accidents of bus drivers

an epidemiological approach

ACCIDENTS OF BUS DRIVERS - AN EPIDEMIOLOGICAL APPROACH

(ONGEVALLEN VAN BUSCHAUFFEURS - EEN EPIDEMIOLOGISCHE BENADERING)

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE

GENEESKUNDE

AAN DE ERASMUS UNIVERSITEIT ROTTERDAM

OP GEZAG VAN DE RECTOR MAGNIFICUS

PROF. DR. M.W. VAN HOF

EN VOLGENS BESLUIT VAN HET COLLEGE VAN DEKANEN.

DE OPENBARE VERDEDIGING ZAL PLAATSVINDEN OP

WOENSDAG 16 OKTOBER 1985 TE 14.00 UUR

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MIROSLAUS LEOPOLD IVO POKORNY

GEBOREN TE PRAAG

PROMOTIEKOMMISSIE:

PROMOTOR : PROF. DR. H.A. VALKENBURG

OVERIGE LEDEN: PROF. DR. DR. J. RUTENFRANZ
PROF. R. VAN STRIK
PROF. DR. D. VROEGE

Dit proefschrift is tot stand gekomen in nauwe samenwerking tussen beide auteurs. Het bestaat uit een algemeen deel met daaraan toegevoegd tien al dan niet reeds gepubliceerde artikelen.
Ieder van de auteurs is verantwoordelijk voor het algemene deel en het proefschrift als geheel; daarnaast in het bijzonder voor die artikelen, waarvan hij de eerste auteur is (c.q. in addendum 5 de tweede auteur).

DANKWOORD

Als men, na vallen en opstaan, aan het eind gekomen is van het schrijven van een proefschrift en terugblikt op de voorbijgegane periode, realiseert men zich hoeveel mensen in feite bij deze onderneming betrokken waren. Sommigen in zeer praktische zin, anderen door het aanhoren van rijpe maar vaker nog onrijpe ideeën, of door het leveren van kritiek tijdens de verschillende voorstadia van het manuskript. Tevens wordt men zich opnieuw ervan bewust dat al deze kontakten een noodzakelijke voorwaarde zijn voor het welslagen van het (leer)proces dat ieder wetenschappelijk onderzoek nu eenmaal is.

Het begin van deze studie werd gemarkeerd door de bereidheid van direktie en verschillende funktionarissen van de NV Verenigd Streekvervoer Westnederland, en in een later stadium de Vereniging ESO, ons met raad en daad terzijde te staan bij het verzamelen en verwerkingsklaar maken van de gegevens uit diverse, soms moeilijk te achterhalen, bronnen en de stimulerende belangstelling van de voormalige direkteur van het NIPG/TNO, Dr M.W. Hartgerink. Met name willen wij hier noemen Mr W. Kuilman en Mr D. van Setten, die de archieven ter beschikking stelden en administratieve ondersteuning mogelijk maakten. Daarnaast de heren A. v.d. Lugt, C.R. Steketee, C. Stam en A. Middelkoop, die steeds bereid waren ons in te lichten over het dagelijks reilen en zeilen van een busonderneming en zijn chauffeurs. Ook de leden van de Begeleidingskommissie Bedrijfsgezondheidszorg van de KNVTO met zijn voorzitter, de bedrijfsarts J. Bosman, kaderleden van de vervoersbonden FNV en CNV en de leden van de werkgroep van de ESO, ingesteld om de resultaten van dit onderzoek op zijn beleidsmatige konsekwenties door te lichten, zij hierbij dankgezegd voor hun geduldige en niet aflatende belangstelling.

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Vele medewerkers van het NIPG/TNO zijn meer of minder intensief bezig geweest bij de vormgeving van het manuskript en zijn diverse voorstadia. In de eerste plaats Mw A.A.M. Paardekooper, verantwoordelijk voor het typen van vele honderden cijfertjes en konsepten; W. v.d. Ziel, projektassistent en verder Mw H. Knijnenburg en Mw J.E. Smit, sekretaressen; Mw H.P. Segaar-Olivier, die de definitieve tekstinvoer verzorgde; de medewerkers van de afdeling Statistiek, R.M. Frese, Ing., Drs A. van Amstel en J.M. Stavleu, die de omvangrijke databestanden hielpen opbouwen en de vele noodzakelijke analyses uitvoerden, bijgestaan door Mw C. de Kruijf, datatatypiste; de huisdrukkerij NIPG/TNO, N.H. de Kleijn (lay-out), F.R. Voerman (illustraties), J.N. van Kampenhout, J. v.d. Plas en J.J. v.d. Zwan (druk). De literatuur-recherche werd verzorgd door Mw J.C.G. de Lange.
Tenslotte mag niet onvermeld blijven de bijstand van de heer A. Oudshoorn bij het verzamelen, kontroleren en tabelleren van de gegevens.

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ACCIDENTS OF BUS DRIVERS - AN EPIDEMIOLOGICAL APPROACH

1. INTRODUCTION

In the history of accident research much emphasis has been laid on general statistics, different types of case studies concentrating on various personal factors, circumstantial influences etc. Often, in certain waves, the unequal initial liability theory (the accident proneness concept; Greenwood and Woods, 1919), the search for personality traits, determining a personal vulnerability for accidents, dominated the research programs. Apart from methodological criticism (e.g. Arbous and Kerrich, 1953) other theories evolved (Hale & Hale, 1972), like the adjustment/stress theory (Kerr, 1950), situational and task-related theories (e.g. Winsemius, 1969; Surry, 1969) or the domino theory (Heinrich, 1950). Additionally, under the influence of ideas formalised in epidemiology accidents tended to be regarded as one of the "modern epidemics", and should be approached with epidemiological methods (Gordon, 1949; McFarland et al, 1955).
Of course, accidents have some relation to health problems (injury, death) although the causal association between the occurrence of accidents and an eventual health problem is not fully understood. This applies to accidents in general as well as to traffic accidents.
One of the first comprehensive studies in this respect was "The causation of bus driver accidents; An Epidemiological study" published by Cresswell and Froggatt in 1963.
Not only the title, but also the methods used in this thesis, is inspired by this epidemiological tradition in accident research. In the interpretation of the results, however, links have been made with physiological, psychological and ergonomic theories.
In 1977 a start was made at the Netherlands Institute for Preventive Health Care/TNO with a project, of which the purpose could roughly be defined as follows: to develop a useful measuring instrument capable of demonstrating the (assumed) effect of the performance of a task on the task performer and, assuming that this would prove possible, to ascertain to what extent the task effect changes under different task conditions. After a series of discussions with the members of the Steering Committee for Indus-

trial Health Care of the Royal Netherlands Association of Transport Companies, in which employers, workers and industrial health-care are represented, it was decided to set up a project for examining the effect of the bus driver's task on the individual bus driver.
The project contained two different studies: I. an experimental field study involving various psychometric and physiological measurements - results of this study will be reported elsewhere;
II. this thesis and the papers of which it is composed, concerns the other part of the project: an accident analysis; this analysis has been carried out on the accidents of the bus drivers employed by a large bus company in the Western part of the Netherlands.

It was assumed that the occurrence of a traffic-accident could contain information about possible effects of the task performance of a bus driver, and of the conditions of this task, on the performer.
This accident study contains two parts. An initial explorative investigation of the accidents in one branch could be followed by a second study of the accidents of another branch of the same bus company. In this second part the hypotheses derived from the results of the first part were tested.

The topics of interest that will be dealt with in this thesis are theoretical and practical problems of accident research, associations of accident risk with some personal factors like age and experience, and with environmental (task-related) factors like type of shift and time on task.

2. THEORETICAL CONCEPTS

The following hypothesis was the basis for the project: the performance of an occupational task has a (cumulative) effect on the individual performing this task; the nature of this effect is determined by characteristics of the task itself, of the environment (of which the task forms an integral part) and by individual qualities of the task performer.
With specific reference to the accident study this means that the occurrence of accidents in task situations might give indications concerning existence and nature of the effect of the performance of the task on the worker. The basic principle applied was the Stimulus-Organism-Response (S-O-R) concept, which has become a classical concept in psychology. This choice is associated with the assumption that changes in the response to various stimuli can lead to statements on changes within the intermediating variable (the organism); the changes can be interpreted as effects of, i.a., the task performance. This concept can also be approached in terms of a man-environment interaction*, well-known in epidemiological research.

In general it can be assumed that the nature of the response on external stimulation is associated, on the one hand, with characteristics of the environment, interpreted as sources of stimulation; and on the other hand, with qualities of the individual, the organism. It is important for the interpretation of the response to have available as much reliable information as possible concerning the stimuli and their sources and concerning the individual reacting to these stimuli.

The use of this general model leads to our conceptual definition:

> "An accident is a result of a hazardous situation with or without damage and/or injury and/or death".

Two main elements can be discerned in this definition:

1. A central position is occupied by the "hazardous situation". This is defined as follows:
   "A hazardous situation is a possible result of certain

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* The term 'interaction' has also been used in this thesis, where applicable, in the statistical sense.

interactions between man and environment, which may or may not result in an accident".

2. A differentiation is made between the hazardous situation on the one hand, and the possible result thereof, the accident, on the other hand.

It should be emphasized that the consequences of the accident in the form of the extent of the damage or the occurrence of injury or death are in this approach more or less independent of the process leading to the hazardous situation.

In both components of the man-environment interaction model, three analogous categories of factors can be distinguished:

1. Constant or during the period of exposure relatively invariant factors.
2. Factors that change with time, but which are controllable, at least in principle.
3. Rapidly or irregularly changing factors.

It can be said that these arbitrarily chosen categories show a diminishing degree of constancy over time, and conversely an increasing difficulty in controlling these factors in an analytical design, from the first to the third category.

Of the many factors that could theoretically influence the interactive process, those in the first and second category, of both human and environmental components, can partly be defined and controlled; partly they cannot be implied in the research design. Factors of the third category of the individual and environmental component have a variable influence on the interactive process possibly leading to an accident. This influence can be of marginal importance, completely unsystematic, or possibly detectable with more or less difficulty.

Factors of both components have a different role in the interaction, again associated with the category in which they are placed. It can be supposed that individual factors from the first to the third category can increasingly be influenced by the environment. The same cannot be said of the environmental factors: many of these cannot be influenced by the individual concerned.

Of each of these factors must be assessed whether it belongs to the set of factors influencing the process leading to a hazardous situation, and/or whether it may influence the eventual outcome of this situation - the accident (addendum 1).

3. MATERIAL AND METHODS

An important discovery at the onset of the project was that because of insurance regulations all bus accidents, whatever the damage may be, with or without injury, have to be reported to the company. This fact, together with the existence of an archive containing information about accidents which had happened in previous years, formed the beginning of the first part of the study. These findings can be considered part of the basic conditions for an accident analysis to yield satisfactory results. The operational definition of an accident was therefore:

> "An accident is an event of damage to a bus, or by a bus, that needed to be reported to the insurance company".

In practice this means all accidents of buses of that company, including the very minor ones. Because of the liability of the bus drivers in case of not reporting the accident one can reasonably assume completeness of the data.

Only part of the information about the accidents and the circumstances in which they occurred was available on the accident forms. The greater part of the context information, however, had to be sought in other sources, like time-tables, duty reports, personal records etc.

As is usual in public transport, the services are organized in various shifts with irregular starting hours. Three main types can be distinguished, viz., early shifts starting between about 5.00 hours and 10.00 hours; late shifts starting between about 13.00 hours and 17.00 hours and split shifts, i.e., compound shifts, consisting of two parts: the first part being performed during the morning rush hours and the second part during the afternoon rush hours. This means that a person on a split shift starts working early in the morning for a shorter part of his shift, is off duty for 3 to 4 hours and then starts working again in the afternoon for the second (longer) part of his shift.
Within each shift subgroups can be distinguished which have different starting hours.
Data with regard to the shifts were derived from the driver's time-tables to which information about the length of the bus line runs in kilometres was added.

Changes in personnel, differences in age and experience of the bus drivers, varying frequency and routing of the bus lines, etc. were accounted for in processing the data.

An important feature of the shift organisation of this particular bus company is that all drivers, regardless of their age, experience etc., perform all shifts on rotating schedules, therefore, it can be assumed that each driver has an equal exposure regarding shifts, bus lines, kilometres driven, hours of service etc.

In the first, exploratory, part of the study data were available on all accidents in which bus drivers of one branch of the bus company were involved in the years 1973-1977. This concerned 197 drivers with a total of 944 accidents.
In the second part of the study, designed as a replication to test the hypotheses derived from the results of the first part, the same applied to all accidents in which bus drivers of a different branch of the same bus company were involved. This time the period of observation was 8 years (1973-1980). In this part a total of 427 drivers with 2130 accidents were involved. Only for the last 5 years, however, daily duty reports were available, resulting in the possibility of linking accidents with shift-data over the years 1976-1980. In both parts of the study the age of the drivers ranged from 21-60 years. Only male drivers were employed at that time.
For various analyses, different subselections of drivers and accidents were used according to well-defined criteria.

The use of the number of days (or weeks etc.) worked in various shifts seemed not to be justified to determine the exposure due to large differences between the contents and length of each shift. The same applied to bus line runs. The best, well-defined, estimator of the actual exposure to the task and its various aspects seemed to be the driving-distance scheduled in the various shifts on each bus line. The use of this unit of exposure gave the possibility to assess risk in terms of the number of accidents per 100,000 km, the most commonly used accident rate in this report. Where applicable also the number of accidents per man-year or comparable rates were used (addendum 2).

In the latter case attention has to be paid to possible yearly differences in exposure, i.e. the number of kilometres driven per man-year. In the first part of the study indeed a declining number of kilometres per man-year was found to correspond to a declining number of accidents per man-year. The accident rate (number of accidents per 100,000 km), however, remained more or less constant.
In the second part of the study both the accident rate and the number of accidents per man-year remained approximately constant, corresponding with a stable number of kilometres driven per man-year.
Again in this context the outstanding importance is emphasized of determining as accurately as possible the exposure to task in (traffic-)accident research.

Apart from the main topics of interest as mentioned in the introduction (which will be dealt with more extensively) a lot of additional information was available on the accident forms.
This included, e.g., the month of the year (season) and day of the week; physical characteristics and circumstances like place of the accident (inside or outside the built-up area of the townships), properties of the road (straight, bend or intersection), weather and road conditions; outcome of the accident (collision-object, extent of the material damage, injury or death) etc. These variables have been used, on the one hand, to check for the presence of various possible selection biases and the internal consistency of the material, and, on the other hand, to investigate possible confounding interactions with the main topics of interest as mentioned in the introduction, e.g., age, shift organisation etc.
No evidence has been found of selection bias nor any meaningful interactions between accident risk, e.g., of various shifts and one of the above named other variables. An interaction has been found, e.g., between collision-object and extent of damage. This interaction, however, was proportionally present within all shifts (Pokorny et al, 1984).

4. SOME INDIVIDUAL VARIABLES

A hypothesis derived from the results of the first part of the study was:

> The variability of the accident liability of bus drivers in various age-groups is high. Experience aside the differences between the age-groups are, therefore, not significant.

This hypothesis need not be abandoned in view of the results of the second part. In both parts of the study the age of the bus drivers (classified in 5-year age-groups), as such, appears to have no decisive influence on their accident liability.

Furthermore, in both parts a clear effect of experience on accident liability was found: on the average, bus drivers have a relatively high accident level at the beginning of their career, followed by a gradual decline.
In the second part of the study a more exact analysis of the influence of age and experience on accident liability during the first few years of service was possible.
The hypothesis derived from the first part was:

> Accident risk of bus drivers is highest for drivers with less than 7 months of task experience, then declines for some time, rises subsequently in the second year and then shows an ongoing decline.

This hypothesis is only tenable for the younger bus drivers of 21-30 years. Older drivers (31-40 years) showed in the analysis of the second part a more continuous decline also after a high initial level.

In general it can be concluded that there is a negative association between experience and accident liability of drivers of various age-groups, and that systematic differences appear between groups of drivers of different age-groups but with comparable experience: younger drivers have higher accident rates than the older, although this can only be demonstrated for drivers with a low number of years of service.

In the second part of the study it was possible to compute the correlation between the accident rates of individual drivers during four consecutive years after employment. Exclusively on group level (with respect to the variability within the groups) this gave evidence that drivers starting their career with a low accident level retain a low number of accidents, while their colleagues with a higher initial level show a decrease in accident liability over time. Given the heavy problems of interpretation, the high correlations found have not been interpreted in terms of accident proneness but in a variation of age and experience within the group of bus drivers under investigation.

Finally, in neither part of the study evidence was found of the existence of a temporary higher accident liability of persons once involved in an accident. The theoretical distribution, based on a Poisson process, of time-intervals between accidents of drivers with varying numbers of accidents closely fits the observed distribution (addenda 3, 4, 5).

5. TASK RELATED FACTORS

With regard to the shifts, in the first part the following hypothesis has been put forward:

> Accident risk of early, late and split shifts is different: shifts that start in the morning (early, split) have a higher accident rate than those starting in the afternoon (late).

This hypothesis is tenable, though a difference is observed between both branches. In the second part of the study accident rates of the split shift were highest (5.08 accidents/100,000 km for the split shift, compared to 3.96 for the early, and 3.24 for the late shift), while in the first part this applied to the early shift (3.39 for the early shift, compared to 3.05 for the split shift, and 2.47 for the late shift).

Concerning the shift-subgroups with different starting hours the hypothesis derived in the first part was:

> Accident rates of subgroups within the different shifts, arranged according to their starting hour are different: the later one started, the lower the accident rate.

This hypothesis is not tenable to its full extent. Despite the fact that this declining trend associated with a later starting hour, was present within the late shift, and detectable (though statistically not significant) within the split shift, one cannot discern a clear rule. Especially the early shift shows a somewhat different picture in the second part. Still, one should allow for an interaction between accident risk during an entire shift and starting hour, though this interaction is probably influenced by other factors. Results of both parts suggest a lower accident risk for shifts that either commence in the late morning, or in the late afternoon.

With respect to accident risk in the course of the service several hypotheses have been formulated on the basis of the results of the first part of the study. The first were:

> Accident risk varies during the course of each service (early, late or split); the pattern of the distributions of accident risk over the various hours of service is different for each shift.

These hypotheses need not be abandoned. In both parts of the stu-

dy, accident risk during the service appears to follow a pattern, characteristic for each type of shift: accident risk during the early shift is relatively low at the beginning of task operation, reaches a peak at about the 3rd and 4th hour of service, is followed by a decline and then increases again during the last hours of task operation. Accident risk during the late shift is relatively high at the beginning of service and then declines towards the end of service. It must be noted, however, that in the second part of the study the increase of accident risk at the end of the early shift was more pronounced.
As the data from the first part of the split shift are rather scanty and do not reveal a clear picture, no hypothesis has been formulated on the pattern of the accident risk. In the second part of the shift (from the 7th to the 12th hour of service) a characteristic pattern could be detected in both parts of the study, viz. an inverted U-shape with a relatively low rate at the 7th hour, a peak value at the 8th or 9th hour followed by a decline towards the end of service (addenda 6, 7).

In both parts of the study a variation of the accident level of bus drivers over the course of the day was observed. However, in view of the above mentioned findings, it can be concluded that the mean accident rate over the course of the day (the diurnal variation) is composed of a confusion of very different values. Depending on the type of shift (subgroup) and the phase of the work, a very different level of accident risk can exist at the same time of the day (addendum 8).

In the second part of the study two other types of analysis were possible. The first was concerned with a possible interaction between the duration of total (added) rest periods during the shift up to the moment of the accident, and accident risk. No association could be detected. The analysis, and, therefore, the conclusions are restricted to possible effects of total resting time and cannot be extended to possible effects of particular rest periods of different duration and at a different stage within a different shift on accident risk (addendum 9).

The other analysis concentrates on the question of whether the sequence of the various shifts influences the actual accident risk on a certain day. The conclusion from different analyses was that no interaction can be demonstrated between the type of shift (or stand-by shift or day-off) on preceding days, actual shift, and accident risk of bus drivers. This leads to the supposition that to an important extent the actual situation on the working day determines accident risk (addendum 10).

6. SOME ADDITIONAL FINDINGS

As stated in chapter 3, many additional data around the accidents were available. Some interesting issues will be mentioned here.

In the long term a seasonal variation in accident risk seems to exist; the accident rate is highest in autumn, declines through winter and spring and is lowest in summer. The predictive power of this pattern for a given year, however, is rather small. Apparantly, the circumstances within each year with regard to, e.g., weather conditions, are highly responsible for the month to month variation within a certain year.
In this context the resemblance to the accident data of truck drivers should be noted. The interpretation of the seasonal influence as suggested by the data is sought, on the one hand, in terms of physical properties of bus and truck and, on the other hand, in the dependance of both categories of professional drivers on working-schedules, even, e.g., in bad weather-conditions.

Furthermore, it must be noted that the share of accidents with injury (or death) in the total number of accidents in which bus drivers were involved, is relatively constant in both parts of the study (7% approximately). This relatively constant share found with two different groups of bus drivers leads one to suppose that this applies to the general traffic as well. The general traffic accident data in the Netherlands, based on about 55,000 accidents with injury (or death), would in that case regard to about 7% of the total of traffic accidents which can then be estimated on 700,000 to 850,000 per year. It is interesting to note that with a different procedure one came to an estimated total of the same order (about 1 million per year as disclosed at the Dutch National Traffic-safety Congress, 1983).
Finally, it should be stressed again, that in neither part of the study any interaction has been demonstrated between extent of damage, accident risk and factors like age, type of shift, etc. (Pokorny et al, 1984).

7. CONCLUDING REMARKS

As has been explained in the theoretical part, in this study an accident is conceived as an observable result of a man-environment interaction. An accident is supposed to be preceded always by a hazardous situation, while, on the other hand, a hazardous situation need not always to result in an accident. Nevertheless, we have argued that this selection does not seriously bias the results of the analysis if the hypothesis is true that factors influencing the outcome of a hazardous situation (whether an accident happens or not, with accompanying damage and/or injury) are mainly distributed at random.

In our opinion, this line of thought becomes plausible in the light of various results. Firstly systematic influences of both individual and situational character have been demonstrated (experience, type of shift, etc.). Secondly, there are no meaningful differences between subselections of accidents according to extent of damage or the occurrence of injury. Neither was this the case with the distributions of various other characteristics and circumstances over such a dominant factor as, e.g., type of shift. Therefore, probably there is no systematic effect of the characteristics mentioned, on accident etiology. Thirdly, even a systematic interaction, as has been found between collision-object and extent of damage, is present in all shifts and has to be viewed as a modifying variable, of importance only for the outcome of an accident. Extrapolating, it is plausible that the systematic influences found with accidents also apply to hazardous situations not resulting in an accident. In other words, analysis of accident data can lead to understanding their etiology and the role of various personal and environmental factors. Likewise, it is in our opinion plausible that the occurrence of accidents can be viewed as an indicator of the influence of work on the task performer.
The nature and number of propositions that can be made about the influence of various (categories of) factors in man and environment on accident risk are, of course, dependent on the amount and quality of the information gathered about the accident. This applies for both information about the exposure at various task characteristics (environment) and about the various characteristics of the task performer (man).

It is important to point once again to the fact that it was possible in this study to make propositions about the influence of a number of factors, because of the equal exposure of the drivers to various environmental factors (like routes, type of bus, task organisation, etc.) through their rotating shift schedules. Thence a comparability has been reached, which in experimental research can only be aimed at by randomisation. The same applies for some individual characteristics: younger and older, more or less experienced drivers are exposed in a comparable manner. When in an accident study this comparability of exposure cannot be realised, the range of the propositions that can be made is seriously compromised. In that case the criticism of Brown (1982) is justified that duration of work or distance driven as such are an insufficient measure of the exposure to the risk of an accident.

Within the framework of these concluding remarks we also wish to emphasize the desirability of replicative research, because, still apart from methodological pitfalls, the probability of finding spurious associations in exploratory research is high. The results of this study show some illustrative examples: in some cases preliminary conclusions had to be changed or at least adjusted. Next to this an analysis of existing data about certain (time- and place-bound) groups of people is at issue. Without replication in our opinion generalizability of the various propositions to other groups and (for the same group) to the future is rather precarious.
Interpretation of the results of accident research in terms of changes in human functioning is only possible with the aid of results from physiological, psychometric and medical research.

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SUMMARY

The subject of this thesis and the papers of which it is composed, is an analysis that has been carried out on the accidents of the bus drivers employed by a large bus company in the Western part of the Netherlands.
It was assumed that the occurrence of a traffic-accident could contain information about possible effects of the task performance of a bus driver, and of the conditions of his task, on the performer.
This accident study contains two parts. An initial explorative investigation of the accidents in one branch could be followed by a second study of the accidents of another branch of the same bus company. In this second study the hypotheses derived from the results of the first part were tested.
The topics of interest that will be dealt with in this thesis are theoretical and practical problems of accident research, associations of accident risk with some personal factors like age and experience, and with environmental (task-related) factors like type of shift and time on task.

In a general model based on the concept of an interactive process between man and environment an accident is viewed as a result of a hazardous situation with or without damage and/or injury and/or death.
Two elements are important in this respect:

a. The hazardous situation, a possible result of certain interactions between man and environment.
b. A differentiation between the hazardous situation on the one hand, and the possible result thereof, the accident, on the other hand.
   It should be emphasized that the consequences of the accident in the form of the extent of the damage or the occurrence of injury or death are in this approach more or less independent of the process leading to the hazardous situation.

The operational definition of an accident was:

"An accident is an event of damage to a bus, or by a bus, that needed to be reported to the insurance company".

In practice this means all accidents of buses of that company,

including the very minor ones. Because of the liability of the bus drivers in case of not reporting the accident one can reasonably assume completeness of the data.
As usual in public transport, the services are organized in various shifts with irregular starting hours.
An important feature of the shift organisation of this particular bus company is that all drivers, regardless of their age, experience etc., perform all shifts on rotating schedules, therefore, it can be assumed that each driver has an equal exposure regarding shifts, bus lines, kilometres driven, hours of service etc.
As an estimator of the actual exposure to the task and its various aspects the driving-distance scheduled in the various shifts on each bus line has been used giving the possibility to assess risk in terms of the number of accidents per 100,000 km, the most commonly used accident rate in this study. Where applicable also the number of accidents per man-year or comparable rates were used.

The results in this study can be summarized as follows:

1. An analysis with regard to the role of age and experience of bus drivers and their accident risk indicates a strong negative association of experience with accident risk, modified to a certain extent by age. The suggested interaction between accident liability, age and experience warranted a more detailed attention for the first few years of employment.
2. A study concentrating on these first years of employment as a bus driver demonstrated the existence of systematic differences between groups of drivers of different age-groups but with comparable experience: younger drivers had higher accident rates than the older. An increase of accident risk during the second year of employment after an initial decline could be detected in the younger group of drivers; the older group only showed a continuous decline.
   Furthermore, a correlation appeared to exist between accident rates of some bus drivers in successive periods of employment. Given the heavy methodological problems these results have not been interpreted in terms of accident-proneness but in a variation of age and experience within the group of bus drivers under investigation.

3. With regard to the distribution of the length of time intervals between successive accidents no significant interaction could be detected between the occurrence of an accident and the length of the time intervals in between.
4. An analysis focused on the effects of type of shift on accidents of bus drivers showed a strong association with accident risk. Shifts starting in the morning appeared to have a higher risk than shifts starting in the afternoon. Furthermore, a certain association could be detected, within each type of shift, with the starting hour of the service reflecting the influence of the starting condition of the worker.
5. The results with regard to the pattern of accident risk in the course of various types of shift indicated a characteristic pattern within each shift. Accident risk during the early shift is relatively low at the beginning of task operation, reaches a peak at about the 3rd or 4th hour of service, is followed by a decline and then increases again during the last hours of task operation. Accident risk during the late shift is relatively high at the beginning of service and then declines towards the end of service. In the first, morning part of the split shift a less clear picture could be detected, while in the second, afternoon part an inverted U-shape could be demonstrated.
6. The issue of interest of the study on the diurnal variation of bus drivers' accident risk was the discussion about the role of time of day or time on task in influencing accident risk. It is concluded, that while allowance must be made for certain variations related to the time of day, in accident research one should take full account of the effects of the structure of the work together with the duration of the work, i.e., time on task.
7. The analysis of an interaction between the duration of total (added) rest periods during the shift up to the moment of the accident, and accident risk showed no association between this two factors. The analysis, and therefore the conclusions are restricted to possible effects of total resting time and cannot be extended to possible effects of particular rest periods of different duration and at a different stage within a different shift on accident risk.

