*	*Sums of Squares*	*Mean Squares*	*V.R.*
Regression	1	8 375·021		2·21
Residual	15	56 786·038	3 785·736	
Total	16	65 161·059		

The significance of the variance ratio of 2·21 lay between the 20 and the 10 per cent levels. Thus the correlation was not established on the 5 per cent level.

Table A.18 *Numbers of Accidents and U.T.A. Bus Drivers (1952–1955); by Age and Experience.*

Men Driving From	*Men Born In*											
	1908		*1911*		*1914*		*1917*		*1920*		*Total*	
1948	1952	18	1952	35	1952	31	1952	41	1952	59	1952	184
	1953	18	1953	18	1953	27	1953	28	1953	55	1953	146
	1954	27	1954	22	1954	22	1954	24	1954	62	1954	157
	1955	9	1955	14	1955	24	1955	14	1955	35	1955	96
											Total	583
	No. of Men	26	No. of Men	35	No. of Men	37	No. of Men	43	No. of Men	78	No. of Men	219
1945	1952	14	1952	12	1952	20	1952	20	1952	20	1952	86
	1953	5	1953	14	1953	14	1953	20	1953	19	1953	72
	1954	8	1954	14	1954	15	1954	19	1954	23	1954	79
	1955	4	1955	9	1955	11	1955	12	1955	11	1955	47
											Total	284
	No. of Men	15	No. of Men	22	No. of Men	31	No. of Men	29	No. of Men	29	No. of Men	126
1942	1952	29	1952	21	1952	35	1952	25	1952	20	1952	130
	1953	28	1953	29	1953	31	1953	9	1953	20	1953	117
	1954	22	1954	29	1954	27	1954	21	1954	17	1954	116
	1955	11	1955	11	1955	21	1955	14	1955	19	1955	76
											Total	439
	No. of Men	37	No. of Men	43	No. of Men	50	No. of Men	34	No. of Men	38	No. of Men	202
Total											*Grand Total*	
	1952	61	1952	68	1952	86	1952	86	1952	99	1952	400
	1953	51	1953	61	1953	72	1953	57	1953	94	1953	335
	1954	57	1954	65	1954	64	1954	64	1954	102	1954	352
	1955	24	1955	34	1955	56	1955	40	1955	65	1955	219
	Total	193	Total	228	Total	278	Total	247	Total	360	Total	1306
	No. of Men	78	No. of Men	100	No. of Men	118	No. of Men	106	No. of Men	145	No. of Men	547

Table A.19 *Accident Rates of U.T.A. Bus Drivers (1952–1955); by Age and Experience.*

Men Driving From	*Year*	*Men Born In*					
		1908	*1911*	*1914*	*1917*	*1920*	*Average*
1948	1952	0·692	1·000	0·838	0·953	0·756	0·840
	1953	0·692	0·514	0·730	0·651	0·705	0·667
	1954	1·038	0·629	0·595	0·558	0·795	0·717
	1955	0·346	0·400	0·649	0·326	0·449	0·438
	Average	0·692	0·636	0·703	0·622	0·676	0·666
1945	1952	0·933	0·545	0·645	0·690	0·690	0·683
	1953	0·333	0·636	0·452	0·690	0·655	0·571
	1954	0·533	0·636	0·484	0·655	0·793	0·627
	1955	0·267	0·409	0·355	0·414	0·379	0·373
	Average	0·517	0·557	0·484	0·612	0·629	0·563
1942	1952	0·784	0·488	0·700	0·735	0·526	0·644
	1953	0·757	0·674	0·620	0·265	0·526	0·579
	1954	0·595	0·674	0·540	0·618	0·447	0·574
	1955	0·297	0·256	0·420	0·412	0·500	0·376
	Average	0·608	0·523	0·570	0·507	0·500	0·543
Average							*Grand Average*
	1952	0·782	0·680	0·729	0·811	0·683	0·731
	1953	0·654	0·610	0·610	0·538	0·648	0·612
	1954	0·731	0·650	0·542	0·604	0·703	0·644
	1955	0·308	0·340	0·475	0·377	0·448	0·400
	Average	0·619	0·570	0·589	0·583	0·621	0·597

Table A.20 *Analysis of Variance*

Source	*Degrees of Freedom*	*Sums of Squares*	*Mean Squares*	*V.R.*
Between Drives (D)	2	0·179 805	0·089 903	3·82 *
Between Ages (A)	4	0·009 838	0·002 459	
Between Years (Y)	3	0·927 291	0·309 097	13·14 ***
D × A Interaction	8	0·104 794	0·013 099	
D × Y Interaction	6	0·032 270	0·005 378	
A × Y Interaction	12	0·170 442	0·014 203	
Residual	24	0·564 521	0·023 522	
Total	59	1·988 961		

The variance ratio (Drives) was significant on the 5 per cent level and that for Years was very highly significant on the 0·1 per cent level.

From the residual, $\sigma_0 = 0{\cdot}153\,4$, an average of 20 results has standard error of $\sigma_0/\sqrt{20}$, and the standard error for the difference of two such averages is $(\sigma_0/\sqrt{20}).\sqrt{2} = 0{\cdot}048\,5$. For a difference to be significant on the 5 per cent level, it should exceed 0·099 9. Thus those who commenced driving in 1947–1949 had a significantly higher accident rate than those commencing to drive before 1947.

Similarly, the standard error for a difference of two averages, each based on 15 results, equals $(\sigma_0/\sqrt{15}).\sqrt{2} = 0{\cdot}056\,0$. For such a difference to be significant on the 5 per cent level (or 0·1 per cent level), it should exceed 0·115 4 (or 0·210 0). Hence the overall accident rate in 1952 was significantly higher than that in 1953; those in 1953 and 1954 were both very highly significantly greater than the accident rate in 1955.

Following a suggestion by Irwin (1943) that the transformed variate $\sqrt{x}$ should be considered instead of x, if x is Poisson, this transformation was used and the resulting tables leading to an Analysis of Variance are supplied as follows.

Table A.21 *Square Root (Accident Rate) of U.T.A. Bus Drivers (1952–1955)*

Men Driving From	*Year*	*Men Born In*				
		1908	*1911*	*1914*	*1917*	*1920*
1948	1952	0·832 1	1·000 0	0·915 3	0·976 5	0·869 7
	1953	0·832 1	0·717 2	0·854 2	0·807 0	0·839 7
	1954	1·018 8	0·792 9	0·771 1	0·747 1	0·891 6
	1955	0·588 4	0·632 5	0·805 4	0·570 6	0·669 9
1945	1952	0·966 1	0·738 6	0·803 2	0·830 5	0·830 5
	1953	0·577 3	0·797 8	0·672 0	0·830 5	0·809 4
	1954	0·730 3	0·797 8	0·695 6	0·809 4	0·890 6
	1955	0·516 4	0·639 6	0·595 7	0·643 3	0·615 9
1942	1952	0·885 3	0·698 9	0·836 7	0·857 5	0·725 5
	1953	0·869 9	0·821 2	0·787 4	0·514 5	0·725 5
	1954	0·771 1	0·821 2	0·734 9	0·785 9	0·668 9
	1955	0·545 3	0·505 8	0·648 1	0·641 7	0·707 1

Square Root (Accident Rate) of U.T.A. Bus Drivers

Table A.22 *Summing over Years*

Drive	*Age*					*Totals*
	1908	*1911*	*1914*	*1917*	*1920*	
1948	3·271 3	3·142 5	3·346 1	3·101 1	3·270 8	16·131 8
1945	2·790 1	2·973 7	2·766 5	3·113 7	3·146 4	14·790 4
1942	3·071 6	2·847 1	3·007 0	2·799 6	2·826 9	14·552 2
Totals	9·133 0	8·963 3	9·119 6	9·014 4	9·244 1	45·474 4

Table A.23 *Summing over Ages*

Drive	*Year*				*Totals*
	1952	*1953*	*1954*	*1955*	
1948	4·593 6	4·050 1	4·221 4	3·266 7	16·131 8
1945	4·168 9	3·687 0	3·923 7	3·010 8	14·790 4
1942	4·003 8	3·718 5	3·782 0	3·047 9	14·552 2
Totals	12·766 3	11·455 6	11·927 1	9·325 4	45·474 4

Table A.24 *Summing over Drives*

Year	*Age*					*Totals*
	1908	*1911*	*1914*	*1917*	*1920*	
1952	2·683 5	2·437 4	2·555 2	2·664 5	2·425 7	12·766 3
1953	2·279 2	2·336 3	2·313 6	2·151 9	2·374 6	11·455 6
1954	2·520 2	2·411 8	2·201 7	2·342 4	2·451 0	11·927 1
1955	1·650 1	1·777 8	2·049 1	1·855 6	1·992 8	9·325 4
Totals	9·133 0	8·963 3	9·119 6	9·014 4	9·244 1	45·474 4

Tables of Analysis of Variance of Square Root (Accident Rate) of U.T.A. Bus Drivers

(a) *Over Years*

(1)	$\sum(\text{individuals})^2/4$	34·593 914
(2)	$\sum(\text{Drive total})^2/20$	34·537 806
(3)	$\sum(\text{Age total})^2/12$	34·469 303
(4)	$(\sum\text{individuals})^2/60$	34·465 290

Table A.25

Source	*D.F.*	*Sums of Squares*
Between Drives (D)	2	0·072 516
Between Ages (A)	4	0·004 013
D × A Interaction	8	0·052 095
Total	14	0·128 624

(b) *Over Ages*

(1)	$\sum(\text{individuals})^2/5$	34·976 076
(2)	$\sum(\text{Drive total})^2/20$	34·537 806
(3)	$\sum(\text{Year total})^2/15$	34·895 098
(4)	$(\sum\text{individuals})^2/60$	34·465 290

Table A.26

Source	*D.F.*	*Sums of Squares*
Between Drives (D)	2	0·072 516
Between Years (Y)	3	0·429 808
D × Y Interaction	6	0·008 462
Total	11	0·510 786

(c) *Over Drives*

(1)	$\sum(\text{individuals})^2/3$	34·978 751
(2)	$\sum(\text{Year total})^2/15$	34·895 098
(3)	$\sum(\text{Age total})^2/12$	34·469 303
(4)	$(\sum\text{individuals})^2/60$	34·465 290

Table A.27

Source	D.F.	Sums of Squares
Between Years (Y)	3	0·429 808
Between Ages (A)	4	0·004 013
Y × A Interaction	12	0·079 640
Total	19	0·513 461

$\sum(\text{individuals})^2$	35·346 213
Total Variance	0·880 923

Table A.28 *Ultimate Analysis of Variance* ($\sqrt{x}$)

Source	Degrees of Freedom	Sums of Squares	Mean Squares	Variance Ratio
Between Drives (D)	2	0·072 516	0·036 276	3·71 *
Between Ages (A)	4	0·004 013		
Between Years (Y)	3	0·429 807	0·143 269	14·67 ***
D × A Interaction	8	0·052 095	0·006 512	
D × Y Interaction	6	0·008 463		
A × Y Interaction	12	0·079 641		
Residual	24	0·234 388	0·009 766	
Total	59	0·880 923		

It is quite apparent that the results of this analysis differ very little from those of the previous analysis (Table A.20).