8. The results concerning the question whether the sequence of the various shift influences the actual accident risk on a certain day suggested no interaction between the type of shift (or stand-by shift or day-off) on preceding days, actual shift, and accident risk of bus drivers. This leads to the supposition that the accident risk is to an important extent determined by the actual situation on the working day.
9. In the long term a seasonal variation in accident risk seemed to exist; the accident rate is highest in autumn, declines through winter and spring and is lowest in summer. The predictive power of this pattern for a given year is rather small. The circumstances within each year with regard to e.g. weather conditions, are highly responsible for the month to month variation within a certain year. The interpretation of the seasonal influence is sought, in terms of physical properties of the bus and in the dependance of bus drivers on working-schedules.
10. The share of accidents with injury (or death) in the total number of accidents in which bus drivers were involved, was relatively constant in both parts of the study (about 7%). This relatively constant share leads one to suppose that this applies to the general traffic as well. The general traffic accident data in the Netherlands, based on about 55,000 accidents with injury (or death), would in that case regard to about 7% of the total of traffic accidents which can then be estimated on 700,000 to 850,000 per year.

In view of the results of this study it is plausible that, on the one hand, an analysis of accident data can lead to understanding their etiology and the role of various personal and environmental factors; on the other hand, that the occurrence of accidents can be viewed as an indicator of the influence of work on the task performer.

SAMENVATTING

Het onderwerp van dit proefschrift en de artikelen, waaruit het is opgebouwd, is een analyse van de ongevallen van buschauffeurs, werkzaam in een grote busmaatschappij in het Westen des lands.
Aangenomen werd dat het vóórkomen van een verkeersongeval aanwijzingen zou kunnen geven voor mogelijke effekten van de taakuitvoering van een buschauffeur en van zijn taakkondities op de taakuitvoerder.
Deze ongevallenstudie bevat twee delen. Een eerste, explorerend onderzoek van de ongevallen in één vestiging van de busonderneming kon gevolgd worden door een tweede onderzoek van de ongevallen in een andere vestiging van dezelfde maatschappij. In deze tweede studie werden de hypothesen, opgesteld op grond van de resultaten van het eerste onderzoek, getoetst.
De onderwerpen, die in dit proefschrift aan de orde zullen komen zijn: theoretische en praktische problemen bij ongevallenonderzoek, samenhangen tussen ongevalsrisiko en enkele persoonsgebonden faktoren, zoals leeftijd en ervaring en omgevingsfaktoren (taakgebonden) zoals soort van dienst en werktijd.

In een algemeen model, gebaseerd op de opvatting van het bestaan van een interaktief proces tussen mens en omgeving, wordt een ongeval beschouwd als het resultaat van een riskante situatie met of zonder schade en/of letsel en/of dood.
Twee elementen zijn in dit verband belangrijk:

a. De riskante situatie als mogelijk resultaat van bepaalde interakties tussen mens en omgeving.
b. Een onderscheid tussen de riskante situatie enerzijds en het resultaat daarvan, het ongeval, anderzijds.

Benadrukt moet worden dat de gevolgen van het ongeval in de vorm van omvang van de schade of ontstaan van letsel of dood in deze benadering min of meer onafhankelijk zijn van het proces, dat tot de riskante situatie aanleiding gaf.

De operationele definitie van een ongeval was:

> "Een ongeval is een geval van schade aan een bus, of door een bus veroorzaakt, dat gerapporteerd moest worden aan de verzekeringsmaatschappij".

In de praktijk betekent dit alle ongevallen met bussen van deze maatschappij, inklusief de lichtste gevallen. Omdat de chauffeurs aansprakelijk waren indien ze de schade niet meldden, kan men redelijkerwijs verwachten, dat de gegevens inderdaad alle ongevallen betreffen.
Zoals gewoonlijk in het openbaar vervoer, is het vervoersaanbod georganiseerd in verschillende diensten met onregelmatige begintijden.
Een belangrijk facet van de dienstorganisatie van deze busmaatschappij is, dat alle chauffeurs, ongeacht hun leeftijd, ervaring enzovoorts, over alle diensten rouleren, zodat aannemelijk is dat iedere chauffeur een gelijke expositie heeft met betrekking tot dienstsoorten, buslijnen, aantal gereden kilometers, diensturen enzovoorts.

Als schatter voor de feitelijke expositie aan de taak en zijn diverse aspekten is de rijafstand gebruikt, zoals die volgens dienstregeling in de diverse diensten op de verschillende buslijnen gereden moest worden. Dit gaf de mogelijkheid om het ongevalsrisiko uit te drukken in het aantal ongevallen per 100.000 km, het meest gebruikte ongevalscijfer in deze studie. Waar van toepassing werd eveneens het aantal ongevallen per manjaar of een vergelijkbare maat gebruikt.

De resultaten van deze studie kunnen als volgt worden samengevat:

1. Een analyse met betrekking tot de rol van leeftijd en ervaring van buschauffeurs bij hun ongevalsrisiko gaf aanwijzingen voor een sterke negatieve samenhang tussen ongevalskans en ervaring, tot op zekere hoogte gemodificeerd door de leeftijd. De interaktie tussen ongevalskans, leeftijd en ervaring, die hier leek te bestaan, gaf aanleiding tot een meer gedetailleerde aandacht voor de eerste dienstjaren.
2. Een studie, met name gericht op deze eerste dienstjaren toonde systematische verschillen aan tussen groepen chauffeurs uit verschillende leeftijdsklassen, maar met vergelijkbare ervaring: jongere chauffeurs hadden hogere ongevalscijfers dan oudere. Bij jongere chauffeurs was, na een aanvankelijke daling, in het tweede dienstjaar een stijging van de ongevalskans te bespeuren; ouderen gaven alleen een voortdurende daling te zien.

Verder bleek er een korrelatie te bestaan tussen de ongevalscijfers van een aantal buschauffeurs in opeenvolgende perioden van hun dienstverband. Gezien de ernstige methodologische problemen zijn deze resultaten niet geïnterpreteerd in de zin van verhoogde ongevalsvatbaarheid, maar als een uitdrukking van de wisselende leeftijd en ervaring binnen de onderzochte groep buschauffeurs.

3. Met betrekking tot de verdeling van tijdsintervallen tussen opeenvolgende ongevallen kon geen signifikante interaktie aangetoond worden tussen het optreden van een ongeval en de duur van de tussenliggende tijdsperioden.

4. Een analyse gericht op de effekten van dienstsoort op ongevallen van buschauffeurs gaf een sterke samenhang te zien met het ongevalsrisiko. Diensten die 's morgens beginnen, bleken een groter ongevalsrisiko te hebben dan diensten, die 's middags beginnen. Verder was een zeker verband waarneembaar, binnen iedere dienstsoort, met het beginuur van het werk, als uitdrukking van de invloed van de konditie van de taakuitvoerder aan het begin van het werk.

5. De resultaten met betrekking tot het patroon van het ongevalsrisiko gedurende de verschillende dienstsoorten wezen op een karakteristiek patroon binnen iedere dienstsoort. Bij de vroege dienst is de ongevalskans betrekkelijk laag aan het begin van de dienst, vertoont een piek omstreeks het 3e of 4e dienstuur, daalt dan weer om vervolgens weer te stijgen gedurende de laatste uren van de taakuitvoering. Bij de late dienst is de ongevalskans in het begin van de dienst betrekkelijk hoog en daalt dan tot aan het eind van de dienst. In het eerste (ochtend)deel van de gebroken dienst was een minder duidelijk patroon te herkennen, terwijl in het tweede (middag)deel een omgekeerde U-vorm aangetoond kon worden.

6. Bij een studie naar de dagelijkse variatie in ongevalskans van buschauffeurs was de aandacht gericht op een diskussie over de rol van de tijd van de dag of de werktijd bij het beïnvloeden van het ongevalsrisiko. Gekonkludeerd werd, dat hoewel rekening gehouden moet worden met enige wisseling in ongevalskans verband houdend met de tijd van de dag, men in het ongevallenonderzoek ter dege rekening moet houden met effekten van de struktuur en duur van het werk, met andere woorden de werktijd.

7. De analyse van een interaktie tussen ongevalskans en de duur van de gesommeerde rustperioden voorafgaande aan een ongeval in een dienst gaf geen samenhang te zien tussen beide faktoren. De analyse en dus ook deze konklusie heeft alleen betrekking op eventuele effekten van gesommeerde rusttijd. Hiermee wordt geen uitspraak gedaan over een mogelijk effekt van afzonderlijke rustperioden van een bepaalde duur en in een bepaalde fase van verschillende diensten, op het ongevalsrisiko.

8. De resultaten met betrekking tot de vraag of de volgorde van de verschillende diensten invloed heeft op het feitelijke ongevalsrisiko op een bepaalde dag, deden geen interaktie vermoeden tussen dienstsoort (of reservedienst dan wel vrije dag) op voorgaande dagen, dienst op de dag van het ongeval en de ongevalskans van buschauffeurs. Dit steunt de veronderstelling dat de aktuele situatie van de werkdag in hoge mate bepalend is voor het ongevalsrisiko.

9. Op lange termijn lijkt er een seizoensvariatie in ongevalskans te bestaan; het ongevalscijfer is het hoogst in de herfst, daalt gedurende de winter en lente en is in de zomer het laagst. De voorspellende waarde van dit patroon voor een bepaald jaar is echter gering. Kennelijk zijn bijvoorbeeld de weersomstandigheden per jaar in hoge mate verantwoordelijk voor de maandelijkse variatie binnen een bepaald jaar. Voor de interpretatie van deze seizoensinvloed wordt gedacht aan de materiële eigenschappen van de bus en aan de afhankelijkheid van de chauffeurs van vaste dienstschema's.

10. Het aandeel van ongevallen met letsel (of dood) in het totale aantal ongevallen waar buschauffeurs bij betrokken waren, was in beide delen van de studie vrij konstant (± 7%). Dit betrekkelijk konstante aandeel doet veronderstellen dat dit ook wel zou kunnen gelden voor het verkeer in het algemeen.

    De gegevens over verkeersongevallen in Nederland, gebaseerd op ongeveer 55.000 letsel ongevallen per jaar, zouden dan betrekking hebben op ± 7% van het totaal aan verkeersongevallen. Dit kan dan geschat worden op 700.000 à 850.000 per jaar.

Gezien de resultaten van deze studie is het aannemelijk dat enerzijds een analyse van ongevalsgegevens kan leiden tot een beter begrip van hun ontstaanswijze en de rol daarbij van verschillende persoons- en omgevingsgebonden faktoren; anderzijds dat het vóórkomen van ongevallen opgevat kan worden als een indikator van de invloed van het werk op de taakuitvoerder.

ADDENDUM 1

POKORNY, M.L.I. & D.H.J. BLOM. Some theoretical considerations on accident research. (Reprinted with permission from Breakdown in Human Adaptation to "Stress" - Part 2: Human performance and breakdown in adaptation (ed.: H.M. Wegmann) 1984, Martinus Nijhoff Publishers, Boston, etc. for the Commission of the European Communities, Luxembourg).

SOME THEORETICAL CONSIDERATIONS ON ACCIDENT RESEARCH

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INTRODUCTION

Since many years the problems of load and load capacity of task performers have been raised with respect to scheduling, duration and nature of the work and the possible effect thereof on the behaviour and well-being of the task performer.
In 1977 a start was made at the Netherlands Institute for Preventive Health Care/TNO with a project*, of which the purpose could roughly be defined as follows: To develop a useful measuring instrument capable of demonstrating the (assumed) effect of the performance of a task on the task performer and, assuming that this would prove possible, to ascertain to what extent the task effect changes under different task conditions.

The majority of research has been concentrated on describing short-duration effects of physical components of a task on the individual performing that task. The investigations aiming to demonstrate more lasting effects of the task performance on the one hand and the effects of an invariably present mental component of a task on the other, are faced with the absence of a good measuring method enabling interpretation of the to be determined effect in a quantitative way (Broadbent, 1979).
Some known indicators of changes in the condition of the organism can be used under properly controlled laboratory conditions, but their indicator value greatly diminishes when they are used in a real field situation (Johnson, 1970; Lacey, 1967).
The spectrum of influences under which such indicators can change is actually so wide that it is difficult to represent them quantitatively and to interpret the effect of the actual task examined.
The conclusion that must be drawn from the foregoing is obvious: measuring results in respect of the effect of the task on the task performer must actually represent this effect and not all kinds of other, possible, underlying factors.
It was decided to set up a project for examining the effect of an occupational task on the task performer. For practical reasons the task of a

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* Members of the project-team are Drs C.H.J.M. Opmeer and both authors.

busdriver was chosen.
Measurements performed in this investigation can be roughly divided into two categories, viz., measurements with respect to the individual (physiological and psychometric measurements) and with respect to the bus (involving two components: speed of the bus and steering-wheel movements). These measurements are performed under different task conditions (routes, shifts) with respect to task performers in two age groups. In order to improve interpretation of the data, events in and around the bus were observed during the work. In determining the research strategy it was assumed that the effect of the task performance is a cumulative effect. Thus, we assume that the condition of the organism changes under the influence of the task to be performed by this organism. This consideration led to the decision to measure the assumed effect on physiological and psychometric variables not during performance of the task but before, during some rest intervals, and after the performance of the task. These measurements are carried out in a specially equipped mobile laboratory, designed for the purpose. The task-specific measurements are, of course, carried out during task-operation.
Apart from the field study just described, the project contained a methodologically different but in view of the purpose integrated part: the accident analysis.

THE ACCIDENT STUDY

At the beginning of the above-mentioned project during a general orientation on the busdriver's profession an investigation was started of the archives of accident reports of busdrivers in the company where the project was to be carried out. It appeared that the contents of the archives together with other available information about the accidents, the busdrivers and their work-organization, might be interesting for a more detailed analysis relevant for the purpose of the project. It was assumed that the occurrence of a traffic-accident could contain information about possible effects of the task performance of a busdriver, and of the conditions of this task, on the man. However, also in the field of accident research one is faced with the absence of a generally applicable methodology (Hale and Hale, 1972).

The accident study contains two parts because the initial explorative investigation of the above-mentioned accident archives could be followed by a second study of the accidents of a different establishment of the bus

company. In this second study the hypotheses derived from the first part were tested.
In this paper a brief outline will be given of a conceptual model on which accident research could be based. Some practical and methodological problems encountered during the study will be considered in another paper (Blom and Pokorny, 1983).
The results of the first part of the study are published (Pokorny et al., 1983) and the results of the second part will be published in the near future.

THEORETICAL CONCEPTS

Introduction

The following hypothesis was the basis for the project: The performance of an occupational task has a (cumulative) effect on the individual performing this task; the nature of this effect is determined by characteristics of the task itself, of the environment (of which the task forms an integral part) and by individual qualities of the task performer.
With specific reference to the accident study this means that the occurrence of accidents in task situations might give indications concerning existence and nature of the effect of the performance of the task on man.
The basic principle applied was the Stimulus-Organism-Response (S-O-R) concept, which has become a classical concept in psychology. This choice is associated with the assumption that changes in the response to various stimuli can lead to statements on changes within the intermediating variable (the organism); the changes can be interpreted as effects of, i.a., the task performance.
This concept should not be taken as a chain of separate reactions on solitary stimuli, but only serves as a schematic representation of a very complicated interactive proces. With regard to the accident study this proces can also be approached in terms of a man-environment interaction, well-known in epidemiological research (figure 1).

In general it can be assumed that the nature of the response on external stimulation is associated on the one hand with characteristics of the environment, interpreted as sources of stimulation; and on the other with qualities of the individual, the organism.

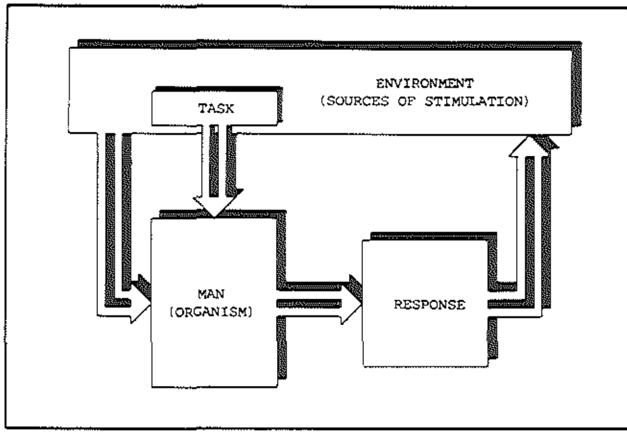

Fig. 1 Scheme of the interaction model.

It is important for the interpretation of the response to have available as much information as possible concerning the stimuli and their sources and concerning the individual reacting to these stimuli.

The use of this concept leads to our conceptual definition:

"An accident is a possible result of a hazardous situation with or without damage and/or injury and/or death".

This is illustrated in figure 2.

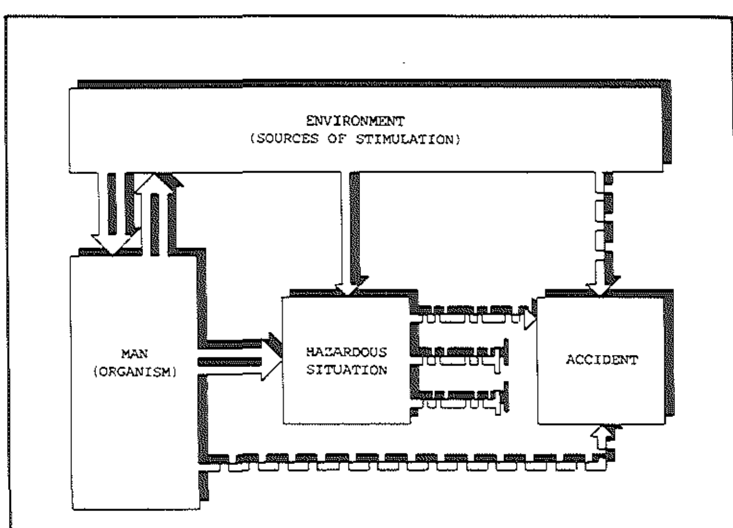

Fig. 2 Scheme of Accident Aetiology.

Two main elements can be discerned in this diagram (figure 2).

1. A central position is occupied by the "hazardous situation".

This is defined as follows:

"A hazardous situation is a possible result of certain interactions between man and environment, which may or may not result in an accident".

2. A differentiation is made between the hazardous situation on the one hand and the possible result thereof, the accident, on the other.

It should be emphasized that the consequences of the accident in the form of the extent of the damage or the occurrence of injury or death are in this approach more or less independent of the process leading to the hazardous situation, since: "..... the same error can have many different consequences, ranging from injury, through damage to equipment, to momentary dislocation of production. The factors which cause errors are not necessarily the same as the factors which cause errors to produce injuries" (Hale and Hale, 1972).

This approach,partly inspired by the critical reports on accident research by, i.a., Kerr (1959), Haddon et al (1964) and Hale & Hale (1972), the epidemiological approach of Mc Farland et al (1955, 1958), the emphasis placed on the process character of accidents by Arbous and Kerrich (1953), can in our view be applied in many task situations in two ways:

1. For analytical-epidemiological investigations of accidents in certain risk groups (as is the case in this study).
2. In any systematic recording of hazardous situations, as done in the work of Hildebrandt et al (1973), and Prokop and Prokop (1955).

In the two components of the man-environment interaction various factors can be distinguished, which to a different extent and in different ways can be important in the process leading to an accident. This will be discussed in more detail further on.

The man-environment interaction

The factors discussed in this section have been subdivided into three categories. This classification (with regard to the individual factors after Häkkinen, 1958) is of an arbitrary nature. In effect the categories gradually merge. In addition, it should be pointed out that only some factors will be mentioned for purpose of illustration.

The following three categories are distinguished with respect to the human component of this interaction:

1. Constant factors or factors showing relatively little change during the

survey period. Factors that would come to mind in this respect are the sex of the individual or his (her) personality structure.

2. Factors that change in the course of time, but which are, in principle, controllable, such as age and experience.
3. Rapidly and(or irregularly changing factors, such as an intercurrent disease, fatigue, etc.

This division into 3 categories has of course consequences for the analysis. It can be said that these categories show a diminishing degree of constancy over time, and conversely an increasing difficulty for controlling these factors in an analytical design, from the first to the third category. Another consequence is that the relevant factors, depending on, i.a., the length of the period surveyed, the composition of the population examined and the questions to be answered by the analysis, will form an uncontrollable source of variability at the level of analysis. The factors of the first and partly the second category can be conceived as personal "qualities", those of the third category as temporal "attributions".

With respect to the environmental component of the interactive process three categories of factors can be distinguished in the same way, both as regards the physical and the social dimensions of the environment:

1. Constant factors or factors showing relatively little change. Factors that come to mind here are static environmental characteristics, ergonomic quality of task instruments or the socio-cultural context of the individual.
2. Factors that change in the course of time, but which, at least in principle, are controllable e.g. secular factors (years, months, etc.) or the alternation of light and darkness, changes in the technical properties of task instruments or organization of the work.
3. Rapidly and/or irregularly changing factors, such as weather conditions, behaviour of other individuals, type of shift, duration of service, etc.

When analysing the accidents allowance must be made for diminishing constancy and/or controllability of the relevant factors from category 1 down to category 3.

Only some of the numerous factors that can come to mind, both in the individual and in the environmental component, are of varying importance in the interactive process that can lead to an accident.

With some of the factors from the first and second categories, which are relatively constant, readily definable and detectable, it may be possible to determine the course of the interaction and the extent to which these factors contribute to the process causing an accident, while other factors cannot or hardly be implied in the research design. In the case of factors from the third category (both with the human and with the environmental component) at least three possible forms of influence on the interactive process can be distinguished:

a. The influence on the interaction is only of marginal importance (in the accident literature sometimes referred to as 'Act of God'). On the individual side this could be for instance a sudden heart attack or stroke, suicide attempts and the like; with respect to the environmental component an example would be a suddenly occurring breakdown of equipment or a natural disaster.
b. The influence on the interaction is completely unsystematic or cannot be determined. Examples: incidental excitement or a light form of hypoglycemia.
c. The influence on the interaction can be established in principle, but is difficult to quantify, at least in an epidemiological study such as the present. Examples: Fatigue and the like (individual); behaviour of other individuals and the like (environment).

Whereas in the case of eventualities mentioned under a. there is actually no question of interaction and a definite cause of the accident can often be demonstrated, the possible causal contribution of factors mentioned under b. will probably remain undetected. The factors mentioned under c. will be discussed further.

The foregoing discussion concerned some categories of individual- and environment-related factors and their influence on the interactive process, which may lead to an accident, arranged according to their degree of constancy. It proved possible to draw up an analogous order for both the individual and the environmental components. Another approach to these factors, which in our view is also of great importance, is to draw up an order according to the degree of (mutual) influence. With this approach, however, a difference can clearly be observed between the two components. Whereas with a number of factors of the individual component the influence by situational aspects may be assumed to increase as the constancy of the relevant factors is diminishing, a comparable reasoning cannot be followed in the case of the environmental component. It would after all be true to say that the momentary situation in the time preceding the accident cannot be influenced by the individual concerned.

As mentioned before, the influence of individual factors is reversely associated with the constancy of these factors. It need hardly be pointed out that age or sex for instance are not at all dependent on the interaction, while hazardous behaviour for example and to an even greater extent such factors as "fatigue" and speed of information processing can be influenced by the interaction with the environment.

Selection problems

In the approach outlined above one should, ideally, wish to have information concerning all events which could be defined as "hazardous situations", i.e. information concerning the distribution of the probability of such an event taking place. In the analysis of (road) accidents one is, however, confronted with the fact that the information usually available only relates to registered accidents. Quite apart from representativity problems in connection with the completeness of the various registration systems, the implication is that the analysis of factors that may have contributed to the occurrence of the situation from which an accident resulted is influenced by selection bias right from the start.
Hence, only those data are available for which the results of these events have acquired a given form, viz. damage and/or injury and/or death, i.e. information concerning the distribution of the probability of an accident. The two probability distributions are theoretically not identical. One could say that the probability of an accident is determined by the probability of a given event and some other factors. This means that the probability of an accident is a selection from the distribution of the probability of a given event taking place.

Nevertheless, we take the view that this selection need not necessarily distort the analysis results to any serious extent, if the hypothesis is correct that the above-mentioned other factors determining the result of a hazardous situation (hence, whether or not an accident, with appertaining damage and/or injury, takes place) follow mainly a random distribution. This hypothesis can be illustrated with the following example: A driver of a car applies the brakes suddenly on a wet road - the hazardous situation. The result of this situation can differ widely, ranging from simply driving on after braking; a fright for the driver if the skids, but manages to regain control over the car; a dent in the wing of the car, if a small post happens to be in the way; serious material damage with possible injury to the driver, if there happens to be a tree in the way during skidding; to a complete catastrophy, if there is no post or tree in the way during skidding, but a class of infants happens to be walking there.

Only in some cases the results might still be influenced systematically. Such influence could take the form for instance of an association between the extent of the damage and the size of the vehicle (heavy trucks; Bygren, 1974), or the suspicion expressed in the literature that during the night shift fewer, but more serious accidents take place (Andlauer and Metz, 1967; Fröberg, 1974). Hence, it is important when analysing possibly causal influences on the occurrence of accidents to make allowance for this selection and, if possible, to imply these factors in the analysis by checking the results of categories of accidents with different extent of damage.

The interaction

In the analysis it will generally be easier to include data from categories 1 and 2 of both the individual and the environmental components of the interaction model described in the preceding section than from the categories 3. In order to improve the possibility of explaining the variability in the occurrence of accidents, it would seem necessary not just to involve the more or less constant factors from these categories in the analysis, but also as much as possible factors from the two categories 3. It must be endeavoured to establish a possible systematic influence on individual factors in this category by situational aspects. Since these rapidly and/or irregularly changing individual factors are hard to define and to operationalize (Muscio, 1921; Broadbent, 1979), a description of the conditions under which the individual must function might be helpful. The results of these analyses could then be interpreted under specified conditions as effects of momentary attributions of the individual. A certain amount of variability will for that matter probably remain unexplained. For the sources of such variability reference may be made to the previously mentioned non-systematic influences from the two components of the man-environment interaction, as well as to possible systematic influences from the environment on the individual, of which the source of stimulation cannot be detected or be implied in the analysis. Examples of this would be changes emanating from the environment to which individuals can, of course, react quite differently, but which may nevertheless have a systematic effect on the occurrence of accidents.

SUMMARY

- In accordance with the purpose of this study it is assumed that the occurrence of an accident might present indications of the existence and nature of effects of the task performance on man.

- An accident is defined as a possible result of a hazardous situation with or without damage and/or injury and/or death.
- A hazardous situation is defined as a possible result of an interaction between man (the organism) and his environment (sources of stimulation).
- The consequences of the accident (extent of the damage, etc.) are more or less independent of the process that led to a hazardous situation.
- In both components of the man-environment interaction three analogous categories of factors can be distinguished within the analytical-epidemiological design used:
  1. Constant factors or factors showing relatively little change during the survey period.
  2. Factors which change in the course of time, but which are, at least in principle, controllable.
  3. Rapidly and/or irregularly changing categories.

From category 1 to category 3 one can speak of a diminishing constancy, an associated diminishing controllability, and in the case of the individual component of an increasing possibility to be influenced in the interaction.

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ADDENDUM 2

BLOM, D.H.J. & M.L.I. POKORNY. Accidents of bus drivers - practical and methodological problems. (Reprinted with permission from: Breakdown in Human Adaptation to "Stress" - Part 2: Human performance and breakdown in adaptation (ed.: H.M. Wegmann) 1984, Martinus Nijhoff Publishers, Boston, etc. for the Commission of the European Communities, Luxembourg).

ACCIDENTS OF BUSDRIVERS - PRACTICAL AND METHODOLOGICAL PROBLEMS

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INTRODUCTION

An important discovery at the onset of the project (as mentioned in the previous paper, Pokorny and Blom, 1983) was that because of insurance regulations all bus accidents, whatever the damage may be, with or without injury, had to be reported to the company. This fact, together with the existance of an archive containing information about accidents which had happened in previous years, formed the beginning of this part of the study. These findings can be considered as some of the basic conditions for an accident analysis to yield satisfactory results. The operational definition of an accident was therefore:

"An accident is an event of damage to a bus, or by a bus, that needed to be reported to the insurance company".

In practice this means all accidents of busses of that company, including the very minor ones. Because of the liability of the busdrivers in case of not reporting one can reasonably assume completeness of the data. The accident data collected represent that part of the hazardous situations as meant in the previous paper, in which the result has taken a given form.

Part of the information about the accidents and the circumstances in which they occurred was available on the accident forms. The greater part of the context information, however, had to be sought in other sources, like time-tables etc. (figure 1).

In this paper the various sources used and the problems encountered therewith will be discussed. A brief outline is given of the method to assess accident risk under different conditions of work, and of the consequencies for the analysis.

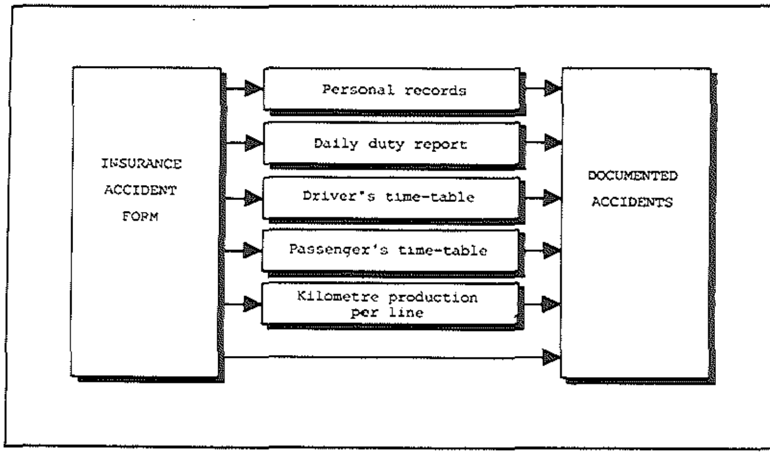

Fig. 1 Sources of the documented accidents.

SOURCES OF INFORMATION

The accident form

This form, the basis of the data used in this study contained the following information:

- Name of the busdriver;
- Date, hour and place of the accident;
- A number of other relevant data as type of bus, weather, road condition, collision-object, extent of damage or injury, etc.

The name of the driver, date, time and place of the accident gave the necessary connection to context information from other sources.

Not every form was completed correctly, resulting in missing data, but also in the impossibility to identify the exact shift the driver was working on the day of the accident.

Personel records

Information about the bus drivers was available from the personel department of the bus company. This included date of birth, date of entering into employment, if applicable termination of employment not only of bus drivers involved in one or more accidents, but of all drivers of the company. These data are necessary to describe the population under study with regard to the possibility to incur an accident. In other words: the population at risk. A problem encountered in this respect is, that sometimes it is difficult to establish the date of a person entering into employment as a bus driver - not as an employee in other functions.

Another source of data for possibly important individual factors influencing accident risk could be the results of entry-examination, periodic health examinations etc. These data are however collected in a nonstandardized way and were therefore left out of consideration.

Daily duty reports

Daily duty reports are forms containing day to day information about the bus drivers on duty, their names, the number of the shift they were working, the number of the bus they were taking from the garage etc. These reports which are kept in the archives of this particular bus company for at least five years proved to be almost essential to connect a certain accident to the necessary context information. Using the name of the driver, date, time and place of the accident from the accident form it was possible to reconstruct exact information about the actual shift the driver was working on the day of the accident.
Problems: Besides missing reports, sometimes the information from the accident form differed from the data on the daily duty report, due to irregularities in the execution of the services (illness of driver on duty, etc.).

Driver's Time-tables

Every time a new passengers' time-table of bus-line operations is issued and sometimes in between, due to changes in the drivers' schedule-organization, new drivers' time-tables are made with more or less changes, or completely renewed. Such a time-table is valid for some months up to more than one year. They contain information about all line-runs to be made by all drivers on the different buslines on every day of the week during the period of validity. This includes time of departure and arrival of every run, and, because a certain number of runs is combined into a shift, the time of commencement and ending of each (numbered) shift. Multiplied by the number of weeks of validity, these tables contain the basic information about the *exposure* of all drivers of that company to their task, viz. when and how long each of them was on duty, and therefore also their exposure to the risk of incurring a bus accident.
Complementary to this information the time-tables also contain the shift schedule system for the current period of validity, i.e. the order in which (groups of) drivers were supposed to be on duty in each of the numbered shifts described, during the successive days, weeks, months etc. of that

period of validity. This shift schedule forms the basis of the daily duty report already mentioned.

Some of the problems in this part of the data collection can be described as follows:

1. All information in the time-tables is related to the *scheduled* line-runs and shifts, not the *actual* time or distance covered by each driver;
2. One has to decide which unit of exposure should be used (see below);
3. As routes, frequencies of runs and therefore schedules change from time to time it is necessary to assess this exposure apart for each period of validity of a schedule.

In figure 2 some of the changes from period to period are shown.

	PERIODS OF VALIDITY								
	1	2	3	4	5	6	7	8	9
number of shifts per week	415	486	528	578	578	549	554	537	525
number of weeks per period	22	31	20	49	28	28	11	40	32

year of registration: 1973 | 1974 | 1975 | 1976 | 1977

Fig. 2 The various periods a time-table was valid, length of the period of validity and number of shifts per week in each period (first study).

Not only the length of the period and the number of shifts per week as shown in figure 2 are varying but also the relative frequency of the different types of shift (figure 3). In the company at issue three types of shift can be discerned:

- Early shift: shifts with a mean duration of 8 hours, starting between about 5.30 hours and 10.00 hours (before noon);
- Late shift: shifts with a mean duration of 8 hours, starting between about 13.00 hours and 17.00 hours (after noon);
- Split shift: compound shifts, consisting of two parts. The first part starting between 6.00 to 8.00 hours and lasting for about 3 hours; the second part starting between 13.00 to 15.00 hours and lasting for about 5 hours. This means that a person on a split shift starts working early in the morning for a shorter part of his shift, is off duty for 3 to 4

hours and then starts working again in the afternoon for the second (longer) part of his shift.

The relative frequency of these shifts, in the successive periods of validity of a time-table are shown in figure 3.

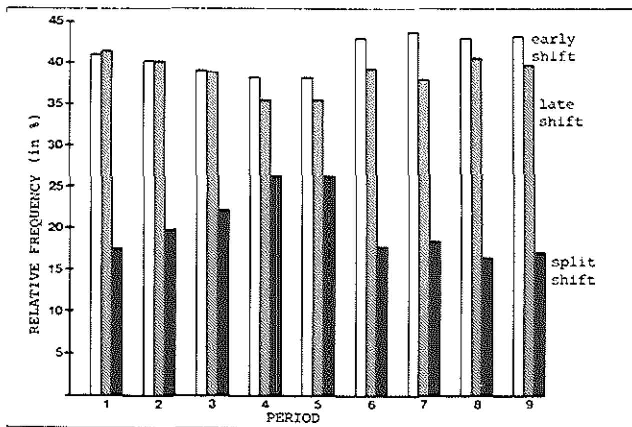

Fig. 3 Relative frequency of early, late and split shifts in the successive periods of validity (first study, 1973 - 1977).

Passenger's time-tables

These time-tables contain basically the same information on all line-runs as the driver's time-tables, only arranged in a different way, viz. per line (route) number and not per shift. They are used for reference and clarification only.

Kilometre production per line

From time to time the accounting office of the bus company makes an assessment of the number of passengers-kilometres (as unit of production), based on the known length and frequency of each line-run, during a certain period of validity of a schedule.
A problem is that this assessment is not made for every period.
For the missing periods one has to assess the kilometre-production by extrapolation from the known periods using the information on changes of line-runs (frequency, length) from the time-tables. Alternatively this assessment can be made by computing from the time-tables after addition of the number of kilometres to each line-run.

EXPOSURE

An important feature of the shift-organization of this particular bus company is that all drivers perform all shifts on rotating schedules, therefore each driver has a comparable exposure regarding shifts, bus line, kilometres driven, hours of service etc. This can be described as a 'found experiment' (Boyle, 1980) because in this population at risk a kind of randomization has taken place with regard to the mentioned variables of interest. The comparability of the exposure of all members of the population is a 'conditio sine qua non' for a valid analysis.

As to the *unit of exposure*, the use of the number of days (or weeks etc.) worked in various shifts seems not to be justified due to large differences between the contents and length of each shift and therefore its exposure to the risk of the driver to be involved in an accident. The same applies for line-runs.

This is illustrated in figure 4 in which a scheme is drawn of a part of the shift-schedule with three shifts (No. S_1, S_2 and S_3) and in each shift a varying number of line-runs of various length (above the line). The first run covers a distance of x_1 km and has a duration of y_1 hours etc. Below the line are shown the rest periods between the line-runs, also of variable duration (sometimes non-existent) the first r_1 min. etc.

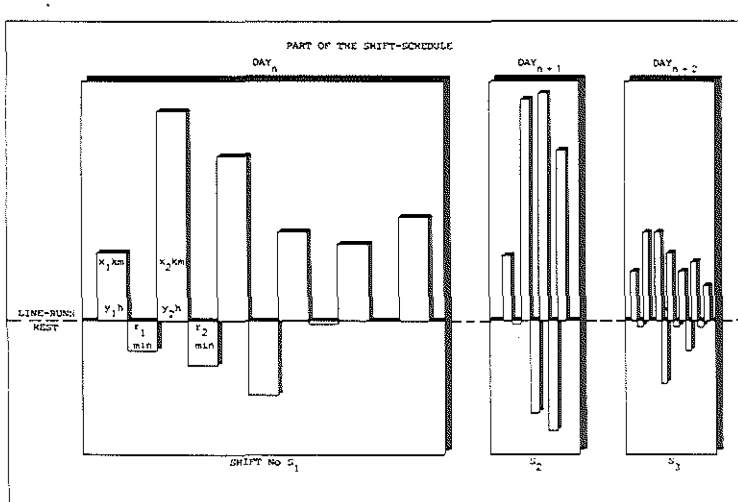

Fig. 4 Schematic representation of a part of the shift-schedules*

* The diagram of shift No. S_1 has been magnified to show the contents more clearly.

The best, well-defined, estimator of the actual exposure to the task is, in our opinion, the driving-distance and/or driving time scheduled in the various shifts on each bus line. The use of this unit of exposure gives the possibility to assess risk in terms of the number of accidents per 100.000 km or per 1000 hours driven, the most commonly used accident rate in this study. Where applicable also the number of accidents per man-year or comparable rates are used. The choice of the accident rate is an important one, a different rate can give a different picture because of a different assessment of the exposure to risk (Bygren, 1974; Borkenstein, 1977). Thus accident rates can be computed per bus line, type of shift, year, month, day and hour etc., and the statistical testing of differences between various rates can be based on expected numbers of accidents, derived from the number of kilometres driven under each condition (see Appendix).

THE TWO PARTS OF THE STUDY

Because of the nature of the available data, knowledge about the population at risk and an estimation of their exposure to the risk of incurring an accident, the possible influence of various factors of the man-environment interaction as mentioned in the previous paper could be assessed and in the explorative part of the study hypotheses could be derived about the strength of their association with the occurrence of accidents and with hazardous situations. In the first part only accident rates based on the number of kilometres driven were used. These numbers were estimated from the kilometre-production data of the company for some periods and our extrapolation for the other periods.
Data were available of 944 accidents in 5 years (1973 - 1977) of 197 bus drivers from one establishment of the bus company, which covered a total of more than 27 million kilometres. A complete report on the results is available (Pokorny et al., 1983) and a series of papers is in preparation.
In the second part of the study on accidents of busdrivers of another establishment of the same company, all data, not only from the accident forms and personel records, but also from all time-tables with addition of the number of kilometres per line-run, were put into computer-files. Accident rates will be computed based on both the number of kilometres and the number of hours driven. The procedure is illustrated in figure 5.

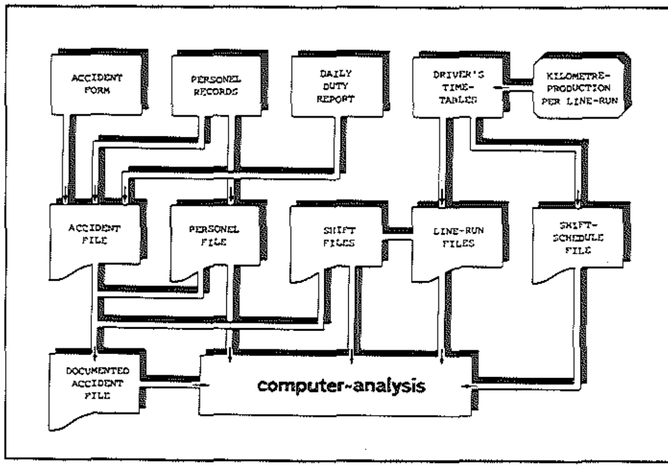

Fig. 5 Scheme of the data-handling in the 2nd part of the study.

To test the hypotheses derived from the first part of the study, data are available of 2130 accidents of 427 drivers in a period of 8 years (1973 - 1980). During this period they covered more than 42 million kilometres in 1,762,000 hours.

APPENDIX

Format of statistical testing

Suppose for a certain variable A the material is distributed in i categories $A_1, A_2, \ldots A_i$, and let $K_1, K_2, \ldots K_i$ be the corresponding numbers of kilometres driven, $O_1, O_2, \ldots O_i$ the observed numbers of accidents.

Given the null hypothesis that the probability of an accident is only depending on the number of kilometres driven, the expected number of accidents can be calculated using the following expression:

$$E\,(O_{A_i}) = \frac{K_i}{\sum_{i=1}^{i} K_i} \sum_{i=1}^{i} O_i \qquad (1)$$

The value of

$$X^2 = \sum_{i=1}^{i} \frac{\left[O_{A_i} - E(O_{A_i})\right]^2}{E(O_{A_i})} \qquad (2)$$

approximates a χ^2-distribution with i-1 degrees of freedom.

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ADDENDUM 3

BLOM, D.H.J., M.L.I. POKORNY & P. VAN LEEUWEN. The role of age and experience in bus drivers' accidents. (Submitted for publication).

THE ROLE OF AGE AND EXPERIENCE IN BUS DRIVERS' ACCIDENTS

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Abstract

This paper contains a part of the results of a repetative and comprehensive analysis of accidents of bus drivers. In a series of articles different aspects of the etiology of bus drivers' accidents will be high lighted. The results presented indicate a strong negative association of experience with accident risk,modified to a certain extent by age. The suggested interaction between accident liability, age and experience warrants a more detailed attention for the first few years of employment.

INTRODUCTION

Among the human variables studied in accident research much emphasis is given to age as a factor in the causation of industrial or traffic accidents. Although it is commonly noted that experience has a modifying effect in this respect, difficulties often arise in implementing the latter factor in the research design because of the confounding influence of age. In the literature this problem is recognised (1) and different solutions have been tried. Johnson & Garwood (2) e.g. used the duration of an insurance policy as an estimation of experience in their investigation of the claim records of a motor insurance company. They found a high claim rate during the first year of insurance, and some evidence of a further improvement over the next few years which might be attributed to learning. As regards age, it appeared that the group which starts between the ages of 18 and 27 tends to have a claim rate higher than the average, for about 8 years. However, as the authors pointed out themselves, it is the liability of policies to claims rather than of drivers to accidents that have been studied. Variations of mileage per year were not known so that the results cannot be interpreted in terms of accident rate per mile.

Adelstein (3) found in his study of the accidents of railway shunters that experience was the most critical variable in the initial year of service, but that age played some part also, because the initial accident -rate of workers aged 21-25 was significantly higher than that of workers aged 26-30. Van Zelst (4) came to similar conclusions.

The role of age and experience in traffic accidents was part of an investigation of bus drivers' accidents and the results are presented in this paper. This accident study formed part of a large-scale project of which the purpose can roughly be described as follows: To develop a useful measuring instrument capable of demonstrating the (assumed) effect of the execution of an occupational task on the task performer and, assuming that this would prove possible, to ascertain to what extent the task effect changes under different task conditions. Measurements performed in this project can roughly be divided into two categories, viz., measurements with respect to the individual (physiological and psychometric measurements) (5) and with respect to the bus (involving two components: speed of the bus and steering- wheel movements). These measurements are performed under different task conditions (routes, shifts) for task performers in two age groups. In order to improve interpretation of the data, events in and around the bus were observed during the work (6, 7).

Apart from this experimental oriented field study, the project contained a methodologically different, but in view of the purpose, integrated part: the accident analysis.
The following assumption was the basis for both parts of the project: the performance of an occupational task has a (cumulative) effect on the individual performing this task; the nature of this effect is determined by characteristics of the task itself, of the environment (of which the task forms an integral part) and by individual qualities of the task performer.
With specific reference to the accident study this means that the occurence of accidents in task situations might give indications concerning existence and nature of the effect of the performance of the task on the performer. In a theoretical model of accident etiology as the result of a man-environment interaction, more broadly described in Pokorny & Blom (8), age and experience can

be distinguished as individual factors which change in the course of time, but which are, at least in principle, controllable in the analytical - epidemiological design. Experience is referred to in terms of numbers of years of employment by the bus company where the study was conducted.

MATERIAL AND METHODS

This accident study contains two parts. The initial, explorative, investigation was followed by a second, replicative, part of the study of the accidents of a different branch of the same bus company. In this second study the hypotheses derived from the first part were tested.
The operational definition of an accident was:

> **"An accident is an event of damage to a bus, or by a bus, that needed to be reported to the insurance company".**

In practice this means all accidents of buses of the company involved, including the very minor ones. Because of the liability of the bus drivers in case of not reporting one can reasonably assume completeness of the data.
Part of the information about the accidents and the circumstances in which they occurred was available on the accidents forms, e.g. name of the bus driver, time and date, environmental circumstances. The greater part of the context information, e.g. type of shift, date of employment, however, had to be found in other sources, like time-tables, duty reports, personal records, etc.
Changes in personnel, differences in age and experience (in the company at issue) of the bus drivers, varying frequency and routing of the buslines, etc.were accounted for in processing the data (9).

An important feature of the shift organization of this particular bus company is that all drivers perform all shifts on rotating schedules, therefore each driver has an equal exposure regarding shifts, bus line, kilometres driven, hours of service, etc. Thus a comparability is reached, which in experimental research can only be attempted by randomization. Younger and older, more or less experienced drivers are exposed in a comparable manner.
When in an accident study this comparability of exposure cannot

be realised, the range of the propositions that can be made is seriously degraded.
In the first study information was available about 197 drivers and 944 accidents in 5 years (1973-1977). In these years they covered a total of more than 27 million kilometres. In the second study 427 drivers and 2130 accidents were investigated over a period of 8 years (1973-1980). During this period they covered more than 42 million kilometres in 1.762.000 hours of driving.
In both parts of the study subselections of drivers and their accidents have been used to ensure comparability of time of exposure, because not all drivers were in service during the full period of observation. Because of the comparability of contents and duration of the driver's task a man-year can be used in this analysis as a valid estimator of exposure, provided that where applicable allowance is made for yearly changes in task-content of a man-year (e.g. distance driven per man-year).

RESULTS

Age

In the first study 96 drivers were in service during the full 5 years of observation*. For the analysis of the effect of age, without considering experience, they have been classified in 5-year age groups, according to their age in the middle of the observation period (1-7-1975). These drivers were involved in a total of 592 accidents. In fact the frequency of accidents in 5 year birth-cohorts are compared in this analysis. In each group the number of persons was counted with 0, 1, 2 ...x accidents in 5 years time. The results are presented in table 1.
An analysis of variance has been performed on these data. The overall result showed no statistical differences between age groups. The linear regression component gave a value of $F_{(1.90)}=6.76$; ($p \cong 0.01$), indicating a negative association of the number of accidents with age. The residual component had a value of $F_{(4.90)}= 1.65$; ($p \cong 0.20$).

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* On methodological grounds only the data of these drivers were presented. The results are not biased by selection problems of other, not included, drivers as the results of the analysis of the total data did not differ (7).

Table 1. Number of drivers with different number of accidents, total number of accidents, total number of drivers and mean number of accidents per man in 5 years, for different age-groups. Part 1, 1973-1977.

Age-group	Number of accidents												Total number per age-group		$\bar{X}$ acc/ bus driver
	0	1	2	3	4	5	6	7	8	9	10	≥11	Acc.	Bus drivers	
21 - 25	-	-	-	-	-	-	-	1	-	-	-	1	21	2	(10.5)*
26 - 30	1	2	-	1	1	2	2	6	1	2	3	5	190	26	7.3
31 - 35	-	1	-	1	5	1	2	1	1	2	-	2	101	16	6.3
36 - 40	1	-	1	1	2	2	1	2	1	1	2	-	80	14	5.7
41 - 45	-	-	4	2	2	1	-	-	1	1	-	2	66	13	5.1
46 - 50	-	-	-	4	2	2	1	3	-	-	-	-	57	12	4.8
51 - 55	-	2	1	1	-	2	-	1	-	1	-	2	61	10	6.1
56 - 60	-	-	-	1	-	-	1	-	-	-	-	-	12	2	(6.0)*
61 - 65	-	-	-	-	1	-	-	-	-	-	-	-	4	1	(4.0)*
Total	2	5	6	11	13	10	7	14	4	7	5	12	592	96	6.2
Testing of differences between age-groups	$F_{(5.90)} = 1.62$; $p \cong 0.16$; n.s.														

* Means of extreme small groups. In testing included in age-group <31 years, or >51 years resp.

This result has been taken as a hypothesis to be tested in the second study. For reasons of symmetry in the second study the analysis has been performed twice: firstly for exactly the same period and the same age-classification (1973-1977; age at 1-7-75), secondly for the last 5-year period (1976-1980; age at 1-7-78). Both times, of course, drivers and their accidents were selected, who were in service during the full 5 year period concerned. For the first analysis 515 accidents of 106 drivers were available, for the second the figures were 584 and 117 resp. Both are presented in table 2.

The analyses show no significant differences in accident liability between the various age-groups (age at 1-7-75: $F_{(5.97)} = 1.79$; age at 1-7-78 : $F_{(4.105)} = 0.47$). In this second part the linear regression component had in the first analysis a value of $F_{(1.97)} = 5.45$; $p \cong 0.02$; the residual component $F_{(4.97)} = 0.88$; $p \cong 0.40$, whereas in the second analysis the regression component gave $F_{(1.105)} = 1.92$; $p \cong 0.17$; and the residual component $F_{(3.105)} = 0.04$; $p \cong 0.90$. Of course, these analyses are not completely independent as they regard in part the same persons and accidents. These results, which are graphically presented together with the findings from the first part in figure 1, confirm the hypothesis and it can be concluded, that though a tendency for declining accident risk with age is apparent, no significant effect of age can be demonstrated because of the high variability within each age-group.

Figure 1. Mean number of accidents (per man in 5 years) in different age groups. Part 1 (1973-1977), Part 2 (1973-1977) age at 1-7-75: 75 and (1976-1980) age at 1-7-78): 78

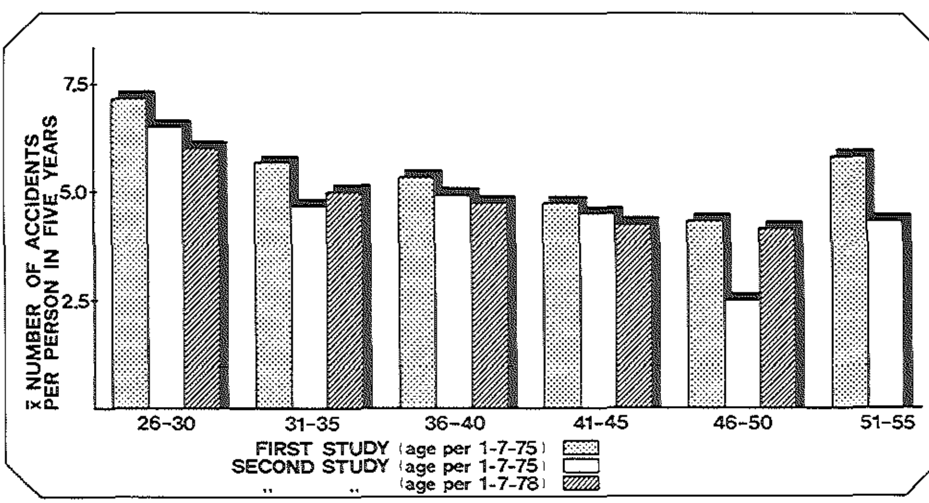


Table 2. Number of drivers with different number of accidents, total number of accidents, total number of drivers and mean number of accidents per man in 5 years, for different age-groups. Part 2, 1973-1977 (age at 1-7-75) : 75; 1976-1980 (age at 1-7-78) : 78

Age-group		Number of accidents												Total number per age-group		$\bar{X}$ acc/ bus driver
		0	1	2	3	4	5	6	7	8	9	10	≥11	Acc.	Bus drivers	
21-25	75	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-
	78	-	-	-	-	-	-	-	-	-	-	1	1	28	2	(14.0)*
26-30	75	-	1	1	1	3	4	2	1	1	2	-	4	132	20	6.6
	78	-	3	1	2	-	1	3	-	-	1	-	3	86	14	6.1
31-35	75	-	4	4	1	4	2	4	1	2	1	2	-	117	25	4.7
	78	3	2	3	3	6	4	4	3	3	4	1	3	183	36	5.1
36-40	75	-	3	3	4	3	4	1	-	-	-	2	3	116	23	5.0
	78	-	2	4	3	3	6	1	1	1	1	-	2	116	24	4.8
41-45	75	5	-	3	1	1	3	2	-	-	2	-	2	87	19	4.6
	78	1	5	3	4	1	2	4	4	-	1	-	1	111	26	4.3
46-50	75	1	1	1	2	1	1	-	-	-	-	-	-	18	7	2.6
	78	1	1	3	1	-	1	-	1	-	-	2	-	42	10	4.2
51-55	75	1	-	3	-	1	1	1	1	-	-	-	1	40	9	4.4
	78	-	-	1	1	-	-	-	-	-	-	-	-	5	2	(2.5)*
56-60	75	-	1	-	1	-	-	-	-	-	-	-	-	4	2	(2.0)*
	78	-	-	-	1	-	2	-	-	-	-	-	-	13	3	(4.3)*
61-65	75	-	1	-	-	-	-	-	-	-	-	-	-	1	1	(1.0)*
	78	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-
total	75	7	11	15	10	13	15	10	3	3	5	4	10	515	106	4.9
	78	5	13	15	15	10	16	12	9	5	4	3	10	584	117	5.0

Testing of differences between age-groups

LF = 75 : $F_{(5.97)} = 1.79$, $p \cong 0.12$; n.s.

LF = 78 : $F_{(4.105)} = 0.47$, $p \cong 0.75$; n.s.

* Means of extreme small groups. In testing left out of consideration.

Age and experience

When the interrelated factors age and experience are studied together, one is faced with the fact that within a certain 5-year age group, viewed as a cohort of persons that can be followed for e.g. 5 years, experience is changing every year. As the first few years of employment are the focus of interest one has to depart from yearly data. In the analyses to be presented, therefore, numbers of accidents and numbers of man-years have been calculated for every year of registration separately. As these yearly figures relate to far too small groups, the age-groups have been expanded to 10 years and the yearly figures have been summarized for the consecutive years.
A methodological flaw of this approach is that the denominator does not represent persons, but man-years in a certain constellation of age and years of employment. Nevertheless, an impression can be derived from this analysis, as is shown in the following tables and graphs. Data from the first study are presented in table 3 and figure 2.