Standardised Accident Rates—U.T.A. Bus Drivers (1952–1955)

As mentioned in Chapter 4, in order to show the effect of age upon the accident rate, the accident rates for different experience groupings within each Age—Calendar Year cell were averaged to supply a representative figure for that particular cell. A simple average was taken instead of one weighted by the numbers of drivers contributing to each experience group accident rate. The reason is that if the latter procedure were adopted, then peculiarities of the numerical distribution of drivers by experience would likely distort any eventual comparisons between accident rates by age and thus the whole object of the analysis would have been defeated. Corresponding remarks apply to the construction of Table A.30.

Table A.29 *Accident Rates by Age and Calendar Year*

Year	*Born in*				
	1908	*1911*	*1914*	*1917*	*1920*
1952	0·80	0·68	0·73	0·79	0·66
1953	0·59	0·61	0·60	0·54	0·63
1954	0·72	0·65	0·54	0·61	0·68
1955	0·30	0·36	0·47	0·38	0·44

Table A.30 *Accident Rates by Experience and Calendar Year*

Year	*Drive from*		
	1948	*1945*	*1942*
1952	0·85	0·70	0·65
1953	0·66	0·55	0·57
1954	0·72	0·62	0·57
1955	0·43	0·36	0·38

The Effect of Age: U.T.A. Bus Drivers, commencing to drive before 1941

Table A.31 *Accident Rate by Age and Year*

Year	*Date of Birth*				*Totals*
	1913–1918	*1907–1912*	*1901–1906*	*–1901*	
1952	0·66	0·49	0·57	0·78	2·50
1953	0·50	0·55	0·63	0·57	2·25
1954	0·32	0·53	0·47	0·74	2·06
1955	0·27	0·27	0·26	0·46	1·26
Totals	1·75	1·84	1·93	2·55	8·07

Table A.32 *Analysis of Variance*

Source	*Degrees of Freedom*	*Sums of Squares*	*Mean Squares*	*Variance Ratio*
Between Ages	3	0·098 569	0·032 856	3·91 *
Between Years	3	0·215 619	0·071 873	8·56**
Residual	9	0·075 606	0·008 401	
Total	15	0·389 794		

Both Ages (on the 5 per cent level) and Years (on the 1 per cent level) were significant. In particular, drivers over 50 years of age had a significantly higher accident rate in the last two years (roughly 50 per cent up).

Table A.33 *Accident Rates of B.C.T. Bus Drivers (1952–1955); by Age and Experience*

Date of Birth	*Date of Commencing to Drive*			
	After 1948		*Before 1948*	
1902–12	*17 men*	*Average*	*60 men*	*Average*
	1952–18	1·06	1952–56	0·93
	1953–23	1·35	1953–54	0·90
	1954–28	1·65	1954–53	0·88
	1955–28	1·65	1955–61	1·02
1913–17	*16 men*	*Average*	*25 men*	*Average*
	1952–14	0·88	1952–16	0·64
	1953–25	1·56	1953–18	0·72
	1954– 8	0·50	1954–16	0·64
	1955–24	1·50	1955–23	0·92
1918–27	*27 men*	*Average*	*14 men*	*Average*
	1952–31	1·15	1952– 9	0·64
	1953–33	1·22	1953– 9	0·64
	1954–27	1·00	1954–13	0·93
	1955–21	0·78	1955–12	0·86

Table A.34 *Analysis of Variance*

Source	*Degrees of Freedom*	*Sums of Squares*	*Mean Squares*	*Variance Ratio*
Between Drives (D)	1	0·874 017	0·874 017	12·76 *
Between Ages (A)	2	0·386 433	0·193 217	
Between Years (Y)	3	0·222 483	0·074 161	
D × A Interaction	2	0·050 633	0·025 317	
D × Y Interaction	3	0·132 350	0·044 117	
A × Y Interaction	6	0·498 767	0·083 128	
Residual	6	0·411 100	0·068 517	
Total	23	2·575 783		

The variance ratio (Experience) was significant on the 5 per cent level and almost attained the 1 per cent level. Thus those commencing to drive before 1948 had a significantly lower accident rate than those commencing to drive after 1948.

Table A.35 *Accident Rates of B.C.T. Trolley-Bus Drivers (1951–1955); by Age and Experience*

Date of commencing to drive	*Date of Birth*			*Year*
	1918–	*1913–1917*	*1904–1912*	
1948–	1·71	2·55	1·29	1951
	1·52	2·09	1·29	1952
	1·29	0·73	0·71	1953
	1·29	1·00	1·43	1954
	1·00	0·91	1·00	1955
1946–1947	1·00	1·00	0·75	1951
	1·30	1·25	0·69	1952
	0·90	1·00	1·13	1953
	0·30	1·00	0·94	1954
	0·60	2·00	0·63	1955

Table A.36 *Analysis of Variance*

Source	*Degrees of Freedom*	*Sums of Squares*	*Mean Squares*	*Variance Ratio*
Between Drives (D)	1	0·943 414	0·943 414	5·39 *
Between Ages (A)	2	0·714 527	0·357 264	
Between Years (Y)	4	1·041 734	0·260 434	
D × A Interaction	2	0·146 726	0·073 363	
D × Y Interaction	4	1·219 652	0·304 913	
A × Y Interaction	8	1·098 006	0·137 251	
Residual	8	1·399 608	0·174 951	
Total	29	6·563 667		

The variance ratio (Experience) was significant on the 5 per cent level. Thus those who commenced to drive from 1948 and later had a significantly higher accident rate than those commencing to drive in 1946–47.