Figure 2. Accidents per man-year, by age and year of employment Part 1, 1973-1977

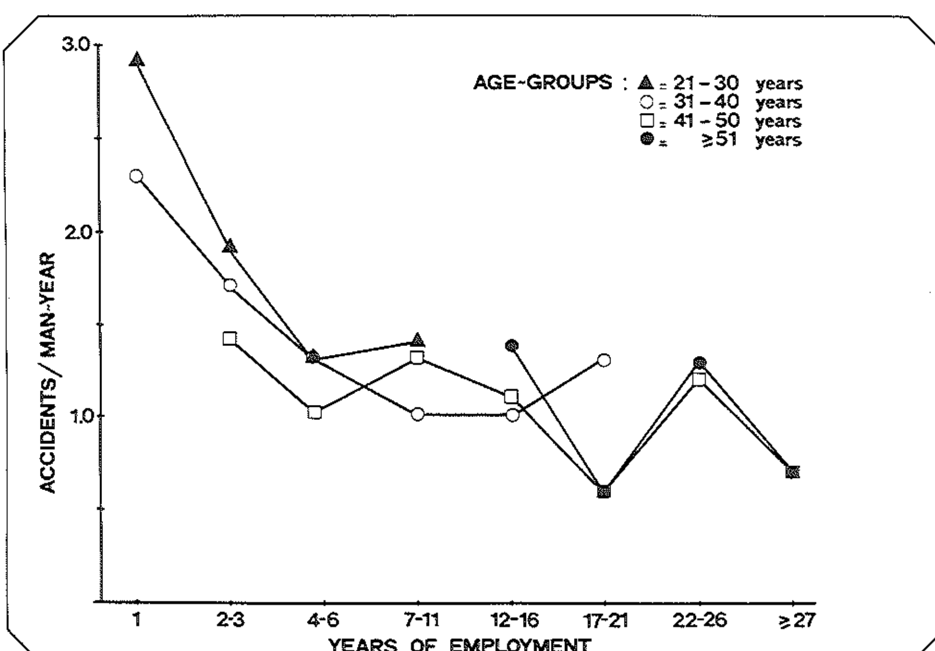


Table 3. Accidents per man-year, by age and year of employment. Part 1, 1973-1977

Age-group		Years of employment							
		1	2-3	4-6	7-11	12-16	17-21	22-26	27 or more
	a	2.9	1.9	1.3	1.4	-	-	-	-
21 - 30 years	b	78	165	100	36				
	c	27	89	78	26				
	a	2.3	1.7	1.3	1.0	1.0	1.3	-	-
31 - 40 years	b	34	88	53	65	48	9		
	c	15	52	41	68	47	7		
	a	-	1.4	1.0	1.3	1.1	.6	1.2	.7
41 - 50 years	b		10	19	48	51	21	15	4
	c		7	20	38	48	34	13	6
	a	-	-	-	-	1.3	.6	1.3	.7
51 years or older	b					19	5	31	43
	c					15	8	23	59

a = mean number of accidents per man-year

b = number of accidents

c = number of man-years

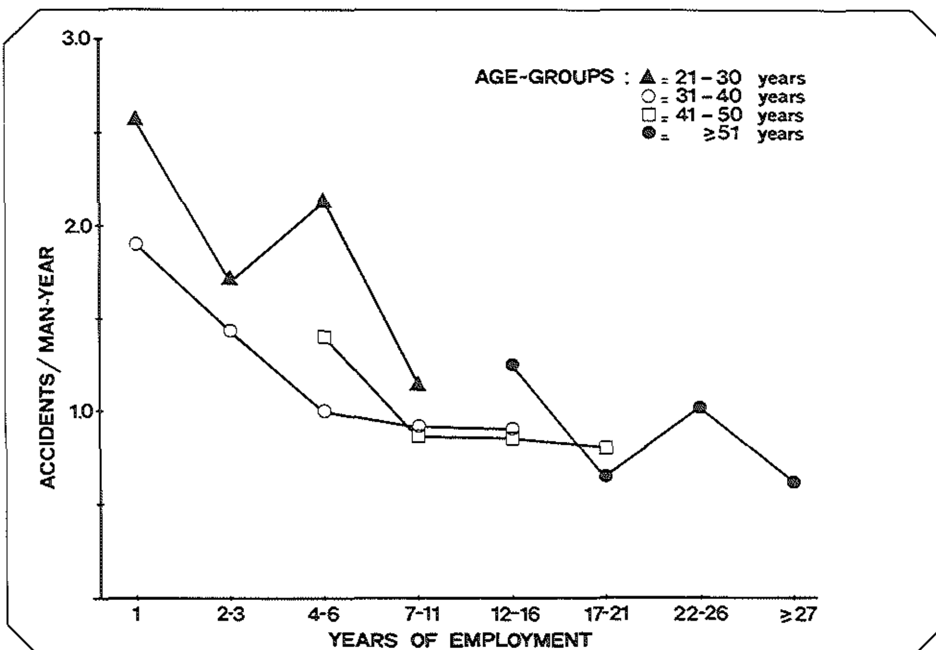
Clearly the mean number of accidents becomes gradually lower for the groups with more experience. On the other hand, age appears to be a modifying factor during the first few years of employment: drivers aged 21-30 years had a somewhat higher mean number of accidents per man-year than their colleagues aged 31-40 years.

The same approach has been used on the material of the second study. And again the analysis was performed twice: with age at 1-7-75 for the first five years (1973-1977) and with age at 1-7-78 for the last five years (1976-1980). The results confirmed the picture found in the first part of the study. This is illustrated with the data of the last five years in figure 3.
Therefore, the negative association of accident risk with age as demonstrated in the preceding section, can probably be attributed

in part to the presence of less experienced drivers in the younger age-groups.

On this level of analysis no statistical tests were performed, as the method of summarized man-years used provides an unsatisfactory basis for calculating expected values from a statistical point of view.

Figure 3. Accidents per man-year, by age and year of employment Part 2, 1976-1980



DISCUSSION

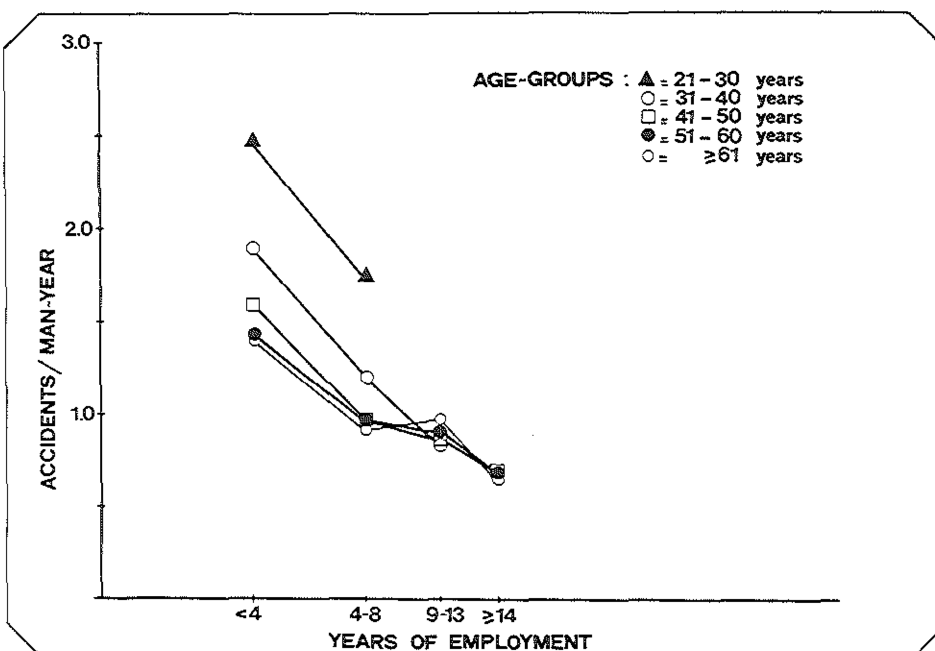
The results of both the explorative and the hypothesis-testing part of the study indicate no decisive effect of age, as such, on accident liability. When experience is accounted for, a decrease of accident level shows up during the first few years of employment, while age seems to play a modifying role.
These findings corroborate other studies of accidents by bus dri-

vers e.g. Cresswell & Froggatt (10), Cornwall (11), Spratling (12).

Comparison of these studies with the material presented in this paper, is possible, because they all analyze data on bus drivers and all the authors used the same definition of accidents. Data of the study of Cornwall on accidents of London Transport bus drivers have been reconstructed and are presented in figure 4.

A comparable pattern emerges from this figure, suggesting a curve-linear association with experience in the interaction between accident liability, age and experience, warranting a more detailed attention for the first few years of employment.

Figure 4. Accidents per man-year, by age and year of employment. Reconstructed (with permission) after Cornwall (11) (Copyright, 1962, Pergamon Press)



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(Submitted for publication to the International Journal of Epidemiology)

ADDENDUM 4

BLOM, D.H.J., M.L.I. POKORNY & P. VAN LEEUWEN. The first years of employment as a bus driver and accident liability. (Submitted for publication).

THE FIRST YEARS OF EMPLOYMENT AS A BUS DRIVER AND ACCIDENT LIABILITY

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Abstract

This paper contains a part of the results of a repetative and comprehensive analysis of accidents of bus drivers. In a series of articles different aspects of the etiology of bus drivers' accidents will be high lighted.
The data presented in this paper show a negative association of experience and accident liability of bus drivers.
Systematic differences appeared to exist between groups of drivers of different age-groups but with comparable experience: younger drivers had higher accident rates than the older. An increase of accident risk during the second year of employment after an initial decline could be detected in the younger group of drivers; the older group only showed a continuous decline.
A correlation appeared to exist between accident rates of some bus drivers in successive periods of employment. Given the heavy methodological problems these results have **not** been interpreted in terms of accident-proneness but in a variation of age and experience within the group of bus drivers under investigation.

INTRODUCTION

In a previous publication (1) the role of age and experience in bus drivers' accidents was investigated. The conclusions suggested an important influence of experience warranting a more detailed attention for the first few years of employment. Within the frame of a larger project concerning task effects of a bus driver task on the man, of which the accident study formed a part (2), data were available of groups of bus drivers who could be followed with respect to their accidents, during some years after employment.

In the history of accident research often personal characteristics presumed to contribute to accident liability have been viewed within the concept of accident-proneness. Originating from a statistical approach by Greenwood and Woods (3) this concept has met both enthousiastic support and severe criticism. Apart from methodological pitfalls much of the controversy arises from the conceptual confusion which has surrounded the use of this term from the beginning. In his critical review McKenna (4) discerned its use as a unitary trait, a general characteristic, an innate and unmodifiable characteristic or an explanatory concept. In the same paper he points to "the traditional assumption that accident involvement is necessarily a stable phenomenon", and then comments: "This is a factor to be tested not assumed".

Beside the methodological discussion on the fitness of negative binomial or Poisson distributions to accident data and the corresponding assumptions on initial liability and stability of the phenomenon, a technique has been applied, among others, to study differential liability in accident involvement, viz. the use of a correlational approach of accidents incurred in subsequent periods (5). This analysis has been performed on the data of this study as well. As has been explained in the previous paper (1), some notorious flaws of accident research could be accounted for: comparability of exposure to risk, comparability of age and experience, and avoidance of selection-bias through non-reporting.

MATERIAL AND METHODS

The accident study contained two parts (1) - an exploratory investigation of accident data of one branch of a bus company; this study was followed by a replicative analysis of accident data of another branch of the same company. The hypotheses derived from the first part could be tested in the second. It is important to note that bus drivers within both branches had a comparable exposure with regard to bus lines, number of kilometres driven, types of service etc. The first part of the study concerned all accidents of bus drivers in the period 1973-1977. The second part investigated the period 1973-1980.
In the first part data were available on accidents of 54 bus dri-

vers who could be followed during their first 3 years of employment. In the analysis age was left out of consideration because of the small numbers. In general age of these drivers upon employment varied between 21-40 years. A correction had to be made for a yearly changing number of kilometres driven per man-year* as is shown in table 1. As indicated in this table the number of kilometres per man-year declined throughout this period. The weighting factor was used for correction of differences in exposure between the years.

In the second part of the study accident data were available on 86 drivers who could be followed during their first three years of employment; 60 of these drivers could be followed for one additional year, and 45 for two additional years, respectively. In this analysis no correction was necessary for yearly differences in exposure, because the number of kilometres driven per man-year remained constant**. In this part, however, a differentiation could be made with regard to age upon employment of the driver.

Table 1. Number of kilometres per man-year and weighting factors used for the number of accidents in the consecutive years 1973-1977

	Year				
	1973	1974	1975	1976	1977
Number of kilometres driven per man-year	60.200	51.300	44.500	43.300	35.200
weighting factor*	1.00	1.17	1.35	1.39	1.71

* Applied to each individual accident.

* The decline in the number of kilometres driven per man-year was reflected by a decline in the yearly number of accidents per man-year, while the yearly accident rate (viz. the number of accidents per 100,000 km) remained constant.

** Again this was reflected in the yearly number of accidents per man-year and in the accident rates, which both remained constant over the years in this part of the study.

For the analysis of correlation between accident frequencies in successive periods, data were available on 431 accidents of the 60 persons within the second part of the study, who could be followed during the first 4 years after employment as a bus driver; aged 21-40 years at the date of employment.

RESULTS

In table 2 the results are presented of the analysis in the first part of the study. The number of accidents is shown per six month periods after entering into employment. In the first column the observed number of accidents is presented, in the second column the estimated number after correction for yearly differences in exposure.

Table 2. Number of accidents per half-year after employment with and without correction for differences in exposure; mean number of accidents per half-man-year ($N_{drivers}$= 54, Part 1, 1973-1977)

Number of months in service	Number of accidents (observed)	Estimated number number of accidents after applying weighting factor	Mean number of accidents per half-man-year
1 - 6	85	72	1.57
7 - 12	57	57	1.06
13 - 18	37	36	0.69
19 - 24	52	56	0.96
25 - 30	39	42	0.72
31 - 36	32	39	0.59
Total	302	302	-
Testing of differences between consecutive half-years (observed)	$\chi^2_{(5)}= 37.57$; $p < 0.01$		
Testing of differences between consecutive half-years (after correction	$\chi^2_{(5)}= 18.91$; $p < 0.01$		

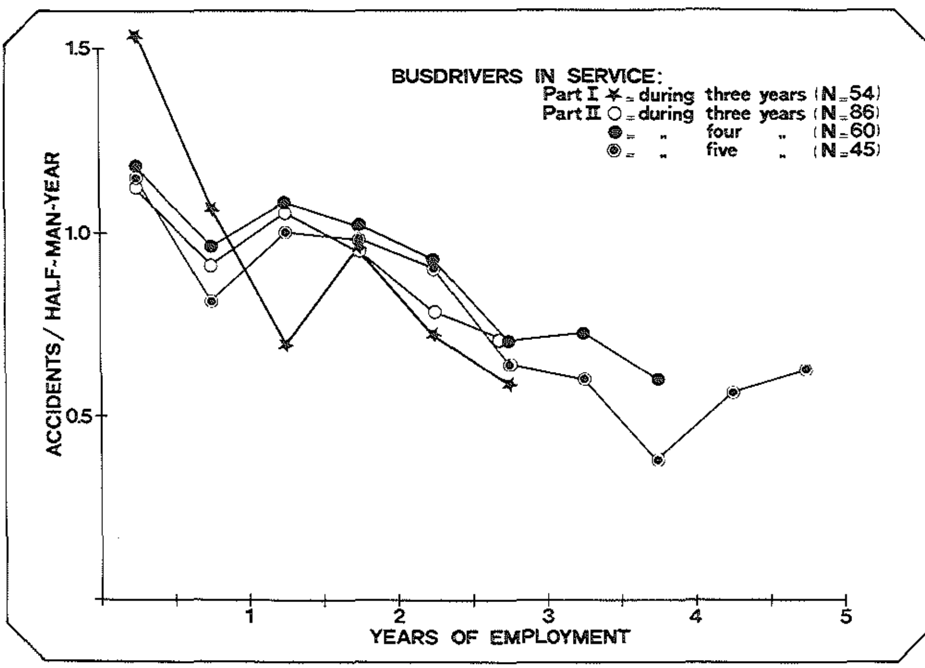
This analysis shows a statistical significant difference between the consecutive half-years of employment (with or without correction).
The mean numbers of accidents per half-year showed a decline from 1.57 for the first half-year to 0.59 in the sixth half-year.
There appears to be a temporary increase in the fourth half-year followed by a further decline.
In the second part the same analysis was performed, but extended to subselections of drivers, who could be followed for a longer period (4, resp. 5 years after employment). The analyses as presented in table 3 are, therefore, not independent of each other. For all three (sub)-selections the picture is very much comparable to the data from the first part. As shown in the table the differences between consecutive half years are again significant.

Tabel 3. Number of accidents per half-year after employment; mean number of accidents per half-man-year for 86 bus drivers during the first 3 years of employment (A), resp. 60 of them during 4 years (B), resp. 45 of them during 5 years (C) (Part 2, 1973 - 1980)

		Number of months in service										
		1-6	7-12	13-18	19-24	25-30	31-36	37-42	43-48	49-54	55-60	total
Number of accidents	A	96	78	90	82	67	60	-	-	-	-	473
	B	71	57	64	62	56	42	43	36	-	-	431
	C	52	37	45	44	41	29	27	17	25	28	345
Mean number of accidents per half-man-year	A	1.12	0.91	1.05	0.95	0.78	0.70	-	-	-	-	-
	B	1.18	0.95	1.07	1.03	0.93	0.70	0.72	0.60	-	-	-
	C	1.16	0.82	1.00	0.98	0.91	0.64	0.60	0.38	0.56	0.62	-
Testing of differences between consecutive half years	A: $\chi^2_{(5)}=11.74$; $p < 0.05$				B: $\chi^2_{(7)}=19.58$; $p < 0.01$				C: $\chi^2_{(9)}=31.33$; $p < 0.001$			

A steady decline in the mean number of accidents is apparent, associated with increase in experience and continuing even beyond the third year of employment. A difference can be noted between the two parts of the study with respect to the temporary increase in the number of accidents during the second year after employment. In the second study this increase shows up half a year earlier. Results of both parts are presented together in figure 1.

Figure 1. Mean number of accidents per half-man-year of 54 drivers during 3 years (Part 1, 1973-1977); and of 86 drivers during 3 years, resp. 60 during 4 years, resp. 45 during 5 years (Part 2, 1973-1980)

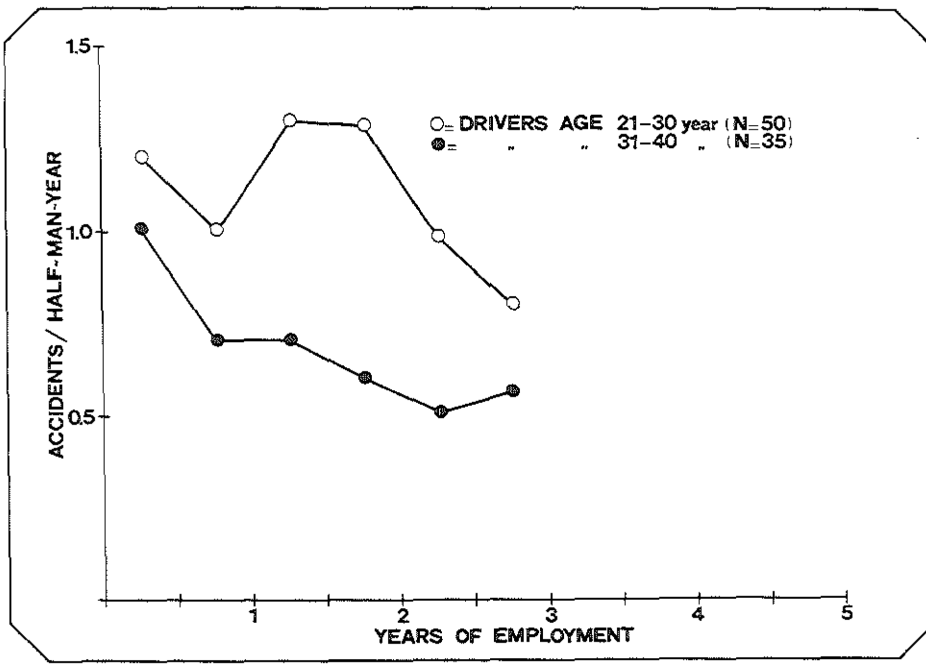


In the second part of the study the group of drivers who could be followed for three years has been subdivided into two age groups: one group aged 21-30 years at employment, consisting of 50 persons and another group of 35 persons, who were 31-40 years old at employment. The accident rates per half year were calculated and are presented in figure 2.

Accident rates of the younger group ranged from 1.20 during the first half year to 0.80 in the sixth half year of employment while a distinct increase is visible in the 3rd and 4th half year in service (1.28 resp. 1.26) Contrary to this pattern the older

group showed a continuous declining rate ranging from 1.03 in the first half year to 0.57 in the last half year.
Apart from the different pattern the general level of the accident rates appeared to be lower for the older age group.

Figure 2. Mean number of accidents per half-man-year for two subgroups aged upon employment 21-30 years and 31-40 years resp. (Part. 2, 1973-1980)



In tabel 4 correlation-coëfficients are presented between accident frequencies of the first and second year of service, the first with third year etc.
Beside the relatively low correlation between the first and second year these results suggest a stable association between the accident levels of successive years, and even between years at some more remote interval.
The correlations have been computed from the individual accident data of which the distributions within each year are presented in table 5.

Table 4. Correlation-coëfficients of accident frequencies in successive years (N drivers = 60)

		Year in service		
		2	3	4
Year in service	1	.20	.37*	.50**
	2	-	.43**	.41**
	3	-	-	.60**

* $p < 0.01$

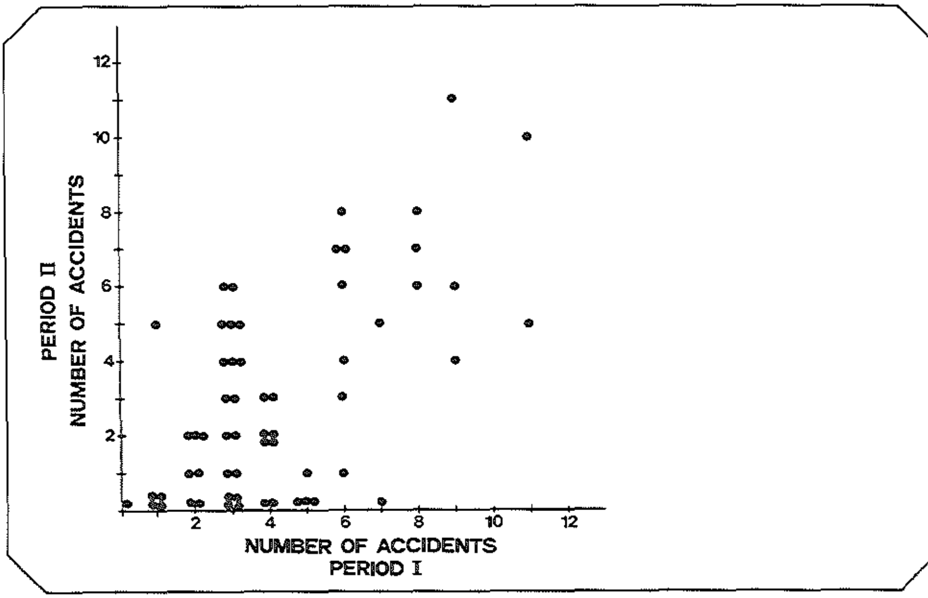
** $p < 0.001$

Table 5. Number of persons with 0, 1, 2 etc. accidents during the first and following years of employment (N drivers = 60)

Number of accidents in first year	Years in service: 2 — Number of accidents									3 — Number of accidents									4 — Number of accidents									Number of persons
	0	1	2	3	4	5	6	7	8	0	1	2	3	4	5	6	7	8	0	1	2	3	4	5	6	7	8	
0	1	2	2	1	-	-	-	-	-	2	1	1	2	-	-	-	-	-	4	1	1	-	-	-	-	-	-	6
1	3	4	11	3	1	-	-	-	1	8	5	7	2	1	-	-	-	-	12	6	1	3	1	-	-	-	-	23
2	1	5	3	1	2	-	1	-	-	4	5	2	-	1	-	1	-	-	6	3	2	-	2	-	-	-	-	13
3	1	2	2	2	-	-	-	-	-	2	2	2	-	1	-	-	-	-	3	1	2	-	1	-	-	-	-	7
4-5	-	1	3	1	-	-	1	-	-	1	1	3	-	-	1	-	-	-	2	-	2	2	-	-	-	-	-	6
>6	-	-	2	2	1	-	-	-	-	-	-	1	2	-	1	1	-	-	-	1	-	-	2	-	2	-	-	5

These data show, despite the relatively high correlation, a considerable variability within each year. It can be argued that part of the correlation is associated with the fact that within one year an accident is a relatively rare event: 70 to 80% of the drivers have 0, 1 or 2 accidents in a certain year. Therefore the four-year period has been divided into two periods of two years to increase the number of observations per period. The resulting scatter-diagram is presented in Figure 3.

Figure 3. Scatter-diagram of paired observations: number of accidents per person of the first 2-year period (x) vs number of accidents per person of the second 2-year period (y)



The correlation coëfficent computed from these data appeared to be r= 0.62 ($p < 0.001$). The origin of this high correlation is clearly visible in this figure: a relatively small group with high numbers of accidents in both periods is apparently responsible. However, within this group with high numbers of accidents in both periods the year-to-year variability is still great (as can be traced in table 5) while in the remaining group subgroups can be identified with either high numbers of accidents in the first and low in the second period, or vice versa.

DISCUSSION

The data presented in this paper show a negative association of experience and accident liability of bus drivers. This finding corroborates results from various accident studies (6). Furthermore, systematic differences appeared to exist between groups of drivers of different age-groups but with comparable experience:

younger drivers had higher accident rates than the older. Finally, the increase of accident risk during the second year of employment after an initial decline could be attributed to the younger group of drivers; the older group only showed a continuous decline.
This latter finding may be interpreted with the model offered by Brown (5). His model tries to explain the finding by Pelz and Schuman (7) that accidents tend to peak two or three years after people acquire a driving licence, by assuming, that because young people acquire perceptual-motor skills relatively easily, they will fairly quickly feel confident in their ability to control the vehicle. As a result younger drivers may well be overconfident in their ability. "Accidents will therefore tend to rise to a peak, until such time as the driver acquires roadcraft and begins to realise that there is more to driving than just controlling a vehicle" (8).

The interpretation of the results of correlational analysis is a notorious problem in accident research (if not in general). The main elements of the discussion have been reviewed by McKenna (4). In general he argues that a non-significant correlation between accident frequencies in successive periods would provide unambiguous evidence against, while a significant correlation would not provide unambiguous evidence for accident proneness. The problems of inferring predictions on an individual level from past accident history by statistical means have been elaborated by e.g. Arbous and Kerrich (9).
An important point in the controversy on accident-proneness is the danger of circularity: Accident-proneness is (e.g. by correlational techniques) used to describe the pattern of accident involvment and then used as a causal explanation (4).What is, in fact, known about possible causes for high accident frequencies of some members of this group? Little is known about many possibly important personal characteristics of the drivers involved, e.g. previous experience before employment, personality traits, education, (transient)psycho-social factors like life-events, transient (minor)illness etc.

Generally speaking, for members of the group of bus drivers involved, exposure to a variety of environmental factors is com-

parable. and certain effects of organizational characteristics (e.g. type of shift, duration of service) have been demonstrated (10). But on an individual level nothing is known about the type of interaction of a certain person with these factors at a certain moment.
A possible explanation, however, for part of the high correlation found, can be that within the group of drivers under investigation a variation of age and experience did exist of which the influence on accident risk has been demonstrated.

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ADDENDUM 5

NOOTEN, W.N. VAN, D.H.J. BLOM, M.L.I. POKORNY & P. VAN LEEUWEN. Time-intervals between bus drivers' accidents. (Submitted for publication).

TIME-INTERVALS BETWEEN BUS DRIVERS' ACCIDENTS

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Abstract

This paper contains a part of the results of a repetitive and comprehensive analysis of accidents of bus drivers. In a series of articles different aspects of the etiology of bus drivers' accidents will be high lighted. The results presented in this paper concentrate on the distribution of the length of time intervals between successive accidents. No significant interaction could be detected between the occurence of an accident and the length of the time intervals in between.

INTRODUCTION

In the past much attention has been paid in accident research to individual variations in accident liability, both between persons and within persons over time.
Whether some personal constancy of accident risk over time exists or not, has occasionally been the focus of attention.
One of the methods is the analysis of the distribution of time-intervals between accidents (1, 2, 3, 4).
This type of analysis has been performed also in a study of accidents of bus drivers from a large bus company in the Western part of the Netherlands. In previous publications (5, 6, 7) amongst others the role of age and experience has been discussed. This paper reports on the theoretical considerations of the analysis of time-intervals, and gives the results of such an analysis.

MATERIAL

In the study presented here the definition of an accident was as follows:

"An accident is an event of damage to a bus, or by a bus, that needed to be reported to the insurance company".

In practice this means all accidents of buses of the company involved, including the very minor ones. Because of financial liability of the bus drivers in case of not reporting one can reasonably assume completeness of the data.
For the analysis of time-intervals between successive accidents, data were available on 1655 accidents of 317 bus drivers who had in an 8-year period (1973-1980) at least 2 accidents.*
Data were obtained from the insurance accident forms, which contained, among others, date and time of the accident, and the identification of the driver. An important feature of the shift organization of the bus company at issue should be stressed. All drivers perform all shifts on rotating schedules, therefore each driver has an identical exposure regarding shifts, bus lines, kilometres driven, hours of service etc. In this 'natural experiment' also the general environmental characteristics (driving environment) and the organization of different shifts with regard to the sequence of line-runs and rest-periods were practically identical for all drivers.

METHODS

Accident records of bus drivers can be regarded as time-series: the occurrence of certain incidents with the time elapsed since a given starting-point.

With respect to these time series one can consider the mechanism leading to, or the theoretical model behind these incidents. This will be done by comparing properties of the observed time series with those that would apply if the mechanism were a Poisson process. This means that for each time period t the probability $P_r(t)$ of r incidents in a time interval of length t is given by:

$$P_r(t) = \frac{(\lambda t)^r}{r!} e^{-\lambda t}$$

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* This analysis has also been performed on data of a preceding part of the study, concerning 921 accidents of 152 bus drivers in a different branch of the same bus company.

The Poisson process is operative under the following conditions (8): 1. Whatever the number of incidents in (0,t) the conditional probability that during (t, t+h) an incident occurs is $h + o(h)$*
2. The probability that more than one incident occurs in (t, t+h) is of a smaller order of magnitude than h (o(h) indicates a function of smaller order of magnitude than h, that is, a function (f(h) for which $\lim_{h \to 0} \frac{f(h)}{h} = 0$.

Reversely every Poisson process satisfies those requirements. Under those conditions the occurrence of an incident in a time interval does not depend on the previous history, and the probability of the occurrence of an incident in a small time interval is virtually constant.

Consequently, the actual processes may deviate from the Poisson process in the sense that the probability of the occurrence of an incident in an interval does depend on previous incidents or that this probability varies over time.

Considering a time series in a fixed time interval one can discriminate between: 1. the total number of incidents in the interval (n); 2. the exact position of the incident within the interval, given their number.

The value of λ governs the distribution of n, and n contains just all information about λ, a quantitity that can vary from one time series to another. The distribution of the n incidents over the interval is relevant to the question of whether or not a Poisson process is applicable. Therefore one should concentrate on the proporties of that distribution, given n. To that end the probability distribution of the intervals between successive incidents will be derived, given n, in the case that a Poisson process would be operative. The observed distribution can then be compared with this theoretical distribution.

First we derive an intermediate result in the following way.

The total time interval (0,T] considered is divided into sub intervals with the endpoints $t_0 = 0 < t_1 < t_2 \ldots < t_{k-1} < t_k = T$. Therefore the i^{th} sub interval is $(t_{i-1}, t_i]$. This division is called V.

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* Here the o-symbol of Landau is used; o(h) indicates a function f(h) for which $\lim_{h \to 0} \frac{f(h)}{h} = 0$(9)

The probability of r_i incidents in $(t_{i-1}, t_i]$ for $i= 1, 2, \ldots, k$ is then given by

$$P(r_1, r_2, \ldots, r_k | V) = \lambda^n e^{-\lambda T} \prod_{i=1}^{k} \frac{(t_i - t_{i-1})^{r_i}}{r_i!} \qquad \ldots.(1)$$

Here $n = \sum_{i=1}^{k} r_i$

The probability of n incidents in $(0,T]$ is:

$$\frac{(\lambda T)^n}{n!} e^{-\lambda T} \qquad \ldots.(2)$$

Consequently the conditional probability of $r_1, r_2, \ldots, r_k$ for given n is the ratio of (1) and (2):

$$P(r_1, r_2, \ldots, r_k | n; V) = \binom{n}{r_1\ r_2 \ldots r_k} \prod_{i=1}^{k} \frac{(t_i - t_{i-1})^{r_i}}{T} \qquad \ldots.(3)$$

a multinomial distribution, in which λ does not appear any longer.

Next we apply this result to a special subdivision $V(a,t)$ of $(o,T]$ leading to the following intervals:

$(o,a]$, $(a,a+da]$, $(a+da, a+t]$, $(a+t,T]$.

We consider the event that in these four intervals $u-1$, 1, 0 and $n-u$ incidents occur successively. The purport of this is as follows: the u^{th} incident is fixed in the interval $(a,a + da]$, where u satisfies $0 < u < n$ but is otherwise arbitrary da is a differential, a an arbitrary fixed moment for which $o < a < T-t$.

In these circumstances the fact that no incidents occur in $(a+da, a+t]$ means that the interval between the u^{th} and $(u+1)^{th}$ incident exceeds t. By integrating with respect to a we arrive at the probability of that interval being longer than t.

In view of (3) we have:

$$P(u-1, 1, 0, n-u | n; V(a,t)) = \binom{n}{u-1,\ 1,\ 0,\ n-u} \frac{a^{u-1}(T - t - a)^{n-u} da}{T^n}$$

Introduce $b=a/(T-t)$. Since $0 < a < T-t$, we have $0 < b < 1$. $db=da/(T-t)$. Therefore

$$P(u-1, 1, 0, n-u | n; V(a,t)) = \frac{n!}{(u-1)!(n-u)!} b^{u-1} (1-b)^{n-u} (1- \frac{t}{T})^n db$$

Integration with respect to b gives

$$P(t | n) = (1- \frac{t}{T})^n \qquad \ldots.(4)$$

This is the probability that in an interval of length T with a total of n incidents, the interval between the u^{th} and the $(u+1)^{th}$ incident exceeds t. Evidently the probability distribution of t does not depend on u.

Let us consider the alternatives. In the first place the probability of an incident can depend on the previous history, e.g. a temporary increase after the occurrence of an incident. In that case there will be a tendency to a fast succession of incidents; if, however, a next incident is absent for some time, the probability of such an incident may regain its initial value and, therefore, it might take considerable time before an incident or group of incidents again occur. The effect of this is of two sorts: the total number of incidents is influenced, expressed in estimates of λ. Furthermore, a greater emphasis is placed on the number of shorter and longer intervals between incidents than the Poisson process would permit.
Analogously, a decrease of the probability of an incident following a preceding incident would decrease the number of incidents, and diminish the contrast between shorter and longer intervals.
In the second place the probability of an incident can vary over time but independent of the previous history. During periods of increased probability there will be a tendency to clustering and, therefore, to shorter intervals, in between these periods to longer intervals. Again, a greater emphasis on longer and shorter intervals between incidents would arise than the Poisson proces would permit.
Prior to a comparison of the hypothetical and the observed distributions of intervals a correction procedure has been performed on the latter in order to eliminate as much as possible an eventual influence of seasonal variations. When the accidents are classified according to the month of occurrence a pattern of accident frequencies emerges, more or less reappearing each year.
Each day in the period of observation was weighted inversely proportional to the frequency of accidents, as observed in that month. The length of an interval between two accidents was now computed as the sum of the weights assigned to the days of the interval. The operation has the effect that the months obtain a varying length and that the total number of accidents per month is exactly proportional to this length. Therefore we concentrate

on changes in accident probability, not caused by, e.g., type of weather, slipperiness etc.

In the following, n indicates the total number of accidents of a driver in the period of observation. For n= 2,3,4,...x, the probability distribution was used that would be valid if the n accidents would be distributed in the period of observation according to a Poisson proces. For each n the probability was computed that an interval-length would be between the boundaries of 0 and 49,5 'days', 49,5 and 99,5 'days' and so on in steps of 50 time-units, using (4). These probabilities were multiplied by (n-1) x k_n, where k_n denotes the number of drivers with n accidents and n-1 the number of intervals contributed by each of these drivers, resulting in an 'expected' number between each of these boundaries. Finally, these expected numbers were added for n= 2,3,4,...x, and compared with the observed distribution of (corrected) interval-lenghts, arranged likewise in above named classes.

RESULTS

The results of this analysis are presented in figure en table 1.

Figure 1. Theoretical distribution and observed frequencies of time-intervals between accidents

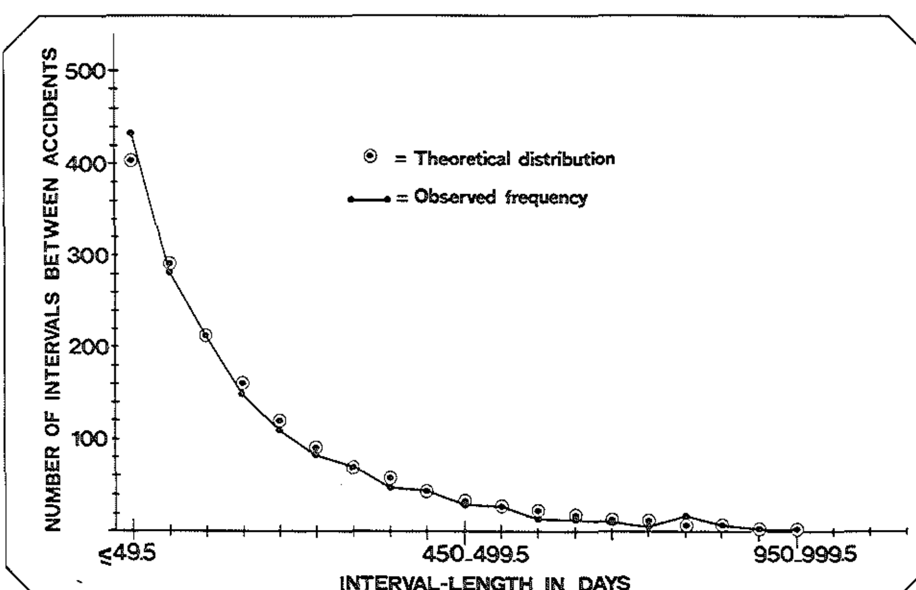

Table 1. Theoretical distribution and observed frequencies of time-intervals between accidents*

Interval boundaries	Total		Testing of differences between the distributions
	theoretical distribution	observed frequencies	
49.5	405.846	436	
99.5	291.213	283	
149.5	212.971	211	
199.5	158.055	152	
249.5	118.874	113	
299.5	90.771	83	
349.5	70.397	90	
399.5	55.309	49	
449.5	43.904	43	
499.5	35.181	32	
549.5	28.439	28	
599.5	23.169	17	
649.5	19.003	17	
699.5	15.689	15	
749.5	13.027	8	
799.5	10.878	17	
849.5	9.119	11	
899.5	7.667	7	
949.5	6.474	8	
999.5	5.490	4	
1049.5	4.670	1	
1099.5	3.987	4	
1149.5	3.416	2	
1199.5	2.932	2	
1249.5	2.521	5	
1299.5	2.172	3	
1349.5	1.875	2	
1399.5	1.620	1	$\chi^2_{(25)} = 22.51$ n.s.
1449.5	1.401	0	
1499.5	1.213	2	
1549.5	1.051	1	
1599.5	0.913	2	
1649.5	0.794	0	
1699.5	0.692	0	
1749.5	0.603	0	
1799.5	0.525	0	
1849.5	0.457	0	
1899.5	0.397	0	
1949.5	0.345	1	
1999.5	0.300	3	
2049.5	0.260	0	
2099.5	0.226	0	
2149.5	0.195	0	
2199.5	0.169	0	
2249.5	0.145	2	
2299.5	0.123	0	
2349.5	0.104	0	
2399.5	0.087	0	
2449.5	0.072	0	
2499.5	0.060	0	
2549.5	0.049	0	
2599.5	0.040	0	
2649.5	0.032	0	
2699.5	0.025	0	
2749.5	0.019	0	
2799.5	0.014	0	
2849.5	0.009	0	
2899.5	0.004	0	
2949.5	0.000	0	

* In case of a theoretical expectation of < 4 the surrounding classes of intervals have been put together before testing

This result indicates clearly that no statistical difference could be detected between expected and observed distributions of the summarized data. This also holds for the separate distributions of time-intervals from groups of drivers with 2,3,4...x accidents.

Strictly speaking, χ^2 testing is not completely appropriate in this case, because of an intra individual dependency of the lengths of time-intervals. However, this dependency can be expected to be minimal, and, therefore, not to distort the results of the analysis.

The same analysis has been performed on a subselection of drivers who had been in service for the full length of the 8-year observation period to allow for a possible interaction with difference in length of exposure, as well as on accident data of a different group of bus drivers under otherwise comparable conditions. Both analyses gave identical results. It can, therefore, be concluded that with the chosen interval-length of 50 days no deviation from a Poisson process is demonstrable.

DISCUSSION

The following comments could be given on this result:

In the first place, the boundaries of 50 'days' (time-units) have been chosen arbitrarily, based on the average frequency of about one accident per man-year. Of course, this choice may influence the result.

In the second place, as discussed in the methods section, different alternatives may play a role. In one group of drivers, e.g., a different distribution of time-intervals might be demonstrable, if not compensated by another group of drivers showing the opposite.

Finally, one may have here an inversion of the well known phenomenon of 'the princess and the pea'. By this we refer to the problem that rather drastic changes in accident probabilities must occur in a sufficient number of drivers, in order to be able to detect any influence on such a variable as time-intervals between accidents. On an individual level, e.g, a certain influence of the occurence of an accident by a preceding accident, can, therefore, not be excluded.

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ADDENDUM 6

POKORNY, M.L.I., D.H.J. BLOM & P, VAN LEEUWEN. Effects of type of shift on accidents of bus drivers. (Submitted for publication).

EFFECTS OF TYPE OF SHIFT ON ACCIDENTS OF BUS DRIVERS

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Keywords: Accident risk; shift work; bus drivers; task effects.

Abstract

This paper contains a part of the results of a repetitive and comprehensive analysis of accidents of bus drivers. In a series of articles different aspects of the etiology of bus drivers' accidents will be high lighted.
The results presented in this paper indicate a strong effect of type of shift on accident risk. Shifts starting in the morning appeared to have a higher risk than shifts starting in the afternoon. Furthermore, a certain association could be detected, within each type of shift, with the starting hour of the service reflecting the influence of the starting condition of the worker.

INTRODUCTION

In the past relatively frequent attention has been paid to the occurrence of accidents in a variety of task operations under shift-work conditions. Wanat e.g. (1962) reported the highest accident frequencies of miners during night shift, the lowest during morning shift, and an intermediate value during afternoon shift. Adams et al (1981) and ARPES (1979), on the contrary, mentioned a higher frequency of accidents for workers in the steel and petrochemical industry during morning shift compared with afternoon and night shifts. Other studies on the occurrence of accidents in steel plants mentioned highest frequencies during afternoon shifts and lowest during night shifts (Hill & Trist, 1955; ARPES 1979). The frequency of hospital accidents finally, was found highest during night shift and lowest during morning shift (Smith et al., 1979).

The discrepancies between the conclusions of studies of this type may in part be attributed to differences between the various tasks, between shifts (with regard to the task load), differences in personal characteristics of the task-operators (e.g. age, experience, etc.). They may be eventually ascribed to differences in starting hour of the work. Hildebrandt et al. (1974) found that locomotive drivers who started their job early in the morning had a higher error frequency (expressed as number of automatic brakings) than their colleagues starting later. Also the study of Powell et al (1971) gives the impression that the frequency of industrial accidents was higher for a shift starting at 8.00 hours than for a shift starting later (11.00 hours).
In this study traffic accidents incurred by bus drivers in various shifts were investigated in a project of which the main purpose can be described as follows: to develop a measuring instrument capable of demonstrating the (assumed) effect of the performance of a task on the task performer and, assuming that this would prove possible, to ascertain to what extent the task effect changes under different task conditions. The project contained two methodologically different, but in view of the purpose integrated parts: An experimental field study in which both physiological and psychometric measurements were performed on bus drivers working under various task conditions (Pokorny et al., 1981a, 1981b), and an epidemiological study of all accidents in which bus drivers were involved of two branches of the bus company from which the subjects of the field study had been recruted.
The following assumption served as the basis for this study: The performance of an occupational task has an effect on the individual performing this task; the nature of this effect is determined by characteristics of the task itself, of the environment (of which the task forms an integral part) and by individual qualities of the task performer. A possible consequence of this man-environment interaction may be the occurrence of an accident (Pokorny & Blom, 1984). From this viewpoint the type of shift (and its starting hour) is regarded as part of the environmental influences.

MATERIAL AND METHODS

This accident study contains two parts. An initial explorative investigation was followed by a second, replicative, part of the study of the accidents of a different branch of the same bus company. In this second part the hypotheses derived from the first part were tested. An important discovery at the onset of the project was that, because of insurance regulations, all bus accidents, whatever the damage may be, with or without injury, had to be reported to the company. This fact, together with the existence of an archive containing information about accidents which had happened in previous years, formed the beginning of the accident study. These findings can be considered as some of the basic conditions for an accident analysis to yield satisfactory results. The operational definition of an accident in this study was therefore:

> **"An accident is an event of damage to a bus, or by a bus, that needed to be reported to the insurance company".**

In practice this means all accidents of buses of that company, including the very minor ones. Because of the liability of the bus drivers in case of not reporting one can reasonably assume completeness of the data.

Part of the information about the accidents and the circumstances in which they occurred was available on the accidents forms. The greater part of the context information, however, had to be sought in other sources, like time-tables, duty reports, personal records etc. Changes in personnel, differences in age and experience of the bus drivers, varying frequency and routing of the bus lines, etc. were accounted for in processing the data (Blom & Pokorny, 1984; Pokorny et al, 1984b)

Exposure

The use of the number of days (or weeks etc.) worked in various shifts seemed not to be justified due to differences between the contents and length of each individual shift. The same applied for line-runs. The best, well-defined, estimator of the actual exposure to the task and its various aspects seemed to be the

driving-distance scheduled in the various shifts on each bus line. The use of this unit of exposure gave the possibility to assess risk in terms of the number of accidents per 100,000 km. (Blom & Pokorny, 1984).
This choice is justified, because an important feature of the shift organization of this particular bus company is that all drivers, regardless their age, experience, etc. perform all shifts on rotating schedules, therefore each driver has an equal exposure regarding shifts, bus line, kilometres driven, hours of service etc. In this 'natural experiment' also the general environmental characteristics (driving environment) and the organization of different shifts with regard to the sequence of line-runs and rest-periods were practically identical for all drivers.
In the first part of the study data were available on 944 accidents which occurred over a period of 5 years (1973-1977). In these years 277.16 x 100.000 km. were covered in 611 man-years. For 820 accidents it was possible to determine the type of shift in which it happened.
In the second part of the study, the period of observation was 8 years (1973-1980); only for the last 5 years, however, were daily duty reports available, resulting in the possibility of linking accidents with shift-data over the years 1976-1980. This concerned 990 accidents from a total of 1251. In these years 163.06 x 100,000 km were covered in 953 man-years.

Data about the shifts were derived from the driver's time-tables to which information about the length of the line-runs in kilometres was added.
As mentioned, accident risk was expressed in an accident rate, viz., the number of accidents per 100,000 km. A comparison has been made in the second part of the study with another rate, the number of accidents per 1000 hours of driving. Both rates appeared to correlate highly with each other. Therefore, one way of expressing accident risk (the number of accidents per 100,000 km) had been chosen.

Shifts and their subgroups

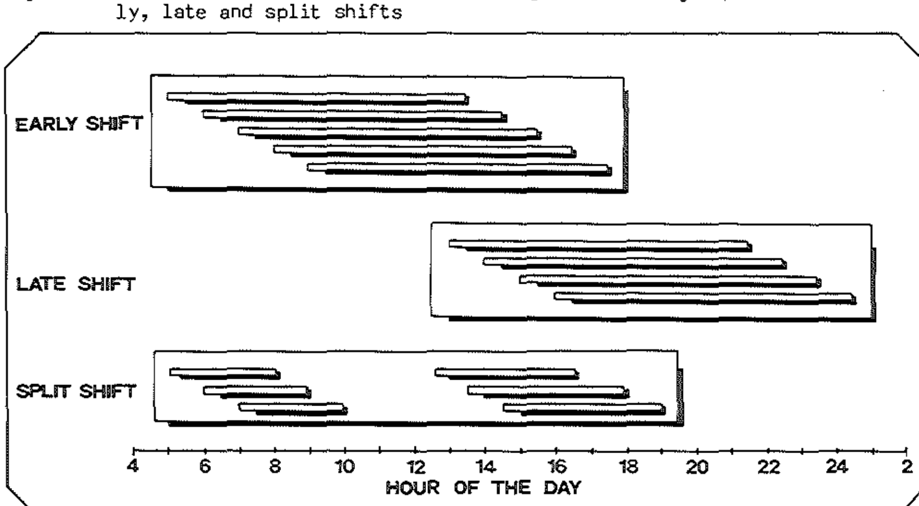
In the bus company at issue three different types of shift can be distinguished performed by all drivers:

1) Early shift: a shift which a mean duration of 8 hours; starting between 5.00 hours and 10.00 hours.
2) Late shift: a shift with a mean duration of 8 hours; starting between 12.00 hours and 17.00 hours.
3) Split shift: a compound shift, consisting of two parts. The first part starting at about 5.00 hours to 8.00 hours and lasting for about three hours; the second part starting between 13.00 hours to 15.00 hours and lasting for about five hours. This means that a person on a split shift starts working early in the morning for a shorter part of his shift, is off duty for at least one and a half hour and then starts working again in the afternoon for the second (longer) part of his shift.

For each shift separately the number of kilometres driven was available. As mentioned, the early shifts started between 5.00 and 10.00 hours, so not all at the same time. In fact, five subgroups could be selected within the early shifts, the first group starting between 5.00 and 6.00 hours, the second starting between 6.00 and 7.00 hours, the third between 7.00 and 8.00 hours, the fourth between 8.00 and 9.00 hours and the fifth between 9.00 and 10.00 hours.

In the same way subgroups with a different starting hour could be selected within the late and split shifts (Figure 1).

Figure 1. Schematic illustration of the working time of subgroups within the early, late and split shifts



These subgroups differ with respect to the starting hour but not with regard to the contents and composition of their shifts. But, of course, the number of kilometres driven, linked up with the number of buses on the road within each subgroup, could be quite different depending on the number of buses scheduled at certain times of the day.
With respect to the split shift it should be noted that the break between the first and second part of the shift cannot be regarded as real leisure time - often the drivers do not even have the opportunity to go home. For this reason the split shift and its subgroups are treated each as one complete entity; the subgroups are classified according to the starting hour of the first part only.

Format of statistical testing

Suppose for a certain variable A (e.g. type of shift or subgroup) the material is distributed in i categories A_1, A_2,. . . . A_i, and let K_1, K_2,. . . K_i be the corresponding numbers of kilometres driven, O_1, O_2,. . . O_i the observed numbers of accidents.
Given the null hypothesis that the probability of an accident is only depending on the number of kilometres driven, the expected number of accidents can be calculated using the following expression:

$$E\,(O_{A_i}) = \frac{K_i}{\sum_{i=1}^{i} K_i} \sum_{i=1}^{i} O_i \qquad (1)$$

The Value of

$$X^2 = \sum_{i=1}^{i} \frac{\left[O_{A_i} - E(O_{A_i})\right]^2}{E(O_{A_i})} \qquad (2)$$

approximates a X^2-distribution with i-1 degrees of freedom (Blom & Pokorny, 1984).
This format gives the opportunity to test a possible difference between the number of accidents actually found and the number one would expect from the amount of kilometres driven only.

RESULTS

Type of shift

In the first part of the study accident risk of the three types of shift (early, late and split) appeared to differ to a great extent, as is shown in Table 1.

Table 1. Number of accidents, number of kilometres driven and accident rates per shift - Part 1, 1973 - 1977

shift	number of accidents	number of kilometres driven (x 100,000)	accidents per 100,000 km
early	380	112.24	3.39
late	267	108.25	2.47
split	173	56.67	3.05
total	820	277.16	2.96
testing of differences between shifts		$\chi^2_{(2)} = 15.95;\ p < 0.001$	

Shifts starting in the morning (early and split shift) had higher accident rates than shifts starting in the afternoon (late shift). This result formed the hypothesis to be tested in the second part of this study.
The results of the second part confirmed in general this hypothesis. A difference between both parts was formed by the fact that in the second part the accident rate of the split shift was higher than the rate of the early shift (Table 2).

Table 2. Number of accidents, number of kilometres driven and accident rates per shift - Part 2, 1976 - 1980

shift	number of accidents	number of kilometres driven (x 100,000)	accidents per 100,000 km
early	431	108.78	3.96
late	395	122.02	3.24
split	164	32.26	5.08
total	990	263.06	3.76
testing of differences between shifts		$\chi^2_{(2)} = 25.07;\ p < 0.001$	

Subgroups within each type of shift

In the first part of the study 5 subgroups were discerned within the early shift according to their starting hour; 4 subgroups within the late shift and 2 within the split shift. Accident rates were computed for each of these subgroups separately. The results are presented in Table 3.

Apparently accident rates of the different subgroups are varying. Accident risk of bus drivers seems therefore to be associated with the starting hour of the work, and there seems to be a tendency towards a higher risk for subgroups starting earlier within each type of shift.

The same analysis was performed again on data of the second part of the study. In this material 5 subgroups could be discerned within the early shift, 6 within the late shift and 3 within the split shift. The results are shown in Table 4.
From the analysis it must be concluded that, despite the fact that a declining trend associated with a later starting hour, was present within the late shift, and detectable (though statistically not significant) within the split shift, one cannot distinguish a clear pattern. Especially the early shift shows a somewhat different picture in the second part of the study. Still, one should allow for an interaction between accident risk during an entire shift and starting hour, though this interaction is probably influenced by other factors as well. Results of both parts suggest a lower accident risk for shifts that either commence in the late morning, or in the late afternoon.