Effect of Age: B.C.T. Trolley-Bus Drivers (who commenced to drive before 1944)

Table A.37 *Accident Rate by Age and Year*

Year	*Date of Birth*					*Totals*
	1893–1897	*1898–1902*	*1903–1907*	*1908–1912*	*1913–1917*	
1951	1·55	1·61	1·52	1·00	1·69	7·37
1952	1·50	1·18	1·25	0·59	1·15	5·67
1953	1·18	0·79	0·91	0·85	1·15	4·88
1954	1·55	1·15	1·20	0·74	1·38	6·02
1955	1·68	1·03	0·89	0·74	1·15	5·49
Totals	7·46	5·76	5·77	3·92	6·52	29·43

Table A.38 *Analysis of Variance*

Source	*Degrees of Freedom*	*Sums of Squares*	*Mean Squares*	*Variance Ratio*
Between Ages	4	1·354 784	0·388 696	13·49 ***
Between Years	4	0·687 144	0·171 786	6·84 **
Residual	16	0·401 776	0·025 111	
Total	24	2·443 704		

The variance ratio (Years) was highly significant on the 1 per cent level and the variance ratio (Ages) was very highly significant on the 0·1 per cent level. Thus those born in 1893–1897 had a significantly higher accident rate than those born later.

Determination of Sample Moments

Because of their utility in the sequel, it seems well to note the following formulae here.

Suppose the value x is observed to occur with frequency $f(x)$ in a sample of size N, then the following sums are formed—

$$\sum x.f(x), \qquad \sum x^2.f(x) \quad \text{and} \quad \sum x^3.f(x).$$

Then the following expressions are valid for the first three moments—

$$m_1' = \frac{1}{N}[\sum x.f(x)],$$

$$m_2 = \frac{1}{N}[\sum x^2.f(x)] - \frac{1}{N^2}[\sum x.f(x)]^2$$

and

$$m_3 = \frac{1}{N}[\sum x^3.f(x)]$$
$$- \frac{3}{N^2}[\sum x.f(x)][\sum x^2.f(x)]$$
$$+ \frac{2}{N^3}[\sum x.f(x)]^3$$

Examples of Fitting the Theoretical Distributions

The Negative Binomial Distribution: B.C.T. Trolley-Bus Drivers (1952–1955)

If the first two sample moments are denoted by m_1' and m_2, $m_1' = 4{\cdot}446\,721$ and $m_2 = 8{\cdot}927\,490$,

whence $c = m_1'/(m_2 - m_1') = 0{\cdot}992\,401$
and $p = (m_1')^2/(m_2 - m_1') = 4{\cdot}412\,930.$
Since $N = 244$, $N[c/(c+1)]^p = 11{\cdot}263.$

Then using the notation below, $E(r) = N[c/(c+1)]^p . \phi_r$.

Table A.39 *Example of Fitting a Negative Binomial Distribution*

r	$\frac{n(r)}{D(r)}$	$D(r)$	$\frac{n(r)}{D(r)}$	$\phi_r = \prod_r \frac{n(r)}{D(r)}$	$E(r)$
0	1	1	1	1	11·3
1	$\frac{p}{(c+1)}$	1·992 401	2·214 880	2·214 880	24·9
2	$\frac{(p+1)}{2(c+1)}$	3·984 802	1·358 394	3·008 680	33·9
3	$\frac{(p+2)}{3(c+1)}$	5·977 203	1·072 898	3·228 006	36·4
4	$\frac{(p+3)}{4(c+1)}$	7·969 604	0·930 150	3·002 530	33·8
5	$\frac{(p+4)}{5(c+1)}$	9·962 005	0·844 502	2·535 643	28·6
6	$\frac{(p+5)}{6(c+1)}$	11·954 406	0·787 403	1·996 573	22·5
7	$\frac{(p+6)}{7(c+1)}$	13·946 807	0·746 617	1·490 675	16·8
8	$\frac{(p+7)}{8(c+1)}$	15·939 208	0·716 029	1·067 367	12·0
9	$\frac{(p+8)}{9(c+1)}$	17·931 609	0·692 237	0·738 871	8·3
10	$\frac{(p+9)}{10(c+1)}$	19·924 010	0·673 204	0·497 411	5·6
11	$\frac{(p+10)}{11(c+1)}$	21·916 411	0·657 632	0·327 113	3·7
$\geqq 12$					6·2
				Total	244·0

Table A.40 *Example of Fitting a Long (or Neyman Type A) Distribution.*

r	θ^r	$(\lambda e^{-\theta})^r$	$[r]$	$\frac{\theta^r}{r!}$	$\frac{\theta^r}{r!}[r]$	$E(r)$
0						116·7
1	0·501 219	2·770 684	2·770 684	0·501 219	1·388 719	162·0
2	0·251 220	7·676 690	10·447 374	0·125 610	1·312 295	153·1
3	0·125 916	21·269 682	47·070 436	0·020 986	0·987 820	115·3
4	0·063 112	58·931 567	243·057 173	0·002 630	0·639 240	74·6
5	0·031 633	163·280 749	1 402·259 503	0·000 264	0·370 197	43·2
6	0·015 855	452·399 359	8 887·181 903	0·000 022 02	0·195 696	22·8
7	0·007 947	1 253·455 665	61 127·771 95	0·000 001 58	0·096 582	11·3
≧8						9·0
					Total	708·0

The Long (or Neyman Type A) Distribution: U.T.A. (Excluding Ballymena, Derry and Newry) Bus Drivers (1952–1955)

By calculation, $m_1' = 2{\cdot}292\,373 = \lambda\theta$,
and $m_2 = 3{\cdot}441\,355 = \lambda\theta\,(1 + \theta)$,
giving $\theta = m_2/\,m_1' - 1 = 0{\cdot}501\,219$, and $\lambda = 4{\cdot}573\,596$.
Now $e^{-\theta} = 0{\cdot}605\,8$, whence $\lambda(e^{-\theta} - 1) = -\,1{\cdot}802\,91$,
$e^{\lambda(e^{-\theta}-1)} = 0{\cdot}164\,8$, and $E(0) = Ne^{\lambda(e^{-\theta}-1)} = 116{\cdot}678\,4$.

Then, from Chapter 13,

$$E(r) = E(0).\frac{\theta^r}{r!}[r],$$

where

$$[r] = \sum_{k=0}^{r}\left\{\begin{bmatrix} r \\ k \end{bmatrix}\frac{(\lambda\, e^{-\theta})^k}{k!}\right\}.$$

Table A.41 *Example of Fitting a Short Distribution.*

r	θ^r	ϕ^r	$(\lambda e^{-\theta})^r$	$[r]$	$\frac{\theta^r}{r!}$	$\frac{\theta^r}{r!}[r]$	$\frac{\phi^r}{r!}$	$\frac{E(r)}{E(0)}$	$E(r)$
0	1	1	1	1	1	1	1	1	110·4
1	0·908 181	1·027 227	0·561 819	0·561 819	0·908 181	0·510 233	1·027 277	1·537 460	169·7
2	0·824 793	1·055 195	0·315 641	0·877 460	0·412 397	0·361 862	0·527 596	1·413 583	156·0
3	0·749 061	1·083 925	0·177 333	1·686 074	0·124 844	0·210 496	0·180 654	1·032 061	113·9
4	0·680 283	1·113 437	0·099 629	3·934 931	0·028 345	0·111 536	0·046 393	0·657 249	72·5
5	0·617 820	1·143 753	0·055 973	10·782 017	0·005 149	0·055 517	0·009 531	0·379 721	41·9
6	0·561 093	1·174 894	0·031 447	33·653 583	0·000 779	0·026 216	0·001 632	0·203 400	22·5
7	0·509 574	1·206 882	0·017 668	117·208 909	0·000 101	0·011 838	0·000 239	0·102 494	11·3
$\geqq 8$									9·8
								Total	708·0

The Short Distribution: U.T.A. (Excluding Ballymena, Derry and Newry) Bus Drivers (1952–1955)

The sample moments, $m_1' = 2{\cdot}292\,373$, $m_2 = 3{\cdot}441\,355$ and $m_3 = 6{\cdot}782\,803$, yield the estimates:
$\theta = (m_3 - m_2)/(m_2 - m_1') - 2 = 0{\cdot}908\,181$,
$\lambda = (m_2 - m_1')/\theta^2 = 1{\cdot}393\,055$ and $\phi \doteq m_1' - \lambda\theta = 1{\cdot}027\,227$.
Thus $e^{-\theta} = 0{\cdot}403\,3$ and $e^{\lambda(e^{-\theta}-1)-\phi} = 0{\cdot}1559$ giving $E(0) = 110{\cdot}377$, since $N = 708$.
Then, from Chapter 13,

$$\frac{E(r)}{E(0)} = \sum_{j=0}^{r} \left\{ \frac{\phi^j}{j!} \cdot \frac{\theta^{r-j}}{(r-j)!} \cdot [r-j] \right\},$$

where

$$[r] = \sum_{k=0}^{r} \left\{ \begin{bmatrix} r \\ k \end{bmatrix} \cdot \frac{(\lambda\, e^{-\theta})^k}{k!} \right\}$$

Table A.42 *Example of Fitting a Modified Short Distribution.*

r	θ^r	ϕ^r	$(\lambda e^{-\theta})^r$	$[r]$	$\frac{\theta^r}{r!}$	$\frac{\theta^r}{r!}[r]$	$\frac{\phi^r}{r!}$	$\frac{E(r)}{E(0)}$	$E(r)$
0									222·4
1	0·428 247	0·578 350	1·084 439	1·084 439	0·428 247	0·464 408	0·578 350	1·042 758	231·9
2	0·183 395	0·334 489	1·176 008	2·260 447	0·091 698	0·207 278	0·167 245	0·643 113	143·0
3	0·078 539	0·193 452	1·275 309	5·887 772	0·013 090	0·077 071	0·032 242	0·306 862	68·2
4	0·033 634	0·111 883	1·382 995	18·351 344	0·001 401	0·025 710	0·004 662	0·124 586	27·7
5	0·014 404	0·064 707	1·499 773	65·937 007	0·000 120	0·007 912	0·000 539	0·045 058	10·0
$\geqq 6$									4·8
								Total	708·0

The Modified Short Distribution: U.T.A. (Excluding Ballymena, Derry and Newry) Bus Drivers (1952–1953)

The first two sample moments are

$$m_1' = 1{\cdot}290\,960, \text{ and } m_2 = 1{\cdot}596\,133.$$

Assuming $\phi/m_1' = 0{\cdot}448$, (i.e. the value over 1952–1955)

then $\phi = 0{\cdot}578\,350$, and $\theta = (m_2 - m_1')/(m_1' - \phi) = 0{\cdot}428\,247$, and $\lambda = (m_1' - \phi)/\theta = 1{\cdot}644\,016$.