DISCUSSION

The results of both parts of the study, as presented in this paper, indicate a consistent difference between the accident rates of the three types of shift: Shifts starting in the morning (early and split shift) show higher rates than shifts starting in the afternoon (late shift).
However, these mean accident rates appeared to be composed of very different accident rates of the various subgroups. Within each

Table 3. Number of accidents, number of kilometres driven and accident rates per subgroup of each shift - Part 1, 1973-1977

	shift										
	early					late				split	
starting-hour of supgroup	5	6	7	8	9	13	14	15	16	6	7
number of accidents	75	180	51	14	16	51	63	83	37	96	50
number of kilometres driven (x 100,000)	9.52	35.04	27.33	23.50	9.37	11.19	24.32	44.90	17.40	29.26	21.91
accident rate	7.88	5.14	1.87	0.60	1.71	4.56	2.59	1.86	2.13	3.28	2.28
testing of differences between subgroups	$\chi^2_{(4)} = 177.40$; $p < 0.001$					$\chi^2_{(3)} = 28.40$; $p < 0.001$				$\chi^2_{(1)} = 3.70$; $p < 0.05$	

Table 4. Number of accidents, number of kilometres driven and accident rates per subgroup of each shift, Part 2, 1976-1980

	shift													
	early					late						split		
starting-hour of supgroup	5	6	7	8	9	12	13	14	15	16	17	5	6	7
number of accidents	29	220	129	41	8	5	97	72	154	44	11	11	98	46
number of kilometres driven (x 100,000)	9.21	52.78	28.53	11.14	4.38	1.53	22.52	18.57	47.28	21.56	6.83	1.91	19.06	10.69
accident rate	3.15	4.17	4.52	3.65	1.83	3.27	4.31	3.88	3.26	2.04	1.61	5.76	5.14	4.30
testing of differences between subgroups	$\chi^2_{(4)} = 9.43$; $p \approx 0.05$					$\chi^2_{(5)} = 25.46$; $p < 0.001$						$\chi^2_{(2)} = 1.27$; n.s.		

type of shift subgroups can be found with rather high accident rates and others with relatively low rates. On the one hand, subgroups from different types of shift, but starting at the same hour, can have very different accident rates while, on the other hand, subgroups from different types of shift and starting at different hours, can have very much comparable rates.
In interpreting these results it should be remembered that in each part of the study the general environmental and organizational conditions of these shifts and subgroups like sequence of line-runs and rest-periods, bus routes etc., were very much comparable and that all drivers were exposed in an equal manner. In general the results of this study could be viewed against the background of shift-work problems as reviewed e.g. by Colquhoun & Rutenfranz (1980). Of particular interest are issues like sleep disturbances, effects of changes in physiological activation and fluctuations in performance during the day (Webb, 1982).

With regard to the early starting shifts (early and split shifts) and especially their early starting subgroups an important issue might be, on the one hand, the duration and quality of sleep. Apart from a probable disturbance of the sleep-pattern (Tune, 1969; Tepas, 1982) there might be interference with the demands of social life. Colquhoun & Edwards (1970) mentioned that shiftworkers go to sleep at "normal" times, regardless of the starting hour of their work on the next day. On the other hand, performance on different tasks and general level of activation (Colquhoun, 1971; Fröberg, 1975, 1979; Van Loon, 1963) at the early hours of the day is reportedly low and may determine to a certain extent the starting position of workers in these early starting shifts.
Results of the experimental part of this project might facilitate further interpretation.

With regard to the late shifts and especially their early starting subgroups possibly various factors are interacting too. Because other studies found a lower level of certain physiological indicators of activation at this time of the day (Zülch & Hossmann, 1967; Fröberg, 1975; Reinberg et al, 1969, 1970; Rieck & Kaspareit, 1976), while performance on various laboratory tasks and in real-life situations is lowered (Monk & Embrey, 1981; Fröberg, 1975; Fuller, 1981; Prokop & Prokop, 1955). As in the early starting shifts probably these factors influence the starting condition of the drivers. Although it might not seem obvious, even with the late shifts the actual duration and quality of sleep can be disturbed by home situations (Thiis-Evensen, 1958; Bruusgaard, 1969).

In general it may be concluded that accident risk during task operation is modified by type of shift and starting hour of the work.

With the assumption that the occurrence of an accident in task situations might give indications concerning the existence and nature of the effect of the performance of the task on the worker, it may be hypothesized that the starting condition of the drivers and the associated state of the organism might interfere with the effect of the task on man during an entire shift. Probably other factors in the man-environment interaction (e.g. traffic situation and leisure time activities) play some part in this respect as well.

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ADDENDUM 7

POKORNY, M.L.I., D.H.J. BLOM & P. VAN LEEUWEN. Shifts, duration of work, and accident risk of bus drivers. (Submitted for publication).

SHIFTS, DURATION OF WORK, AND ACCIDENT RISK OF BUS DRIVERS

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Keywords: Accident risk; bus drivers, duration of work, shift work.

Abstract

This paper contains a part of the results of a repetative and comprehensive analysis of accidents of bus drivers. In a series of articles different aspects of the etiology of bus drivers' accidents will be high lighted.
The results presented in this paper concentrate on the pattern of accident risk in the course of various types of shift. A characteristic pattern could be demonstrated, viz., accident risk during the early shift is relatively low at the beginning of task operation, reaches a peak at about the 3rd or 4th hour of service, followed by a decline and then increase again during the last hours of task operation. Accident risk during the late shift is relatively high at the beginning of service and then declines towards the end of service. In the first, morning part of the split shift a less clear picture could be detected, while in the second, afternoon part an inverted U-shape could be demonstrated.

INTRODUCTION

The results of a study on traffic-accidents of bus drivers as presented by Pokorny et al. (submitted for publication) suggest a difference between the various shifts with regard to accident risk. Shifts starting in the morning appeared to have a higher accident risk than shifts starting in the afternoon. In part this has been shown to be influenced by the starting hour within each shift.
The next step in the analysis was to examine accident risk during the different hours of service. On the one hand this seemed to be interesting in view of the purpose of the project of which the

accident analysis formed a part, viz. to develop methods capable of demonstrating the effect of the performance of an occupational task on the task performer. An accident is in this respect assumed to be an indicator of task effects (Pokorny et al., 1981a, 1981b, 1984a). This approach is supported, on the other hand, by incidental reports in the literature about different numbers of accidents during the work (Harris & Mackie, 1972; Harris, 1977; Hildebrandt et al, 1974; Adams et al., 1981).

MATERIAL

The study has been designed as an exploratory part followed by a replicative part on accident data of two different branches of a bus company in the Western part of the Netherlands. Hypotheses derived from the first part were tested in the second part of the study. Some important features of the material should be noted: in both parts of the study all drivers perform their work in rotating schedules and had, therefore, an equal exposure to task with regard to shifts, bus lines, kilometres driven etc. Accident risk was expressed in the number of accidents per 100,000 km driven, not only within each type of shift or its subgroups, but also per hour of service within each subgroup according to their starting hour. In both parts completeness of the data can readily be assumed because of the liability of the bus drivers in case of not reporting an accident. All accidents are implicated in the analysis including the very minor ones. A more detailed description of the material including various organizational aspects etc. has been given elsewhere (Pokorny et al., submitted for publication). For this analysis data were available in the first part of the study on 820 accidents in the years 1973-1977 of the first branch from which the type of shift (or subgroup) could be identified. For 742 of these it could be determined in which hour of service the accident occurred. The second part of the study concerned 990 accidents, from which of 965 in the years 1976-1980 of the second branch of the same bus company the necessary information was available.

METHODS

Estimation of exposure

Within each subgroup of the shifts the number of kilometres as an estimation of exposure was allocated to the consecutive hours of service. The same applied to the accidents.
The consequence of this approach is that accidents and kilometres driven within each hour of service are partly dissociated from the hour of the day because of different starting points of the service. However, a certain association of patterns of accident risk during the service with the correponding time of the day can readily be assumed.

Statistical analysis

For the analysis of the pattern of accident risk during the service the expected numbers of accidents were calculated, based on the number of kilometres driven within each hour of service, and taking into account the mean accident rate of each subgroup, according to the principles of generalized iterative scaling for log-linear models (Darroch & Ratcliff, 1972). Differences between observed and expected numbers of accidents are reflected in χ^2-values.
Alternatively, the number of accidents per 100,000 km within each hour of service were used for an analysis of variance. This approach however has been restricted to the data of the early and late shift only, as the hours of service of the split shift are, because of the break between the first and the second part of the shift, not completely comparable to those of the other shifts (Pokorny et al., submitted for publication). In this analysis the main effect 'Shift' is nested under the factor 'Starting hour'.
Some of the subgroups within each shift have been excluded from the analysis because of the low numbers of accidents in each hour of service. They did, however, not influence the general picture (Pokorny et al, 1984b). The figures presented in the following sections are based on the complete data.

RESULTS

Early shift

Within the early shift five subgroups could be distinguished in both parts of the study. The starting hours of these subgroups ranged from 5 to 10 hour respectively.
In table 1 data of the first study are presented. For three of these subgroups (starting at 5, 6 and 7 hours) the data were sufficient for analysis at the level of the hour of service representing 91% of the accidents and 67% of the kilometres driven. They include within each subgroup per hour of service the observed numbers of accidents, the numbers of kilometres driven and the accident rates*.

Table 1. Early shift. Analysis of accident data per hour of service within the subgroups arranged according to starting hour. Part 1, 1973-1977

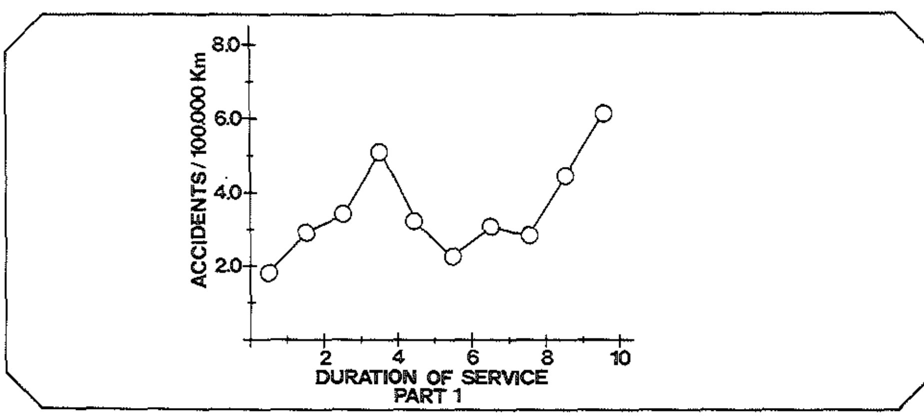
starting hour of subgroup*		duration of service**										
		1	2	3	4	5	6	7	8	9	10	total
5	number of accidents	4	5	16	10	9	9	9	4	8	1	75
	number of kilometres x 100,000	0.929	1.042	1.068	1.079	1.099	1.103	1.106	1.109	0.823	0.159	9.517
	accident rate	4.31	4.80	14.98	9.27	8.19	8.16	8.14	3.61	9.72	(6.29)	7.88
6	number of accidents	13	24	22	36	20	11	20	14	16	4	180
	number of kilometres x 100,000	3.896	4.010	4.047	4.124	4.141	4.133	4.129	3.817	2.344	0.400	35.041
	accident rate	3.34	5.99	5.44	8.73	4.83	2.66	4.84	3.67	6.82	10.00	5.14
7	number of accidents	2	4	4	13	6	2	7	10	3	0	51
	number of kilometres x 100,000	3.140	3.166	3.228	3.242	3.248	3.250	3.219	2.803	1.825	0.213	27.334
	accident rate	(0.64)	1.26	1.24	4.01	1.85	(0.62)	2.17	3.57	(1.64)	-	1.87

* 5 = start of service between 5.00 and 5.59 hr etc.
** 1 = first hour of service etc.

* In case of an observed number of less than 4 accidents, the rate is given in parentheses

Differences between these subgroups with regard to the pattern of the accident rates in the course of the service appeared not to be statistically significant ($\chi^2_{(16)} = 23.91$). The patterns are at a different level, but comparable. Therefore it is hypothesized that a general pattern exists for the accident risk during the early shift. This can be computed by summarizing numbers of accidents and kilometres driven per hour of service.
This early shift accident risk pattern can be described as follows: a relatively low level at the beginning of the service, a peak at about the 4th hour of service followed by a decline and then an increase towards the end of service. This distribution was hypothesized as characteristic for the early shift and to be tested in the second part of the study.

Figure 1. Early shift. Pattern of accident rates per hour of service. Part 1, 1973-1977



From the data of the early shift subgroups in the second part again three subgroups had sufficient numbers to be analysed at this level. In this case the 6, 7 and 8 hour subgroups representing again 91% of the accidents and 87% of the kilometres driven. These data are presented in table 2.
Again no statistical difference between the patterns of accident risk (allowing for differences of level) in the course of the early shift subgroups could be demonstrated ($\chi^2_{(16)} = 13.36$, N.S.). The general pattern was computed analogous to the procedure in the first part (figure 2).

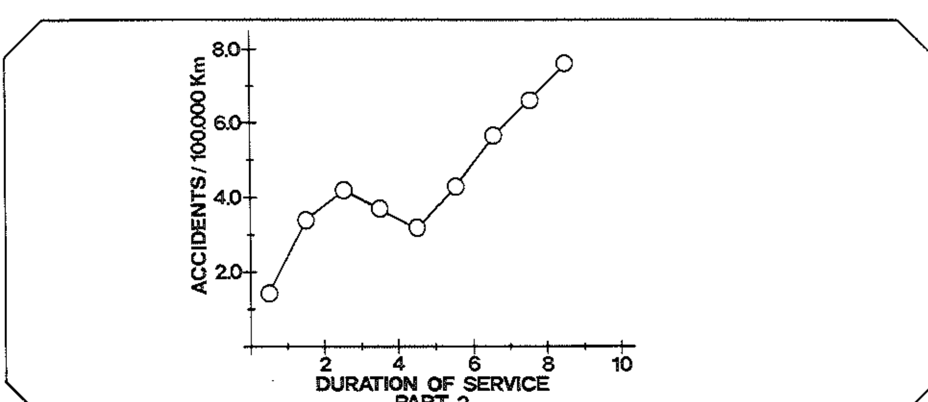
Table 2. Early shift. Analysis of accident data per hour of service within the subgroups arranged according to starting hour. Part 2, 1976-1980

starting hour of subgroup*		duration of service** 1	2	3	4	5	6	7	8	9	total
6	number of accidents	11	21	22	23	22	28	35	36	22	220
	number of kilometres x 100,000	8.84	6.71	5.82	5.90	5.92	6.09	6.13	5.03	2.34	52.78
	accident rate	1.24	3.13	3.78	3.90	3.72	4.60	5.71	7.16	9.40	4.17
7	number of accidents	10	14	16	9	8	15	25	20	12	129
	number of kilometres x 100,000	4.53	3.29	3.04	3.06	3.11	3.39	3.21	2.97	1.93	28.53
	accident rate	2.21	4.26	5.26	2.94	2.57	4.42	7.79	6.73	6.22	4.52
8	number of accidents	2	3	8	7	3	5	4	8	1	41
	number of kilometres x 100,000	1.89	1.37	1.36	1.34	1.31	1.36	1.31	1.02	0.28	11.24
	accident rate	(1.06)	2.19	5.88	5.22	(2.29)	3.68	3.05	7.84	(3.57)	3.65

* 6 = start of service between 6.00 and 6.59 hr etc.

** 1 = first hour of service etc.

Figure 2. Early shift. Pattern of accident rates per hour of service. Part 2, 1976-1980



Testing of differences between the early shift accident patterns from both parts of the study has been performed (table 3). From this analysis a significant difference between the data from both parts of the study could be detected. However, this difference is based mainly on the contribution of two hours of service, viz. the 4th and 8th, which composed about 58% of the χ^2-value. While in the first part the accident rate of the 4th hour still rised compared to the 3rd hour, in the second part a decline is already present. During the 8th hour the opposite phenomenon can be observed. In general the differences between both parts do not seem to contradict the characteristic pattern of accident risk during the early shift as hypothesized from the data of the first part of the study; in the second part, however, the increase at the end of service was more pronounced.

Table 3. Early shifts. Analysis of differences between accident patterns during the shift. Comparison of part 1 and part 2

	duration of service*								
part 1	1	2	3	4	5	6	7	8	9
observed number of accidents	19	33	42	59	35	22	36	28	27
number of kilometres driven (x 100,000)	7.97	8.22	8.34	8.45	8.49	8.49	8.45	7.73	4.99
expected number of accidents	14.00	29.04	38.59	43.10	29.92	29.99	43.16	41.45	31.75
accident rate	2.38	4.01	5.04	6.98	4.12	2.59	4.26	3.62	5.41
χ^2-value	1.79	0.54	0.30	5.86	0.86	2.13	1.19	4.37	0.71
part 2									
observed number of accidents	23	38	46	39	33	48	64	64	35
number of kilometres driven (x 100,000)	15.23	11.37	10.22	10.30	10.34	10.84	10.65	9.02	4.55
expected number of accidents	28.00	41.96	49.41	54.90	38.08	40.01	56.84	50.55	30.25
accident rate	1.51	3.34	4.50	3.79	3.19	4.43	6.01	7.10	7.69
χ^2-value	0.89	0.37	0.24	4.60	0.68	1.60	0.90	3.58	0.75
testing of differences between both parts of the study	$\chi^2_{(8)} = 31.36;\ p < 0.001$								

* 1 = first hour of service etc.

Late shift

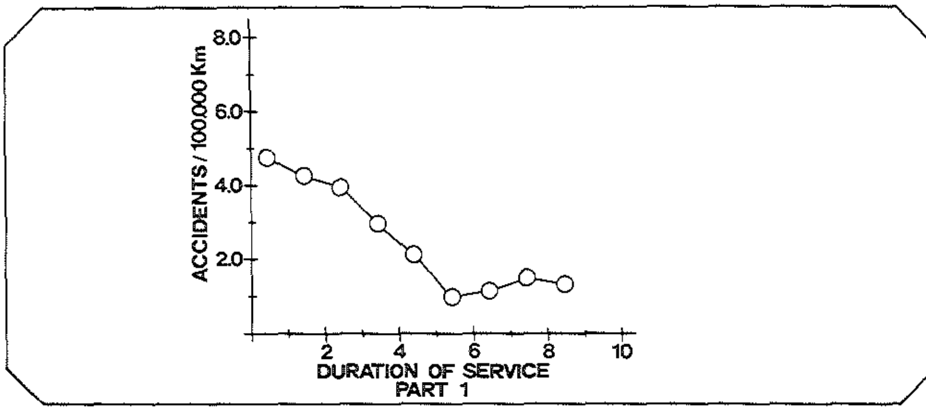
Within the late shift four subgroups could be distinguished in both parts of the study, with starting hours ranging from 13 to 16 hours respectively. In table 4 the data of these four subgroups from the first part are presented analogous to the preceding section.

Table 4. Late shift. Analysis of accident data per hour of service within the subgroups arranged according to starting hour. Part 1. 1973-1977

starting hour of subgroup		duration of service										
		1	2	3	4	5	6	7	8	9	10	total
13	number of accidents	14	7	9	11	7	1	0	2	0	0	57
	number of kilometres x 100,000	1.125	1.188	1.312	1.617	1.733	1.631	1.336	0.661	0.412	0.179	11.194
	accident rate	12.44	5.89	6.86	6.80	4.04	(0.61)	-	(3.03)	-	-	4.56
14	number of accidents	9	7	14	6	6	6	3	7	5	0	63
	number of kilometres x 100,000	2.013	2.219	2.738	2.935	3.013	2.899	2.743	2.496	2.284	0.975	24.315
	accident rate	4.47	3.15	5.11	2.04	1.99	2.07	(1.09)	2.80	2.19	-	2.59
15	number of accidents	10	17	12	13	9	3	6	5	8	0	83
	number of kilometres x 100,000	3.701	4.600	4.950	5.137	5.325	5.307	5.067	5.112	5.317	0.386	44.902
	accident rate	2.70	3.70	2.42	2.53	1.69	(0.57)	1.18	0.98	1.50	-	1.85
16	number of accidents	7	10	7	4	3	1	3	1	1	0	37
	number of kilometres x 100,000	1.625	1.758	1.825	1.891	1.899	1.817	1.843	2.128	2.612	0	17.398
	accident rate	4.31	5.69	3.84	2.12	(1.58)	(0.55)	(1.63)	(0.47)	(0.38)	-	2.13

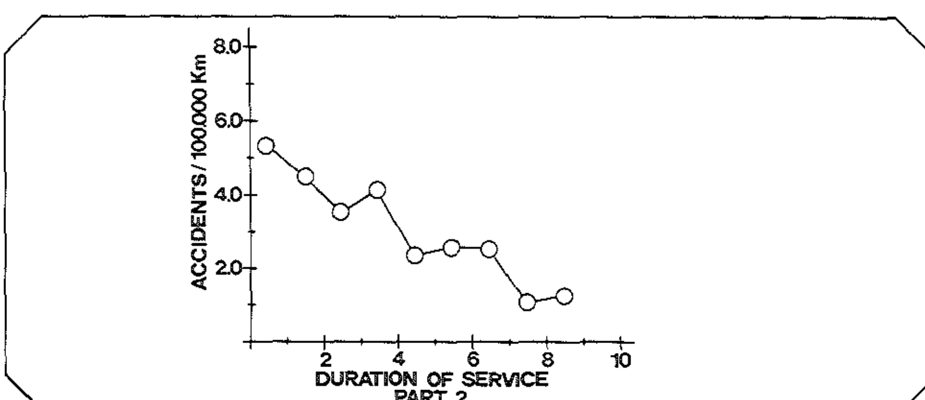
No significant differences between the late shift subgroups with regard to the pattern of the accident risk during the service appeared to exist ($\chi^2_{(24)} = 26.30$). This pattern, hypothesized as characteristic for the late shift, shows a relatively high level of accident risk at the beginning of the service, followed by a continuous decline towards a very low level during the last hours of service (figure 3).

Figure 3. Late shift. Pattern of accident rates per hour of service. Part 1, 1973-1977



In the second part* the same procedure was used (table 5) and no statistical difference between the subgroups did exist ($X^2_{(24)}$ = 33.04). The summarized accident rates of the second part are shown in figure 4.

Figure 4. Late shift. Pattern of accident rates per hour of service. Part 2, 1976-1980



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* Data of a 12 hour and 17 hour subgroup were omitted from this analysis because of insufficient numbers.

Table 5. Late shift. Analysis of accident data per hour of service within the subgroups arranged according to starting hour. Part 2, 1976-1980

starting hour of subgroup		duration of service									
		1	2	3	4	5	6	7	8	9	total
13	number of accidents	21	13	12	21	12	8	8	2	0	97
	number of kilometres x 100,000	3.77	3.03	3.18	3.21	3.18	2.83	2.06	1.05	0.21	22.52
	accident rate	5.57	4.29	3.77	6.54	3.77	2.83	3.88	(1.90)	-	4.31
14	number of accidents	11	12	11	10	11	9	3	1	4	72
	number of kilometres x 100,000	2.73	2.44	2.37	2.56	2.44	2.32	1.74	1.10	0.87	18.57
	accident rate	4.03	4.92	4.64	3.91	4.51	3.88	(1.72)	(0.91)	4.60	3.88
15	number of accidents	35	34	19	24	7	12	12	7	4	154
	number of kilometres x 100,000	5.69	5.05	4.97	5.20	5.11	5.41	5.34	5.46	5.05	47.28
	accident rate	6.15	6.73	3.82	4.62	1.37	2.22	2.25	1.28	0.79	3.26
16	number of accidents	12	6	6	4	2	4	8	1	1	44
	number of kilometres x 100,000	2.57	2.14	2.42	2.52	2.56	2.58	2.83	2.79	1.15	21.56
	accident rate	4.67	2.80	2.48	1.59	(0.78)	1.55	2.83	(0.36)	(0.87)	2.04

Comparison of the late shift accident patterns from both parts of the study did not show statistical differences ($\chi^2_{(8)} = 13.55$; - table 6).

While in the second part the decline of accident risk during the late shift was somewhat irregular compared with the first part, the characteristic pattern of late shift accident risk could be confirmed.

Table 6. Late shifts. Analysis of differences between accident patterns during the shift. Comparison of part 1 and part 2

part 1	duration of service								
	1	2	3	4	5	6	7	8	9
observed number of accidents	40	41	42	34	25	11	12	15	14
number of kilometres driven (x 100,000)	8.46	9.77	10.83	11.58	11.97	11.65	10.99	10.40	10.63
expected number of accidents	37.03	40.09	35.77	37.53	23.66	18.10	18.05	11.46	12.30
accident rate	4.73	4.20	3.88	2.94	2.09	0.94	1.09	1.44	1.32
X^2-value	0.24	0.02	1.08	0.33	0.08	2.78	2.03	1.09	0.24
part 2									
observed number of accidents	79	65	48	58	32	33	31	11	9
number of kilometres driven (x 100,000)	14.76	13.92	12.92	13.49	13.29	13.14	11.97	10.40	7.28
expected number of accidents	81.97	65.91	54.23	55.47	33.34	25.90	24.95	14.54	10.70
accident rate	5.35	4.67	3.72	4.30	2.41	2.51	2.59	1.06	1.24
X^2-value	0.11	0.01	0.72	0.22	0.05	1.95	1.47	0.86	0.27
testing of differences between both parts of the study	$X^2_{(8)}$ = 13.55; p= 0.094; n.s.								

Split shift

With regard to the split shifts it should be noted that, while they consist of two different parts - one early in the morning, the other in the afternoon, with a break of several hours - they are nevertheless considered as one complete entity.
In both parts of the study two subgroups (starting at 6 and 7 hours respectively) could be distiguished. In testing the differences between the subgroups (and between both parts of the study) the data from the 5th and 6th hour of service - the break period - were omitted.
Table 7 gives the data from the first part of the study, showing no significant difference between the subgroups ($X^2_{(9)}$= 11.54).

Table 7. Split shift. Analysis of accident data per hour of service within the subgroups arranged according to starting hour. Part 1, 1973-1977

starting hour of subgroup		duration of service 1	2	3	4	5	6	7	8	9	10	11	12	total
6	number of accidents	13	8	14	2	1	1	3	4	10	16	12	12	96
	number of kilometres x 100,000	3.46	3.88	3.30	1.40	0.46	0.19	0.51	1.90	3.00	3.66	3.78	3.73	29.26
	accident rate	3.76	2.06	4.25	(1.44)	(2.18)	(5.24)	(5.87)	2.10	3.33	4.37	3.17	3.22	3.28
7	number of accidents	4	5	1	0	0	0	2	5	9	10	9	5	50
	number of kilometres x 100,000	2.77	2.46	1.35	0.21	0.09	0.23	1.32	2.37	2.76	2.82	2.87	2.67	21.91
	accident rate	1.44	2.03	(0.74)	-	-	-	(1.52)	2.11	3.27	3.55	3.14	1.87	2.28

The same analysis has been performed in the second part of the study* (table 8) and again no statistical difference could be demonstrated ($X^2_{(9)}= 6.79$).

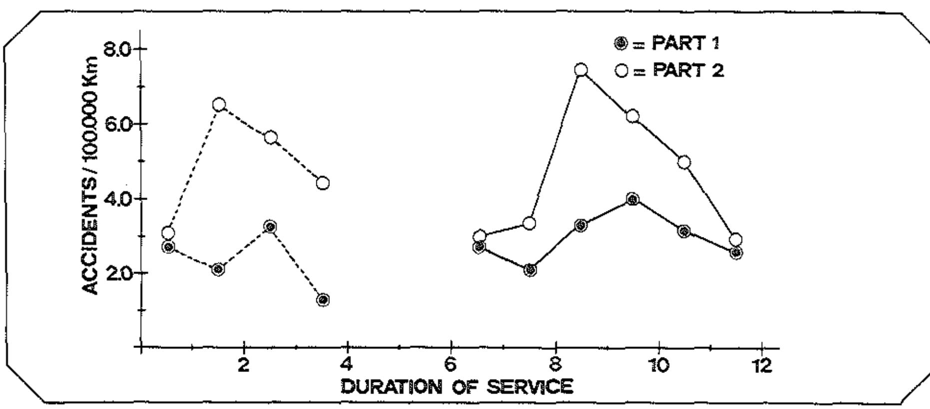
Table 8. Split shift. Analysis of accident data per hour of service within the subgroups arranged according to starting hour. Part 2. 1976-1980

starting hour of subgroup		duration of service 1	2	3	4	5	6	7	8	9	10	11	12	total
6	number of accidents	7	17	12	3	0	0	2	5	20	16	12	4	98
	number of kilometres x 100,000	3.12	2.48	2.11	0.78	0.05	0.00	0.47	1.50	2.24	2.26	2.17	1.87	19.05
	accident rate	2.24	6.85	5.69	(3.85)	0.00	0.00	(4.26)	3.33	8.93	7.08	5.53	2.14	5.14
7	number of accidents	8	7	3	1	0	0	2	4	6	6	5	4	46
	number of kilometres x 100,000	1.79	1.23	0.63	0.12	0.00	0.11	0.89	1.19	1.25	1.30	1.25	0.92	10.71
	accident rate	4.47	5.69	(4.76)	(8.33)	0.00	0.00	(2.25)	3.36	4.80	4.62	4.00	4.35	4.30

* Data of a 5 hour subgroup were omitted from this analysis because of insufficient numbers.

In view of the fact that the data from the first part of the shift are rather scanty, and did not reveal a clear picture no hypothesis has been put forward on the pattern of accident risk in this respect, to be tested in the second part of the study. For the sake of completeness the data have been included in figure 5. In the second part of the shift (from the 7th to the 12th hour of service) a characteristic pattern could be detected in both parts of the study, viz. an inverted U-shape with a relatively low rate at the 7th hour, a peak value at the 8th or 9th hour followed by a decline towards the end of the service.

Figure 5. Split shift. Pattern of accident rates per hour of service. Part 1, 1973-1977; Part 2, 1976-1980



Testing of differences between both parts of the study did not reveal any significant result neither for the first part, nor for the second part of the service (table 9).

Table 9. Split shifts. Analysis of differences between accident patterns during the shift. Comparison of part 1 and part 2 of the study

part 1	duration of service											
	1	2	3	4	5	6	7	8	9	10	11	12
observed number of accidents	17	13	15	2	-	-	5	9	19	26	21	17
number of kilometres driven (x 100,000)	6.23	6.34	4.64	1.61	-	-	1.83	4.28	5.76	6.48	6.65	6.40
expected number of accidents	12.79	17.35	14.00	2.87	-	-	4.11	8.97	22.84	25.53	20.84	14.72
accident rate	2.73	2.05	3.23	1.24	-	-	2.73	2.10	3.30	4.01	3.16	2.66
X^2-value	1.38	1.09	0.07	0.26	-	-	0.19	0.00	0.64	0.01	0.00	0.35
part 2												
observed number of accidents	15	24	15	4	-	-	4	9	26	22	17	8
number of kilometres driven (x 100,000)	4.91	3.71	2.74	0.91	-	-	1.36	2.69	3.49	3.56	3.42	2.79
expected number of accidents	19.21	19.65	16.00	3.14	-	-	4.89	9.03	22.16	22.47	17.17	10.28
accident rate	3.05	6.47	5.47	4.40	-	-	2.94	3.35	7.45	6.18	4.97	2.87
X^2-value	0.92	0.96	0.06	0.24	-	-	0.16	0.00	0.66	0.01	0.00	0.51
testing of differences between both parts of the study	first part of the shift: $X^2_{(3)} = 4.99$; n.s.;						second part of the shift: $X^2_{(5)} = 2.54$; n.s.;					

Comparison of accident patterns between shifts

For testing the differences between accident patterns of the various shifts and their subgroups the approach of analysis of variance was chosen. As mentioned, only the early and late shift subgroups could be entered into this analysis, because of the discontinuous character of the split shift.
In table 10 and 11 the results of this analysis on data of both parts of the study are presented.

Table 10. Early and late shift. Analysis of variance*. Part 1, 1973-1977

	DF	mean square	F	
TOTAL	62	9.4603	-	-
RESIDUE	40	3.6556	-	-
MAIN EFFECTS:				
- shift (early vs. late)	1	70.2781	19.225	p < 0.001
- starting hour	5	39.1885	10.720	p < 0.001
- duration of service	8	10.4385	2.855	p < 0.025
INTERACTION:				
- shift x duration of service	8	11.3232	3.098	p < 0.01

* The exact figures within this analysis are somewhat different from those in a preliminary publication (Pokorny et al, 1981) because of a different (and more correct) allocation of kilometres driven to each hour of service.

Table 11. Early and late shift. Analysis of variance. Part 2, 1976-1980

	DF	mean square	F	
TOTAL	62	3.9957	-	-
RESIDUE	40	1.7624	-	-
MAIN EFFECTS:				
- shift (early vs. late)	1	24.0322	13.636	p < 0.001
- starting hour	5	3.8249	2.170	p = 0.08
- duration of service	8	1.2971	0.736	p = 0.66
INTERACTION:				
- shift x duration of service	8	15.4636	8.774	p < 0.001

The results of this approach in part confirms the outcome of other analyses of the data, as presented in this and previous publications. On the one hand, in both parts of the study the type of shift appears to be a very important explanatory variable for the accident risk of bus drivers.
On the other hand, the difference between both parts of the study with regard to the effect of the starting hour within each shift shows up again: a significant difference between starting hour subgroups in the first part, and a less clear picture in the second part.
The most relevant result of this analysis, however, is the significant interaction between type of shift and duration of service. Apparently the pattern of accident risk in the course of a working day depends heavily on the type of shift.

DISCUSSION

Results obtained in the various analyses of this study indicate a characteristic pattern of accident risk of bus drivers in the course of their working day, dependent on the type of shift. In the early shift, which has a generally high level of accident risk, two peaks can be discerned, viz. in the second quarter of the shift and towards the end of service. The other shift starting in the morning - the split shift - also has a generally high level, while in the second (afternoon) part of this discontinuous shift an inverted U-pattern of accident risk was found.
In the late shift, which has a lower general accident level, a very different pattern could be distinguished. After a relatively high initial accident risk a more or less continuous decline showed up.

These results do not contradict sporadically mentioned differences of accident risk in the course of a working day in the literature (Harris & Mackie, 1972; Hildebrandt et al., 1974; Harris, 1977). Comparability of the data, however, is hampered by differences in exposure, between groups of workers, between task contents, etc.
In this context the study of Adams et al. (1981) should be mentioned. They analysed a number of injuries in a steel plant ta-

king into account the above-named confounding variables. Studying their material on early and late shift data revealed analogous characteristic patterns of accident risk as compared to the results presented in this study.

It should be stressed that the patterns found in our study are probably independent from the actual hour of the day, as they are based on data from different subgroups each with is own starting hour. Therefore, the interpretation of differences found cannot be based primarily on external factors as rush hours, etc.
The question of priority of time on task or time of day in influencing accident risk, however, will be the subject of another paper.
At this stage the following tentative conclusions can be drawn. Assuming that accident statistics have a certain value as indicators for the effects of different tasks, we can conclude that the type of shift and even the different starting hour within each type of shift, do influence the effect of the task on the man.
We might interpret this result in the sense that the physiological state of the organism before and/or at the beginning of the task can modify the task effect significantly at any particular time of the service. On the other hand, it is possible that psychological factors like the attitude of the worker at the beginning of a task is important. These factors could be interpreted as having a relatively long-term influence.
Furthermore, the differences between the shifts with regard to the pattern of accident risk during the services, could be seen in our opinion as representing relatively short-term aspects of the task effect.

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(Submitted for publication to Ergonomics)

ADDENDUM 8

POKORNY, M.L.I., D.H.J. BLOM & P. VAN LEEUWEN. Diurnal variation of bus drivers' accident risk: Time of day or time on task? (Submitted for publication).

DIURNAL VARIATION OF BUS DRIVERS' ACCIDENT RISK: 'TIME OF DAY OR TIME ON TASK?'

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Keywords: Accident risk, bus drivers, diurnal variation, duration of work, shift work.

Abstract:

This paper contains a part of the results of a comprehensive analysis of accidents of bus drivers. In a series of articles different aspects of the etiology of bus drivers' accidents will be high lighted. The subject of this paper is a discussion about the role of time of day or time on task in influencing accident risk. On the basis of the results of this study it is concluded, that while allowance must be made for certain variations related to the time of day, in accident research one should take full account of the effects of the structure of the work together with the duration of the work i.e. time on task.

INTRODUCTION

In previous papers (Pokorny et al, submitted for publication) the results have been reported of a study on bus drivers' traffic accidents. The level of accident risk appeared to be influenced by the type of shift and to a certain extent by the starting hour within each shift. Furthermore, the interaction between type of shift and duration of service has been shown to be an important explanatory factor in the analysis of the variation in accident risk in the course of a working day.
This variation has frequently been described in the various accident statistics as a bimodal distribution in which the morning and evening rush-hours can be distinguished. In the scientific literature fluctuations of accident risk in the course of the day have been studied with comparable results (Bygren, 1974; Cresswell and Froggatt, 1963; Graf and Paul, 1956).

The interpretation of these patterns of accident risk has been associated, on the one hand, with the effects of circadian variations of different physiological and psychological functions, effects of traffic density, changes in light condition or the effects of shift work (Hildebrandt et al, 1974; Colquhoun, 1976). On the other hand, some studies have focused on the effects of task operation and duration of the work (Adams, 1981; Craig and Condon, 1984; McDonald, 1984). The results of this study as mentioned above may contribute to the discussion about the role of time of day or time on task in influencing accident risk.

MATERIAL AND METHODS

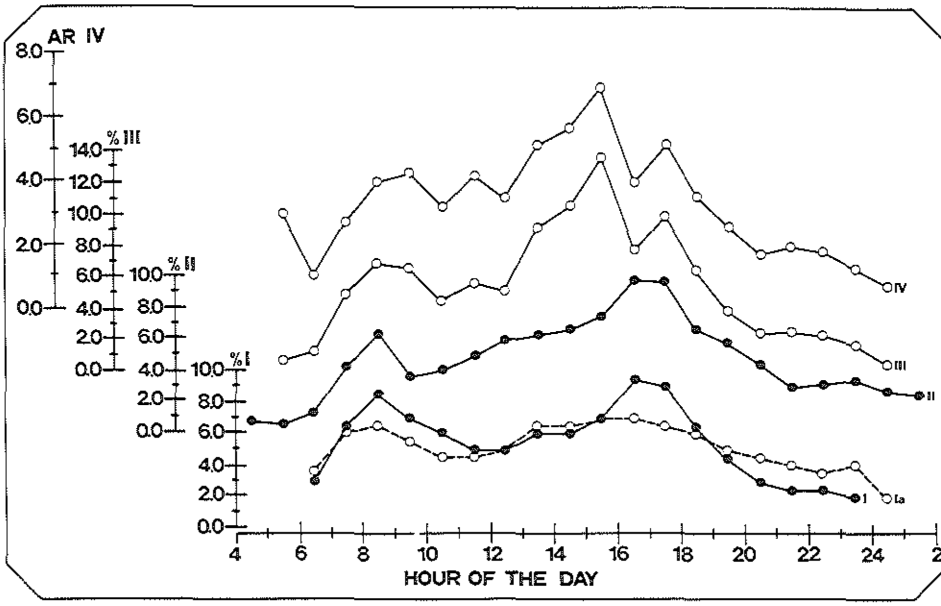
The material used in this study has some important properties. In the company at issue, a large bus company in the Western part of the Netherlands, all drivers, younger or older, more or less experienced, etc. perform their work in rotating schedules and had, therefore, an equal exposure to task with regard to shifts, bus lines, kilometres driven etc. The shift organization in this bus company was, as usual in public transport, of an irregular type. Three main types of shift could be distinguished, viz. early and late shifts (continuous shifts with a mean duration of 8 hours) starting in the morning and in the afternoon respectively; and a split shift (discontinuous), in operation during rush hours: in the morning for about 3 hours; in the afternoon for about 5 hours. Within each shift subgroups could be distinguished with different starting hour. Accident risk was expressed in the number of accidents per 100,000 km driven, not only within each type of shift or its subgroups, but also per hour of service within each subgroup according to their starting hour. Completeness of the data can readily be assumed, because of the liability of the bus drivers in case of not reporting an accident. All accidents are implicated in the analysis, also the very minor ones. A more detailed description of the material including various organizational aspects etc. has been given elsewhere (Blom and Pokorny, 1984). This accident study contains two parts. The initial, explorative, investigation was followed by a second, replicative, part of the study of the accidents of a different branch of the same bus company.

In this second study the hypotheses derived from the first part were tested. As the results with regard to accident risk in the course of the day and in the course of the service did not differ basically, for reasons of simplicity, only the data of the second part of the study have been used in this paper.
Reference will be made to the general traffic accident statistics as published yearly by the Dutch Central Bureau of Statistics (CBS). Some important differences, however, do exist between these data and our material. CBS-data give information about the hourly frequency of accidents **with injury** and as usually no knowledge is available about the actual exposure to risk, e.g. the number of kilometres driven up to the time of accident, time on task etc. Data on traffic density were obtained from the Dutch Public Works Department (PWD). These data together with CBS data will be used as an external frame of reference. Using the results reported in other publications (Pokorny et al, submitted for publication) this paper will discuss in some more detail the way in which the pattern of accident risk of bus drivers during the day is build up. This presentation is based on 990 accidents occurred in 1976-1980 with regard to the distributions per hour of the day in general and per shift. With regard to distributions of accident rates per hour of service this concerned 965 accidents (97.5%).

TIME OF DAY

In figure 1 a comparison has been made between hourly accident data in the general traffic (CBS), general traffic density (PWD), number of kilometres driven by buses, the accident frequencies of the bus drivers of this study and their accident rates (accidents/100,000 km).

Figure 1. Daily distributions of relative frequencies (in %) of general traffic density (I); number of kilometres driven by buses (Ia); general traffic accident data (II); bus drivers' accidents (III); and bus drivers' accident rates (IV)



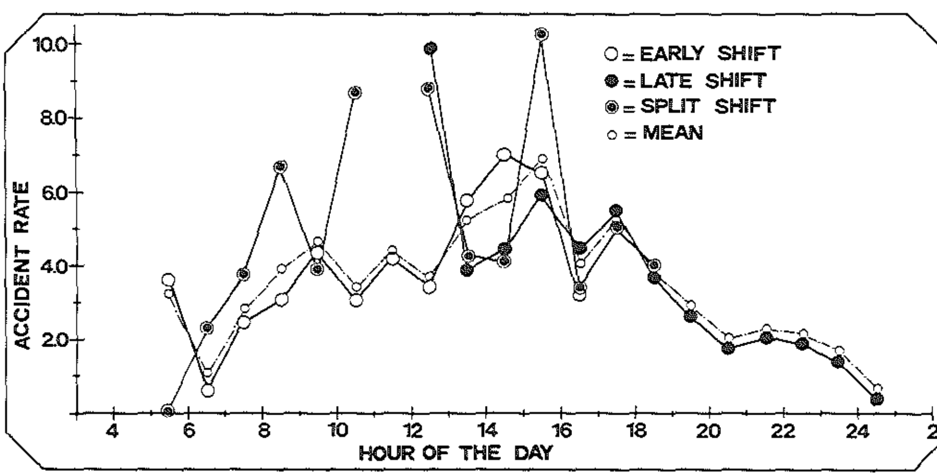
The CBS-data (II) show a well known pattern of accident frequencies with peak values at the morning and evening rush-hours. Allready in the relative accident frequencies of buses (III) a difference can be noted: the highest frequency of bus-accidents can be found in the midafternoon and not so much during the rush-hours. When the actual number of kilometres driven by buses (Ia), representing the number of buses on the road, is accounted for this pattern of accident risk more or less remains the same (IV). Moreover, some indication of a morning peak of bus accidents disappears: the accident rates keep a comparable, relatively high level from 08.00 to 13.00 hours, about the same level as during the evening rush-hours.

When the traffic density (I) is taken as an estimator for the probability of collision and its pattern in the course of the day is compared with the CBS-accident data one can assume that at least a considerable proportion of the hourly variation in accident frequencies in the general traffic is associated with the number of vehicles on the road: The same applies more or less for buses. Here the correlation was computed between number of bus accidents and number of kilometres driven by buses per hour of the day, resulting in r=.84.

TYPE OF SHIFT

Contrary to the general traffic data, however, something more is known about the buses, e.g. the type of shift. From figure 2 the mean accident rate in the course of the day appears to be build up from different contributions of the three shifts. Based on the number of kilometres driven per hour of the day these values do influence the mean rate at a different level.

Figure 2. Accident rates per hour of the day for the early, late and split shifts, and general mean



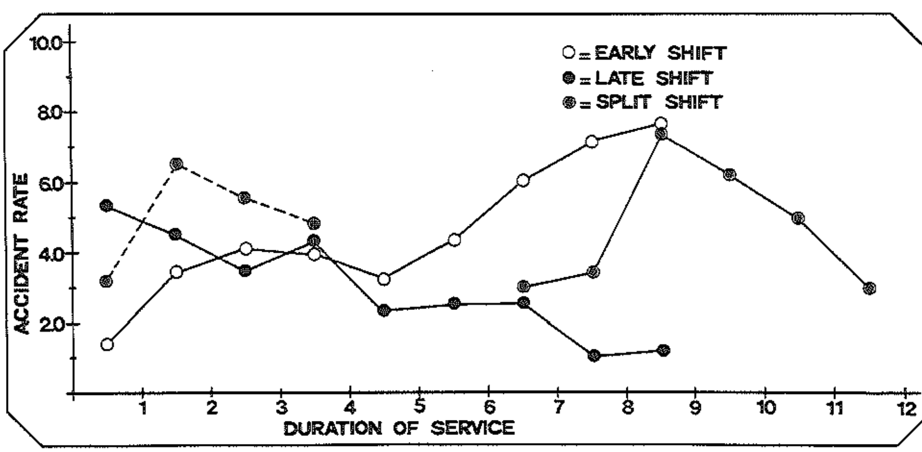
In the morning the mean accident rate is determined mainly by the high numbers of buses in the early shift and to a lesser extent by the split shift. In the evening the pattern is of course completely dependent on the late shift. In the afternoon an intricate picture is visible, composed of accident rate values from the three shifts. It appears that not only the mean accident rates of the consecutive hours of the day differ, but also at the same hour of the day the values from different shifts.

It should be stressed, however, that the shift figures are again composed of different contributions from the various subgroups within each shift, defined by their starting hour.

TIME ON TASK

From the analysis of the subgroup data within each shift it appeared that they are different in respect of the general accident risk level, but comparable with regard to the pattern of the distribution in the course of the working day (Pokorny et al, submitted for publication). These patterns (excluding the first part of the split shift) proved to be characteristic for each type of shift and are presented in figure 3.

Figure 3. Pattern of accident rates per hour of service for the early, late and split shift



Apparently the mean hourly accident distribution is build up from a sequence of consecutive constant patterns of accident rates within the subgroups of each shift. It should be noted that each subgroup contributes to this distribution, dependent on its number of kilometres driven per hour of service, on the starting hour (probably determining to a certain extent its general accident risk level) and to the actual accident risk defined by the time elapsed since the beginning of the task operation.

It seems, therefore, plausible that the rather constant high level of the mean accident rate during the entire morning depends on the peak values in the 3^{rd} and 4^{th} hour of the successive early shift subgroups, starting at different hours, while the high level in the early afternoon seems to be determined by a combination of high accident rates in each of the shifts at that stage of the day: The early shift subgroups showing their increase towards the end of service, the late shift subgroups with their high initial level and the peak value in the course of the second part of the split shift subgroups.

In figure 4 the actual contribution to the mean accident rate of the various subgroups at each hour of the day is illustrated*.
In this figure the striking variation of the accident rates of the subgroups in the course of the day is visible. The level of each point indicates the accident rate of an actual hour of service within a certain subgroup.
The differences in the contribution to the mean has been expressed by the size of the points, representing the number of kilometres driven during that hour of service of a subgroup.
This picture leads to the conclusion that despite the high correlation found between the number of buses on the road and the accident frequency, the mean accident rate in the course of the day (the diurnal variation) is composed of a confusion of very different values. At the same time it demonstrates, that in general no clear association seems to exist between accident risk level and the time of the day. Depending on the type of the shift (or subgroup) and the phase of the work, a very different level of accident risk can exist at the same time of the day.

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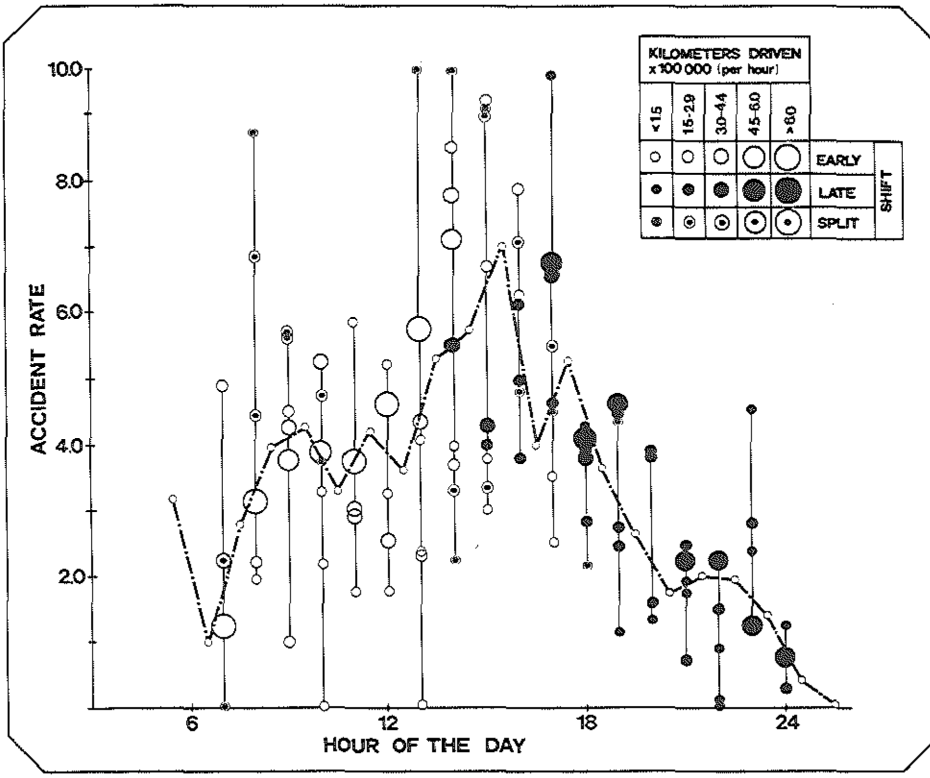
* Within each subgroup of the shifts the number of kilometres as an estimation of exposure were allocated to the consecutive hours of service within each hour. The same applied to the accidents. The consequence of this approach is that accidents and kilometres driven within each hour of service are partly disconnected from the hour of the day because of different starting points of the service within each hour. However a certain association of patterns of accident risk during the service with the corresponding time of the day can readily be assumed.

Figure 4. Contribution of the various shift subgroups to the mean accident rate per hour of the day



DISCUSSION

The consequence of these conclusions for the interpretation of the results from this study, is in our opinion, that the causes of the fluctuations observed in the course of the day, must be found in effects of the interaction between the individual and his environment. This interaction takes, of course, place within a wider frame of individual (circadian) variations, but apparently effects from the (task) environment are at least as important. Powell et al (1971), Richer (1973), McDonald (1981), among others, stress the effects on the number of accidents on different times of the day by the organization of the work (shift work, rest-work-schedules etc.) and by qualitive and quantitative aspects of the task contents. Some other studies (Adams et al

1981; Pokorny et al, submitted for publication) have paid attention to possible combined effects of duration of service and type of shift.

With regard to the influence of individial (circadian) variability in, e.g. performance, many studies have shown effects on, among others, accident risk (e.g. Folkard et al, 1980; Carter & Corlett, 1981). These variations have been connected with fluctuations in physiological functioning or the level of activation (for reviews see Folkard & Monk, 1979; Fröberg, 1975). Interpretation of results of these studies is complicated by the absence of unequivocal conclusions, both with regard to performance rhythms as to physiological variations. On the one hand, low levels of performance have been found on different times of the day (or night) depending, among others, on the type of task (e.g. Monk & Embrey, 1981; Folkard & Monk, 1979). On the other hand different types of physiological rhythms have been demonstrated depending on the type of variable measured, etc. (e.g. Fröberg, 1975; Reinberg et al, 1969, 1970). In this context Monk & Embrey (1981) rightly suggested:"..... that it may be as misleading to speak of a single 'performance rhythm' as it is to speak of a single physiological rhythm, since like physiological rhythms, different performance rhythms can have different phases and rates of adjustment, depending on the variable studied and measure taken". In the case of variable working hours the situation becomes even more complicated by supposed effects of shift work in general (for review see e.g. Colquhoun & Rutenfranz, 1980) or related problems like duration of sleep (e.g. Rutenfranz et al, 1972; Tune, 1969) or quality of sleep (e.g. Masterton, 1965).

Nevertheless, apart from these individual and task-related environmental influences, still remains a certain association of accident risk with traffic density, as becomes most apparent in low density situations in the late evening hours. One can assume that the absence of 'targets' diminishes the probability of an accident to such an extent, that the above named influences will not be effectuated.

In general it can be concluded that while allowance must be made for certain variations related to the time of day (e.g. traffic density, circadian variations), in accident research one should take full account of the effects of the structure of the work together with the duration of work i.e. time on task.

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ADDENDUM 9

POKORNY, M.L.I., D.H.J. BLOM & P. VAN LEEUWEN. Duration of rest periods and accident risk of bus drivers. (Submitted for publication)

DURATION OF REST PERIODS AND ACCIDENT RISK OF BUS DRIVERS

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Abstract

This paper contains a part of the results of a comprehensive analysis of accidents of bus drivers. In a series of articles different aspects of the etiology of bus drivers' accidents will be high lighted. The results presented in this paper concentrate on the interaction between the duration of total (added) rest periods during the shift up to the moment of the accident and accident risk. No association could be detected. The analysis and, therefore, the conclusions are restricted to possible effects of total resting time and cannot be extended to possible effects of particular rest periods of different duration and at a different stage within a different shift on accident risk.

INTRODUCTION

For many years daily working and resting time schedules are a topic of interest and discussion. Employers, trade unions, management and occupational health staff have all paid considerable attention to this issue (Johnson et al, 1981; Hockey, 1983). Researchers have reacted to these signals in a series of scientific publications. Already in the beginning of this century Kraepelin (1902, 1903) stated that pauses are inherent to a human working task as well as fluctuations in the performance. Lehmann & Schmidtke (1961) and Graf (1970) have pointed to the effects of various aspects of the task organization and the distribution of the task load over the day on quality and quantity of the performance of the worker. A recent review (Warm, 1984) paid attention to different backgrounds, both in a psychological and in a physiological sence, of this variability. Some studies have shown the importance of task contents, motivation of the worker, etc. on the performance during a working day. (Chapanis, 1967; Sanders

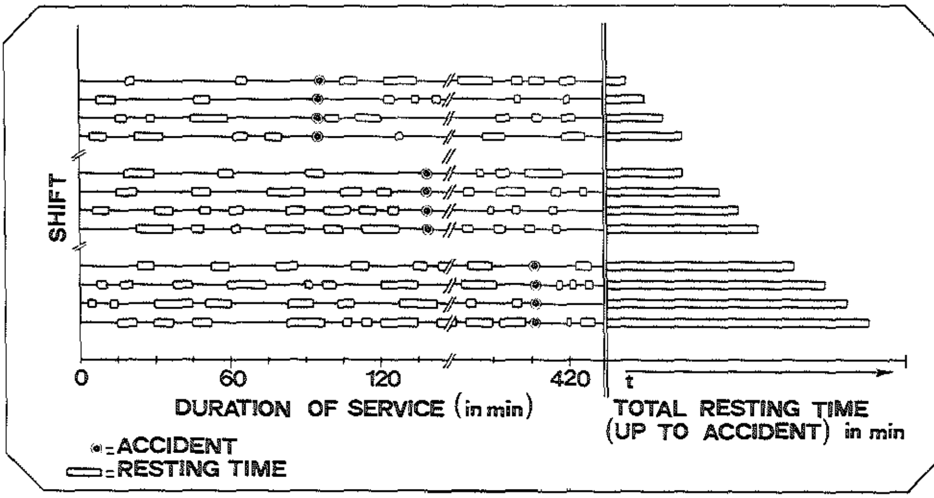
et al. 1971; Teichner, 1974). A universal conclusion about this complicated interaction, however, cannot be drawn yet.
In view of the public interest in working and resting time schedules, frequently focussed on car-driving in general and on the working conditions in the public transport in particular, (McDonald, 1984) and in the context of above mentioned studies about the origins of performance fluctuations, an analysis of the possible effects of resting times, breaks in the task operation, has been performed on accident data of bus drivers. This analysis is based on the assumption that the occurrence of an accident can be considered as an indicator of the effect of the work on the task performer (Pokorny & Blom, 1984).
Research has revealed a certain effect of type of shift, starting hour and duration of service on the accident risk (Pokorny, et al, submitted for publication).
The results presented in this study deals with the relationship between the duration of added (total) rest-periods during a shift up to the moment of an accident and the accident risk.