Thus $e^{-\theta} = 0{\cdot}651\,7$, and $e^{\lambda(e^{-\theta}-1)-\phi} = 0{\cdot}314\,1$, giving

$$E(0) = 222{\cdot}383, \text{ since } N = 708{\cdot}0.$$

Then, from Chapter 13,

$$\frac{E(r)}{E(0)} = \sum_{j=0}^{r} \left\{ \frac{\phi^j}{j!} \cdot \frac{\theta^{r-j}}{(r-j)!} \cdot [r-j] \right\},$$

where

$$[r] = \sum_{k=0}^{r} \left\{ \begin{bmatrix} r \\ k \end{bmatrix} \cdot \frac{(\lambda\, e^{-\theta})^k}{k!} \right\}.$$

Bivariate Negative Binomial—Marginal Distribution
B.C.T. Trolley-Bus Drivers (1952–1953 and 1954–1955)

The probability of a man having r accidents,

$$P(r) = \left(\frac{p}{p+\alpha}\right)^p \cdot \frac{\Gamma(p+r)}{\Gamma(p).r!} \cdot \left(\frac{\alpha}{p+\alpha}\right)^r$$

$$= \left(\frac{p}{p+\alpha}\right)^p \cdot \frac{p(p+1)\cdots\ldots(p+r-1)}{r!} \cdot \left(\frac{\alpha}{p+\alpha}\right)^r$$

Thus

$$P(r+1) = P(r).\frac{(p+r)}{(r+1)}.\left(\frac{\alpha}{p+\alpha}\right)$$

and

$$P(0) = \left(\frac{p}{p+\alpha}\right)^p = 0{\cdot}165\ 3,$$

since $\alpha = 2{\cdot}223\,361$, and $p = 4{\cdot}412\,930$.
With the following notation, the expected number of drivers having r accidents each, is given by $E(r) = E(0).\phi(r)$, $r \geqq 1$.

Table A.43 *Example of Fitting a Bivariate Negative Binomial—Marginal Distribution*

r	$N(r) = \alpha(p+r)$	$D(r) = (r+1)(p+\alpha)$	$\frac{N(r)}{D(r)}$	$\phi(r) = \prod_{i=1}^{r} \frac{N(i)}{D(i)}$	$E(r)$
0					40·3
1	9·811 536	6·636 291	1·478 467	1·478	59·6
2	12·034 897	13·272 582	0·906 749	1·341	54·1
3	14·258 258	19·908 873	0·716 176	0·960	38·7
4	16·481 619	26·545 164	0·620 890	0·596	24·0
5	18·704 980	33·181 455	0·563 718	0·336	13·6
6	20·928 341	39·817 746	0·525 603	0·177	7·1
$\geqq 7$					6·6
				Total	244·0

The Time-Interval Between Successive Accidents
B.C.T. Trolley-Bus Drivers (1951–1955)

(a) *Estimated Number of Repeaters*

It is assumed that the accident proneness hypothesis, associated with the Negative Binomial, is correct. Thus the true accident liability of a man having r accidents is given by $\bar{\lambda} = (p + r - 1)/(c + 1)$. Further, for a man incurring r accidents over five years, the probability that none of his $(r - 1)$ time-intervals between accidents was less than one month is given by $e^{-\xi} = q^{r-1}$, where $q = e^{(-\bar{\lambda}/60)}$ Hence the probability of such a man being a Repeater is given by $1 - e^{-\xi}$. The values of the parameters, in this instance, are $p = 5{\cdot}635$ and $c = 0{\cdot}950$. Table A.44 following shows the calculations involved in obtaining the expected number of Repeaters for varying r.

(b) *Estimated Number of Double-Repeaters*

Again the classical accident proneness model is assumed true. It is to be observed from the above that, for each value of r, $e^{-\xi} = q^{r-1}$. Thus by taking logarithms the value of q may be derived and division yields the corresponding value of q^{r-2}, in each instance. On using the formula

$$P(<2, r) = (r - 1)q^{r-2} - (r - 2)q^{r-1}$$

and taking the complement with respect to unity, the expected number of Double-Repeaters, among those observed to have incurred r accidents each, is given by

$$E(r) = [1 - P(<2, r)].N(r)$$

Table A.45 displays this calculation in detail for varying r.

Table A.44 *Example of Calculating the Expected Number of Repeaters, E(A.P.)*

r	$(r-1)(p+r-1)$	ξ	$e^{-\xi}$	$1-e^{-\xi}$	$N(r)$	$E(A.P.)$
2	6·635	0·056 71	0·944 9	0·055 1	23	1·27
3	15·270	0·130 51	0·877 6	0·122 4	18	2·20
4	25·905	0·221 41	0·801 4	0·198 6	38	7·55
5	38·540	0·329 40	0·719 4	0·280 6	41	11·50
6	53·175	0·454 49	0·634 8	0·365 2	19	6.94
7	69·810	0·596 67	0·550 6	0·449 4	21	9·44
8	88·445	0·755 94	0·469 6	0·530 4	18	9·55
9	109·080	0·932 31	0·393 6	0·606 4	18	10·92
10	131·715	1·125 77	0·324 4	0·675 6	7	4·73
11	156·350	1·336 32	0·262 8	0·737 2	13	9·58
12	182·985	1·563 97	0·209 3	0·790 7	4	3·16
13	211·620	1·808 72	0·163 9	0·836 1	3	2·51
14	242·255	2·070 56	0·126 1	0·873 9	1	0·87
15	274·890	2·349 49	0·095 4	0·904 6	4	3·62
·						
·						
21	512·700	4·382 05	0·012 5	0·987 5	2	1·98
					Total	85·82

Table A.45 *Example of Calculating the Expected Number of Double-Repeaters, E(A.P.)*

r	$e^{-\xi} = q^{r-1}$	$(r-1)\log q$	$\log q$	q	q^{r-2}	$P(<2, r)$	$1 - P(<2, r)$	$N(r)$	$E(A.P.)$
3	0·877 6	$\bar{1}$·943 29	$\bar{1}$·971 64	0·936 8	0·936 8	0·996 0	0·004 0	18	0·07
4	0·801 4	$\bar{1}$·903 85	$\bar{1}$·967 95	0·928 9	0·862 7	0·985 3	0·014 7	38	0·56
5	0·719 4	$\bar{1}$·856 97	$\bar{1}$·964 24	0·921 0	0·781 1	0·966 2	0·033 8	41	1·39
6	0·634 8	$\bar{1}$·802 63	$\bar{1}$·960 53	0·913 1	0·695 2	0·936 8	0·063 2	19	1·20
7	0·550 6	$\bar{1}$·740 84	$\bar{1}$·956 81	0·905 3	0·608 2	0·896 2	0·103 8	21	2·18
8	0·469 6	$\bar{1}$·671 73	$\bar{1}$·953 10	0·897 6	0·523 2	0·844 8	0·155 2	18	2·79
9	0·393 6	$\bar{1}$·595 06	$\bar{1}$·949 38	0·890 0	0·442 2	0·782 4	0·217 6	18	3·92
10	0·324 4	$\bar{1}$·511 09	$\bar{1}$·945 68	0·882 4	0·367 6	0·713 2	0·286 8	7	2·01
11	0·262 8	$\bar{1}$·419 63	$\bar{1}$·941 96	0·874 9	0·300 4	0·638 8	0·361 2	13	4·70
12	0·209 3	$\bar{1}$·320 79	$\bar{1}$·938 25	0·867 5	0·241 3	0·561 3	0·438 7	4	1·75
13	0·163 9	$\bar{1}$·214 57	$\bar{1}$·934 55	0·859 9	0·190 6	0·484 3	0·515 7	3	1·55
14	0·126 1	$\bar{1}$·100 71	$\bar{1}$·930 82	0·852 7	0·147 9	0·409 5	0·590 5	1	0·59
15	0·095 4	$\bar{2}$·979 55	$\bar{1}$·927 11	0·845 5	0·112 8	0·339 0	0·661 0	4	2·64
·									
·									
21	0·012 5	$\bar{2}$·096 91	$\bar{1}$·904 85	0·803 2	0·015 6	0·074 5	0·925 5	2	1·85
							Total		27·20

Table A.46 *B.C.T. Trolley-Bus Repeaters (1951–1955)—Significance Tests*

Number of Accidents		2–4	5	6	7	8	9	≧10	*Total*
No. of Repeaters	O	9	11	6	16	13	14	31	100
	E	11·1	11·5	6·9	9·4	9·6	10·9	26·5	85·9
No. of Non-Repeaters	O	70	30	13	5	5	4	3	130
	E	67·9	29·5	12·1	11·6	8·4	7·1	7·5	144·1
Total		79	41	19	21	18	18	34	230

$\chi^2 = 17{\cdot}346$

$\nu = 7$

$0{\cdot}02 > P > 0{\cdot}01$

SIGNIFICANT

Number of Accidents		2–4	5	6	7	8	9	≧10	*Total*
No. of Repeaters	O	9	11	6	16	13	14	31	100
	E′	9·4	11·6	7·1	10·6	11·0	12·6	24·2	86·5
No. of Non-Repeaters	O	70	30	13	5	5	4	3	130
	E′	69·6	29·4	11·9	10·4	7·0	5·4	9·8	143·5
Total		79	41	19	21	18	18	34	230

$\chi^2 = 13{\cdot}972$

$\nu = 7$

$0{\cdot}10 > P > 0{\cdot}05$

NOT SIGNIFICANT

E gives the number expected on the accident proneness hypothesis, *E′* the number expected on the Random hypothesis, and *O* the number observed.

Table A.47 *B.C.T. Bus Repeaters (1952–1955)—Significance Tests*

Number of Accidents		2–4	5–6	≧7	*Total*
No. of Repeaters	O	12	13	26	51
	E	11·9	9·8	17·6	39·3
No. of Non-Repeaters	O	78	19	5	102
	E	78·1	22·2	13·4	113·7
Total		90	32	31	153

$\chi^2 = 10{\cdot}782$

$\nu = 3$

$0{\cdot}02 > P > 0{\cdot}01$

SIGNIFICANT

Number of Accidents		2–4	5–6	≧7	*Total*
No. of Repeaters	O	12	13	26	51
	E′	12·0	11·9	21·9	45·8
No. of Non-Repeaters	O	78	19	5	102
	E′	78·0	20·1	9·1	107·2
Total		90	32	31	153

$\chi^2 = 2{\cdot}777$

$\nu = 3$

$0{\cdot}50 > P > 0{\cdot}30$

NOT SIGNIFICANT

E gives the number expected on the accident proneness hypothesis, E' the number expected on the Random hypothesis, and O the number observed.

Example of Calculating the Standard Errors of the Short Distribution Parameters.

U.T.A. (Excluding Derry) Bus Drivers (1952–1955)

For this sample, size 893, the momental estimators are

$\bar{\phi} = 1{\cdot}539$, 'chance' component, c,

$$\left.\begin{aligned}\bar{\theta} &= 1{\cdot}536\\ \bar{\lambda} &= 0{\cdot}558\end{aligned}\right\}\text{'personal' component, } p.$$

The 'Chance' Moments

$$E(c) = E(c'^2) = E(c'^3) = 1{\cdot}539$$

$$E(c'^4) = \phi(1 + 3\phi) = 8{\cdot}644\ 563$$

$$E(c'^5) = \phi(1 + 10\phi) = 25{\cdot}224\ 210$$

$$E(c'^6) = \phi(1 + 25\phi + 15\phi^2) = 115{\cdot}429\ 332$$

The 'Personal' Moments

On taking cumulants,

$$\kappa_r = \lambda\theta \sum_{i=1}^{r} \left\{\frac{\theta^{i-1}}{i!} \begin{bmatrix} r \\ i \end{bmatrix}\right\}$$

$$\left.\begin{aligned}\theta &= 1{\cdot}536\\ \lambda &= 0{\cdot}558\end{aligned}\right\}\lambda\theta = 0{\cdot}857\ 088$$

$$\kappa_1 = 0$$

$$\kappa_2 = \lambda\theta(2{\cdot}536) = 2{\cdot}173\ 575$$

$$\kappa_3 = \lambda\theta(7{\cdot}967\ 296) = 6{\cdot}828\ 674$$

$$\kappa_4 = \lambda\theta(29{\cdot}531\ 655) = 25{\cdot}311\ 227$$

$$\kappa_5 = \lambda\theta(124{\cdot}827\ 468) = 106{\cdot}988\ 125$$

$$= \lambda\theta(588{\cdot}548\ 747) = 504{\cdot}438\ 068$$

Using equations (11) in Chapter 13, supplying the moments in terms of the cumulants,

$$
\begin{aligned}
E(p) &= 0{\cdot}857\ 088\\
E(p'^2) &= 2{\cdot}173\ 575\\
E(p'^3) &= 6{\cdot}828\ 674\\
E(p'^4) &= 39{\cdot}484\ 511\\
E(p'^5) &= 255{\cdot}414\ 475\\
E(p'^6) &= 1\ 950{\cdot}017\ 193
\end{aligned}
$$

Combining these 'personal' with the preceding 'chance' moments, we get useful relations of the type,

$$E(c'^2)E(p'^2) = E(c'^3)E(p'^2) = 3{\cdot}345\ 132$$

The following expressions for the Short moments are easily deducible.

$$
\begin{aligned}
\mu_1' &= E(c) + E(p)\\
\mu_2 &= E(c'^2) + E(p'^2)\\
\mu_3 &= E(c'^3) + E(p'^3)\\
\mu_4 &= E(c' + p')^4 = E(c'^4) + 6E(c'^2)E(p'^2) + E(p'^4)\\
\mu_5 &= E(c' + p')^5 = E(c'^5) + 10[E(c'^3)E(p'^2) + E(c'^2)E(p'^3)] + E(p'^5)\\
\mu_6 &= E(c' + p')^6 = E(c'^6) + E(p'^6) + 15[E(c'^2)E(p'^4) + E(c'^4)E(p'^2)]\\
&\qquad + 20E(c'^3)E(p'^3).
\end{aligned}
$$

The values of the moments in the present case are as follows:

$$
\begin{aligned}
\mu_1' &= 2{\cdot}396\ 088 = m_1'\\
\mu_2 &= 3{\cdot}712\ 575 = m_2\\
\mu_3 &= 8{\cdot}367\ 674 = m_3\\
\mu_4 &= 68{\cdot}199\ 866\\
\mu_5 &= 419{\cdot}183\ 295\\
\mu_6 &= 3\ 468{\cdot}977\ 125
\end{aligned}
$$

On substitution into equations (13) of Chapter 13

$$\mathrm{Var}(m_1') = 0{\cdot}004\ 157$$

$$\mathrm{Var}(m_2) = 0{\cdot}060\ 937$$

$$\mathrm{Var}(m_3) = 2{\cdot}620\ 736$$

$$\mathrm{Cov}(m_1', m_2) = 0{\cdot}009\ 370$$

$$\mathrm{Cov}(m_1', m_3) = 0{\cdot}030\ 067$$

and

$$\mathrm{Cov}(m_2, m_3) = 0{\cdot}330\ 258 \tag{1}$$

Equation 14 ($\bar{\theta}$) of Chapter 13 yields

$$\frac{\partial\bar{\theta}}{\partial m_1'} = +\frac{4{\cdot}655\ 099}{1{\cdot}316\ 487^2} = +2{\cdot}685\ 937$$

$$\frac{\partial\bar{\theta}}{\partial m_2} = -\frac{5{\cdot}971\ 586}{1{\cdot}316\ 487^2} = -3{\cdot}445\ 534$$

and

$$\frac{\partial\bar{\theta}}{\partial m_3} = +\frac{1}{1{\cdot}316\ 487} = +0{\cdot}759\ 597 \tag{2}$$

Substitution of (1) and (2) into equation (12) of Chapter 13 gives $\mathrm{Var}\ (\bar{\theta}) = 0{\cdot}486\ 893$

that is

$$\sigma(\bar{\theta}) = 0{\cdot}697$$

Similarly

$$\frac{\partial\bar{\lambda}}{\partial m_1'} = -2{\cdot}375\ 353$$

$$\frac{\partial\bar{\lambda}}{\partial m_2} = +2{\cdot}927\ 247$$

and

$$\frac{\partial\bar{\lambda}}{\partial m_3} = -0{\cdot}551\ 894.$$

Also

$$\frac{\partial \bar{\phi}}{\partial m_1'} = +3{\cdot}149\ 792$$

$$\frac{\partial \bar{\phi}}{\partial m_2} = -2{\cdot}573\ 647$$

and

$$\frac{\partial \bar{\phi}}{\partial m_3} = +0{\cdot}423\ 855.$$

This enables the following table to be constructed.

Table A.48 *Standard Errors of the 'Short' Parameters*

Parameter	*Standard Error*
$\bar{\theta} = 1{\cdot}536$	$\sigma(\bar{\theta}) = 0{\cdot}697$
$\bar{\lambda} = 0{\cdot}558$	$\sigma(\bar{\lambda}) = 0{\cdot}475$
$\bar{\phi} = 1{\cdot}539$	$\sigma(\bar{\phi}) = 0{\cdot}351$