MATERIAL AND METHODS

The analysis was performed on data available from a bus company in the Western part of the Netherlands. Because of insurance regulations, all accidents, whatever the damage may be, with or without injury have to be reported in this bus company and are implicated in the analysis.
In the period under investigation (1976-1980) a total of 1251 accidents occurred. For 990 it was possible (from different sources,Blom and Pokorny, 1984) to determine the type of shift in which the accident happened.

Rest is in this context defined as 'the scheduled periods of resting time between the various bus line runs within the shifts'. As illustrated in figure 1 the distribution and duration of these rest periods vary from shift to shift. Of course this applies as well to the rest periods preceding an accident. This poses severe methodological problems.

Figure 1. Schematic representation of duration and distribution of rest periods preceeding an accident and in the course of various shifts



For this reason the so called 'total resting time' has been defined as 'the sum individual resting times during a given shift'. The advantage of defining the total resting time is that, as stated, it was possible to calculate the resting time within each shift up to the moment of the accident. However, to arrive at conclusions about a possible effect of various length of this resting time on accident risk one should have information about the distributions of resting times within shifts in general, preceding any moment that in some shifts an accident occurred. For this purpose all shifts are devided in fifteen minutes' segments from the beginning of the work (see figure 1). For each quarter of an hour, on the one hand, in shifts with an accident in that quarter of an hour the resting time was computed in the preceding segment(s). On the other hand, from all shifts in general the resting time was computed up to and including that quarter of an hour. These resting times were classified in some categories of 0 minutes, 1-4 minutes, 5-9 minutes etc. (see tables 1-3), both for shifts with an accident and for shifts in general. It should be emphasized that the analysis, and, therefore, the conclusions are restricted to possible effects of total resting time on accident risk.

In the bus company at issue three different types of shift can be distinguished:

1. Early shift: a shift with a mean duration of 8 hours; starting between 5.00 hours and 10.00 hours.
2. Late shift: a shift with a mean duration of 8 hours; starting between 12.00 hours and 17.00 hours.
3. Split shift: a compound shift, consisting of two parts. The first part starting at about 5.00 hours to 8.00 hours and lasting for about three hours; the second part starting between 13.00 hours to 15.00 hours and lasting for about five hours. This means that a person on a split shift starts working early in the morning for a shorter part of his shift, is off duty for at least one and a half hour and then starts working again in the afternoon for the second (longer) part of his shift.

An important feature of the shift organization of this particular bus company is that all drivers perform all shifts on rotating schedules, therefore each driver has an identical exposure regarding shifts, bus line, kilometres driven, hours of service etc.
In this 'natural experiment' the general environmental characteristics (driving environment) and the organization of these shifts with regard to the sequence of line-runs and rest periods were practically identical for all drivers.

Testing of possible effects of resting time on accident risk was performed by comparing the (observed) distribution of resting times preceding an accident and the (expected) distribution of resting times up to and including a comparable quarter of an hour of service in general. This was based on the assumption that the distribution of total resting times preceding the accidents depends only on the distribution of total resting time in general (null-hypothesis). This procedure has been applied to data of the early, late, and both parts of the split shifts separately. The expected values were computed from the 70,410 early shifts; 87,450 late shifts and 20,780 split shifts driven by the bus drivers in the course of the period of investigation.
For illustration of the procedure the following example is given: From above named 70,410 early shifts 83.6% had 0 minutes of resting time within the first 15 minutes of the service, and 16.4% 1-4 minutes. These percentages were applied to the total number

of shifts (n=4) with an accident in the next 15 minutes and compared with the observed number of 3 (75%) shifts with an accident in the second 15 minutes segment of the shift and 0 minutes of rest in the preceding (first) quarter of an hour of service, and 1 (25%) shift with an accident and 1-4 minutes of rest in the preceding segment.

This example illustrates also that, on the one hand, shifts with accidents within the first 15 minutes of service are excluded from the analysis (as there is no preceding segment); on the other hand, in the first hour of service of course most shifts have resting times up to 5 minutes; therefore, these also have been omitted in the analysis.

These exclusions led to a total number of 386 early shifts with an accident, 273 late shifts, and 101 split shifts to be included in the analysis.

The data have been computed on the basis of 15-minutes-segments. For simplicity and clarity, and with no loss of relevant information (Pokorny et al, 1984) the results are presented in 2-hourly periods (2-3 hours; 4-5 hours, etc.).

RESULTS

The results are presented in table 1 for the early shift data, table 2 for the late shift, and table 3 for the split shift.

In testing in most cases a minimum expected number of 4 was applied; in the case of lower expected numbers subsequent classes were taken together.

Table 1. Early shift. Analysis of distributions of resting time preceeding an accident

summarized resting time preceding the accident	duration of service: 61 t/m 180 min.		181 t/m 300 min.		301 t/m 420 min.		≥421 min.	
	I	II	I	II	I	II	I	II
0	5	4.1						
< 5	12	11.7		0.2				
5 - 9	11	12.6		0.6				
10 - 14	10	15.4	2	1.9				
15 - 19	13	14.9	6	3.6		0.2		
20 - 24	18	13.7	6	7.2		0.2		
25 - 29	9	10.0	10	10.0	1	0.8		0.3
30 - 39	10	6.2	21	21.2	5	5.3		0.2
40 - 49	3	1.6	20	22.1	18	15.4	1	1.8
50 - 59		0.4	15	11.3	17	29.1	9	6.1
60 - 69		0.1	9	6.3	26	28.1	15	20.2
70 - 79			-	2.6	31	21.5	23	21.1
80 - 89			1	0.8	9	10.3	11	12.3
90 - 99				0.4	8	5.6	11	11.6
≥100				1.4	7	5.5	14	10.5
total	90	90	90	90	122	122	84	84
testing of differences between observed and expected distributions	$\chi^2(7) = 6.65$; n.s.		$\chi^2(6) = 2.26$; n.s.		$\chi^2(7) = 11.47$; n.s.		$\chi^2(5) = 3.15$; n.s.	

I = observed number of shifts with an accident

II = expected number of shifts with an accident

With regard to the early shift none of the analyses revealed a significant difference between observed and expected distributions.

In the late shift a significant difference was found in the period between 301-420 minutes of service. This result appeared to be based on non-systematic differences in the classes of 60-69 minutes and 70-79 minutes of resting time and at the end of the distribution: In the first named class the observed number was higher than expected, in the next class lower and at the end of the distribution vice versa again.

With respect to the split shift only at the end of the second part of the shift a difference could be detected, but again non-systematic and based on very small numbers.

Table 2. Late shift. Analysis of distributions of resting time preceeding an accident

summarized resting time preceding the accident	duration of service: 61 t/m 180 min.		181 t/m 300 min.		301 t/m 420 min.		≥421 min.	
	I	II	I	II	I	II	I	II
0	4	4.3						
<5	4	6.3						
5 - 9	8	8.0		0.2				
10 - 14	16	15.3		0.7				
15 - 19	19	20.0	2	1.9	1			
20 - 24	26	21.8	5	4.3	-	0.2		
25 - 29	14	16.6	12	9.2	-	0.5		0.1
30 - 39	18	16.4	23	23.1	3	2.7		0.7
40 - 49	4	4.5	26	24.7	7	9.0		1.3
50 - 59	1	0.7	7	11.6	13	11.9	2	1.4
60 - 69		0.3	4	5.7	18	14.8	4	3.0
70 - 79			4	1.8	4	10.0	1	3.0
80 - 89			-	0.5	3	5.2	3	2.1
90 - 99			1	0.2	5	2.8	1	1.3
≥100				0.1	5	1.9	5	3.1
total	114	114	84	84	59	59	16	16
testing of differences between observed and expected distributions	$\chi^2_{(8)} = 2.80$; n.s.		$\chi^2_{(6)} = 5.46$; n.s.		$\chi^2_{(5)} = 11.46$; $p < 0.05$		$\chi^2_{(2)} = 0.86$; n.s.	

I = observed number of shifts with an accident

II = expected number of shifts with an accident

Table 3. Split shift. Analysis of distributions of resting time preceeding an accident

	duration of service					
	part one		part two			
summarized resting time preceding the accident	61 t/m 180 min.		61 t/m 180 min.		≥181 min.	
	I	II	I	II	I	II the
0	6	5.8	1	1.4		
< 5	11	9.2	2	3.1		
5 - 9	5	5.0	1	1.7		
10 - 14	6	7.6	3	5.9		0.1
15 - 19	5	5.5	8	11.5		0.8
20 - 24	2	1.3	4	4.7		0.5
25 - 29	-	1.1	6	4.9	1	1.4
30 - 39	1	0.5	8	6.6	1	4.8
40 - 49			8	3.9	-	3.7
50 - 59			3	1.7	4	3.9
60 - 69			1	0.6	4	2.2
70 - 79					2	1.0
80 - 89					4	0.3
90 - 99					2	0.3
≥100					1	-
total	36	36	46	46	19	19
testing of differences between observed and expected distributions	$x^2_{(4)} = 0.72$; n.s.		$x^2_{(6)} = 8.82$; n.s.		$x^2_{(2)} = 28.09$; $p < 0.001$	

I = observed number of shifts with an accident

II = expected number of shifts with an accident

DISCUSSION

From the results presented it can be concluded, that no meaningful differences exist between the distributions of total rest periods in shifts with an accident and those in shifts in general. Therefore, no association seems to be present between total duration of rest periods and accident risk. This applies to all three types of shift. As has been mentioned before, however, this conclusion cannot be extended to possible effects of particular rest periods of different duration on accident risk.
An analysis of this latter effect could not be performed because

of the impossibility of constructing expected values from the shifts in general. On the one hand, as may be clear from figure 1 this was caused by the immense variation of distribution and duration of particular rest periods within the shifts. On the other hand, accidents are too rare events to be compared with the enormous numbers of theoretically possible distributions.

The interpretation of the results presented can be done in view of the results of other parts of this study (Pokorny et al, submitted for publication). As mentioned, accident risk of bus drivers depends on different aspects of the task organization. More specifically, the pattern of accident risk in the course of the working day appeared to be characteristic for each type of shift: in the early shift a relatively low level at the beginning of the service, a peak at the third or fourth hour of service, then a decline followed by an increase towards the end of service; in the late shift a relatively high level at the beginning of the service, followed by a more or less continuous decline; the split shift (like the early shift) start with a relatively low accident risk at the beginning of the service, while in the second part an inverted U-shape could be demonstrated.
It might very well be, that possible effects of particular resting times of certain duration also tend to differ in the course of the service. In that case this effect would probably disappear in an analysis of total resting time as performed in this study. Of course, part of the explanation could be found in individual differences in reaction on resting time, which also might contribute to the non significant results of this analysis.
Furthermore, accident risk might primarily be dominated by the type of shift, starting hour and duration of the work, rather then by the interruptions in the course of a working day.

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ADDENDUM 10

BLOM, D.H.J., M.L.I. POKORNY, P. VAN LEEUWEN & W.N. VAN NOOTEN. Shifts sequences and accident risk of bus drivers. (Submitted for publication)

SHIFT SEQUENCES AND ACCIDENT RISK OF BUS DRIVERS.

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Abstract

This paper contains a part of the results of a comprehensive analysis of accidents of bus drivers. In a series of articles different aspects of the etiology of bus drivers' accidents will be high lighted. The results presented in this paper concerned the question whether the sequence of the various shifts influences the actual accident risk on a certain day. The conclusion from different analyses was that no interaction can be demonstrated between the type of shift (or stand-by shift or day-off) on preceding days, actual shift, and accident risk of bus drivers. This leads to the supposition that the actual situation on the working day determines accident risk to any important extent.

INTRODUCTION

In other publications (Pokorny et al, submitted for publication) the type of shift appeared to be an important variable in the etiology of bus drivers' accidents. Shifts starting in the morning (early and split shifts) showed a higher accident rate (number of accidents per 100,000 km driven) than shifts starting in the afternoon (late shifts).
In addition, a certain association with the starting hour could be discerned within each type of shift: a tendency towards a higher risk the earlier one started working within each type of shift. These results should be viewed within the context of shift work problems in general (e.g. Rutenfranz et al, 1981), changes in the psychological and physiological functioning in the course of a working day (e.g. Fröberg, 1975, 1979), quality and quantity of sleep (e.g. Masterton, 1965; Knauth & Rutenfranz, 1972, 1981) irregular, slowly or rapidly rotating shift systems (e.g. Folkard, 1981) etc.

In view of the apparent effects of the type of shift on accident risk the question can be posed, whether or not this effect extends over more than one day. In other words, does the sequence of the various shifts influence the actual accident risk on a certain day.
This question has often been raised in discussions with the management of the bus companies, occupational health officers, and, of course, the bus drivers themselves (McDonald, 1984).

MATERIAL

An analysis of this possible interaction was performed on the accidents of bus drivers in a bus company in the Western part of the Netherlands. In the years 1976-1980 a total of 1251 accidents have been registered. In view of the company regulations on the liability of the drivers in case of not reporting an accident it can readily be assumed, that all accidents are included in the material. Of 990 accidents it was possible to determine from different sources (Blom & Pokorny, 1984) the type of shift in which it occurred. Additionally, for most of these (931) the type of shift on some preceding days could be identified.
The shift organization in the bus company at issue was, as usual in public transport, of an irregular type. As mentioned, three main types of shift could be distinguished , viz. early and late shifts (continuous shifts with a mean duration of 8 hours) starting in the morning and in the afternoon respectively; and a split shift (discontinuous), in operation during rush hours: in the morning for about 3 hours; in the afternoon for about 5 hours. These shifts have been organised in a rotating schedule, taking into account legal constraints and work agreements on hours of work and rest, number of days-off etc. These regulations (e.g. at least 11 hours between successive shifts) do impose certain constraints on the construction of the schedule, but allow nevertheless for numerous combinations of regular shifts, days-off and stand-by shifts.
All drivers in this company, regardless their age, experience etc., performed their shifts in a rotating schedule, therefore, they had an equal exposure to all types of shift, the sequence of these shifts, bus lines, variations in hours of work, environmen-

tal conditions, etc. Of all particular shifts it was possible to calculate the number of kilometres driven. This was used to estimate the exposure of the drivers to the task (Blom & Pokorny, 1984).

METHOD

As mentioned, numerous combinations of shifts, days-off etc. on successive days did exist. For practical purposes the analysis has been confined to the shifts on respectively the first and first and second day preceding a day with an accident.
Given the association between starting hour and accident risk, within each type of shift a subdivision has been made in the analysis: early shifts starting before or after 7.00 hours (Early-early: Ee; Early-late: El), late shifts starting before or after 15.00 hours (Late-early: Le; Late-late: Ll) and split shifts starting before or after 7.00 hours (Split-early: Se; Split-late: Sl).This subdivision has been applied to the actual shift (on the day of the accident) and to the shifts on the first day preceding these shifts (with an accident). With shifts on the two days preceding the actual shift (with an accident) no subdivision has been made.
A statistical analysis has been performed, aimed at the detection of interaction in the data presented. If the type of shift on (a) previous day(s) influences the probability of an accident differentially for the different types of shift, this will show up as an interaction. Three sets of data must be accounted for: the total number of kilometres driven, the marginal totals of accidents for each type of shift, and the marginal totals of accidents belonging to each type of shift on the previous day(s).
A log-linear model was used to represent the no-interaction case, leading to expected values for the number of accidents in each cell of the table involved. These expected values satisfy the following conditions: they are the product of the number of kilometres driven, a factor characteristic for the type of shift (one per column) and a factor characteristic for the type of shift on the previous day(s) (one per row). They sum, both row-wise and column-wise, to the corresponding marginal number of accidents.
An algorithm for calculating these expected values is described

in Darroch and Ratcliff (1972), an application to material comparable to the material of this study may be found in Breslow and Day (1975).
The discrepancy between the number of accidents in a cell and the corresponding expected value is expressed in a χ^2-contribution, and may be roughly judged for significance by ascribing it one degree of freedom. The column totals of these χ^2-contributions, of special interest for this study, are again χ^2-distributed with a number of degrees of freedom one less than the number of cells contributing to it.

RESULTS

In table 1 the results are presented of the analysis of a possible interaction between accident risk, the actual shift (on the day of the accident) and the shift on the preceding day (0 = Day off; R = Reserve or Stand-by shift).
Apparently the observed distributions within each (sub-)type of shift according to the shift on the preceding day, does not differ significantly from the expected distributions. This means that no interaction could be detected between the type of shift (or day-off) on the preceding day, and the actual shift on accident risk.
Inspection of the row-factors (characteristic for the type of shift on the previous day) did not reveal any meaningful difference. This means that no main effect was detectable of shifts, day-off or stand-by shift on the preceding day on the accident risk. The column factors did show differences, indicating a main effect of the actual shift which is not surprising in view of the results mentioned in the introduction (Pokorny et al., submitted for publication).
The same type of analysis has been performed on the various combinations of shifts on the two preceding days. Again no significant interaction could be detected, indicating no effect of any combination of shifts or days-off on preceding days, and the actual shift on accident risk.

Table 1. Distribution of actual shifts (with an accident), number of kilometres driven and χ^2-values, by shift and shift on preceding day

shift on preceding day		shift Ee	El	Le	Ll	Se	Sl	total
Ee	1	25	10	0	0	30	8	73
	2	7.31	1.98	0.66	0.31	5.91	1.58	17.75
	3	3.42	5.05	0.00	0.00	5.08	5.06	4.11
	4	0.30	1.42	-	-	0.08	0.21	
El	1	22	9	3	0	19	9	62
	2	4.85	3.14	0.94	0.84	4.14	2.04	15.95
	3	4.54	2.87	(3.19)	0.00	4.59	4.41	3.89
	4	0.85	0.26	0.01	-	0.01	0.02	
Le	1	0	13	18	23	0	0	54
	2	0.25	4.67	4.03	7.88	0.24	0.30	17.37
	3	0.00	2.78	4.47	2.92	0.00	0.00	3.11
	4	-	0.71	0.97	0.53	-	-	
Ll	1	3	10	65	53	1	3	135
	2	0.54	4.68	13.85	17.35	0.35	0.90	37.67
	3	(5.56)	2.14	4.69	3.05	(2.86)	(3.33)	3.58
	4	-	5.30	0.29	1.52	-	0.72	
Se	1	36	13	0	0	0	0	49
	2	8.92	3.21	0.16	0.08	0.00	0.00	12.37
	3	4.04	4.05	0.00	0.00	-	-	3.96
	4	0.00	1.10	-	-	-	-	
Sl	1	18	12	0	1	0	0	31
	2	3.94	2.91	0.20	0.61	0.03	0.00	7.69
	3	4.57	4.12	0.00	(1.64)	0.00	-	4.03
	4	0.06	0.03	-	-	-	-	
O	1	64	67	34	93	51	28	337
	2	15.04	17.67	10.43	37.11	9.27	5.77	95.29
	3	4.26	3.79	3.26	2.51	5.50	4.85	3.54
	4	0.14	0.05	0.60	0.24	0.25	0.09	
R	1	70	37	45	31	5	2	190
	2	18.78	7.81	12.21	13.58	1.39	0.44	54.21
	3	3.73	4.74	3.69	2.28	3.60	(4.55)	3.50
	4	0.23	2.86	0.02	0.41	0.54	-	
total	1	238	171	165	201	106	50	931
	2	59.63	46.07	42.48	77.76	21.33	11.03	258.30
	3	3.99	3.71	3.88	2.58	4.97	4.53	3.60
	4	1.58	10.73	1.89	2.70	0.88	1.04	
	DF	5	7	3	3	3	2	
	p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	

1 = number of shifts with accidents
2 = number of kilometres driven (x 100,000)
3 = accident rate
4 = χ^2-value

Ee = Early early
El = Early late
Le = Late early
etc.

In table 2 and 3 examples are given of this type of analysis: table 2 shows the distribution of actual shifts (with an accident) by the combination of shifts on two preceding days starting with an early shift on the second day (before the accident); table 3 the same with a day-off on the second day. Data of other combinations are available in Pokorny et al, 1984.

Table 2. Shifts on two days preceding a actual shift (with an accident). Early shift on second day before

shifts on preceding days			shift						
II	I		Ee	El	Le	Ll	Se	Sl	total
E	E	1	9	5	0	0	12	2	28
		2	2.27	0.46	0.06	0.02	1.24	0.49	4.54
		3	3.96	10.87	0.00	0.00	9.68	(4.08)	6.17
		4	0.31	0.82	-	-	0.60	0.87	
E	L	1	0	0	4	3	0	0	7
		2	0.14	0.11	0.29	0.51	0.24	0.14	1.43
		3	0.00	0.00	13.79	(5.88)	0.00	0.00	4.90
		4	-	-	4.10	-	-	-	
E	S	1	25	12	0	0	0	0	37
		2	5.40	2.04	0.02	0.32	0.03	0.00	7.81
		3	4.63	5.88	0.00	0.00	0.00	-	4.74
		4	0.20	0.10	-	-	-	-	
E	O	1	20	11	14	17	18	10	90
		2	5.27	2.39	3.68	9.78	2.77	1.19	25.08
		3	3.80	4.60	3.80	1.74	6.50	8.40	3.59
		4	0.07	0.31	0.10	0.40	0.24	1.33	
E	R	1	46	28	1	3	1	0	79
		2	12.95	4.69	0.44	0.52	0.58	0.03	19.21
		3	3.55	5.97	(2.27)	(5.77)	(1.72)	0.00	4.11
		4	0.01	0.19	-	-	1.69	-	
total		1	100	56	19	23	31	12	241
		2	26.03	9.69	4.49	11.15	4.86	1.85	58.07
		3	3.84	5.78	4.23	2.06	6.38	6.49	4.15
		4	0.59	1.42	4.20	0.40	2.53	2.20	
		DF	3	3	1	(1)	1	(1)	
		p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s	

1 = number of shifts with accidents

2 = number of kilometres driven (x 100,000)

3 = accident rate

4 = χ^2-value

Table 3. Shifts on two days preceding a actual shift (with an accident). Day-off on second day before

shifts on preceding days II	I		shift Ee	El	Le	Ll	Se	Sl	total
0	E	1	15	7	1	0	4	7	34
		2	3.37	1.48	0.25	0.46	2.05	1.02	8.63
		3	4.45	4.73	(4.00)	0.00	1.95	6.86	3.94
		4	0.00	0.08	-	-	0.36	0.82	
0	L	1	3	5	25	26	0	3	62
		2	0.62	1.27	6.63	11.27	0.45	1.18	21.42
		3	(4.84)	3.94	3.77	2.31	0.00	(2.54)	2.89
		4	-	0.08	0.22	0.02	-	0.62	
0	S	1	26	12	0	1	0	0	39
		2	6.55	3.68	0.08	0.10	0.00	0.00	10.41
		3	3.97	3.26	0.00	(10.00)	-	-	3.75
		4	0.03	0.16	-	-	-	-	
0	0	1	22	21	4	49	10	9	115
		2	4.78	4.36	1.25	13.58	2.93	1.58	28.48
		3	4.60	4.82	3.20	3.61	3.41	5.70	4.04
		4	0.33	0.02	0.74	0.20	0.97	0.00	
0	R	1	9	2	5	3	0	0	19
		2	2.87	0.45	1.87	2.67	0.19	0.10	8.15
		3	3.14	(4.44)	2.67	(1.12)	0.00	0.00	2.33
		4	0.20	-	0.01	0.62	-	-	
total		1	75	47	35	79	14	19	269
		2	18.19	11.24	10.08	28.08	5.62	3.88	77.09
		3	4.12	4.18	3.47	2.81	2.49	4.90	3.49
		4	0.56	0.34	0.97	0.84	1.33	1.44	
		DF	3	3	1	1	1	1	
		p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	

1 = number of shifts with accident

2 = number of kilometres driven (x 100,000)

3 = accident rate

4 = χ^2-value

CONCLUSION

The conclusion from this analysis must be that no interaction can be demonstrated between the type of shift on preceding day(s), actual shift, and accident risk of bus drivers. Even two successive days-off do not seem to have any effect which may be called

surprising. Alternatively, if such an effect would exist, it is not reflected in changes in accident risk.
This result, in combination with the reported effects of type of shift and duration of service (Pokorny et al, submitted for publication) leads one to the supposition that the actual situation on the working day determines the accident risk to an important extent.

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CURRICULUM VITAE

Dick Blom werd in 1945 geboren in Gauw (gem. Wymbritseradeel). Na een deel van zijn jeugd op het eiland Sumba in Indonesia te hebben doorgebracht, kreeg hij zijn middelbare schoolopleiding aan het Christelijk Lyceum te Emmen. Hij behaalde in 1963 het einddiploma Gymnasium-B en begon in hetzelfde jaar zijn medische studie aan de Vrije Universiteit te Amsterdam. Hij legde in 1969 met goed gevolg het doctoraal examen af en werd bevorderd tot arts in 1972.

Na een wisselassistentschap (interne geneeskunde, chirurgie en verloskunde) in het St. Josephziekenhuis te Veghel, volgde hij de Nationale Tropencursus voor Artsen (1973) in het Koninklijk Instituut voor de Tropen te Amsterdam. Van 1973 tot 1976 was hij als District Medical Officer werkzaam in het districtsziekenhuis te Senanga (Zambia). Na terugkeer volgde in 1977 zijn aanstelling als wetenschappelijk medewerker aan het Nederlands Instituut voor Praeventieve Gezondheidszorg/TNO te Leiden, om onderzoek te verrichten in het werkveld Mens en Arbeid, onder meer in het projekt Werk-rusttijden en Ongevallen-analyse.

Dit proefschrift is gebaseerd op een deel van de resultaten van dat projekt.

CURRICULUM VITAE

Mirko Pokorny werd geboren in 1943 in Praag (Tsjechoslowakije). Zijn middelbare opleiding werd afgerond met het behalen van een eindexamendiploma in 1962. Deels parallel aan de middelbare opleiding studeerde hij vanaf 1959 viool aan het Muziekconservatorium in Praag. Deze studie werd in 1965 afgesloten met het behalen van een Absolutorium. In deze tijd was hij lid van een aantal kamermuziekensembles en werkte tevens als orkestmusicus.
Hij verliet Tsjechoslowakije in 1966. In hetzelfde jaar werd hem een beurs van de Oostenrijkse regering verleend om zijn opleiding als violist aan de Akademie für Musik und Darstellende Kunst in Wenen te kunnen voortzetten. Ook in deze periode werkte hij als orkestmusicus en nam deel aan een groot aantal kamermuziekaktiviteiten. In het jaar 1968 werd hij geëngageerd als eerste violist bij het Residentie Orkest in Den Haag.
Nadat een ongeval hem verder uitoefenen van zijn violistenberoep onmogelijk maakte begon hij in 1972 met de studie psychologie aan de Rijksuniversiteit te Leiden. In 1976 legde hij met goed gevolg het doctoraal examen af. Tijdens zijn studie werkte hij als leraar muziek en later als student-assistent aan het Nederlands Instituut voor Praeventieve Gezondheidszorg/TNO (NIPG/TNO) in Leiden. In 1976 volgde zijn aanstelling als wetenschappelijk medewerker aan dit instituut. Hij is projektleider van een aantal projekten die in het kader van het werkveld Mens en Arbeid van het NIPG/TNO plaatsvinden, waaronder het projekt Werk- rusttijden en Ongevallen-analyse. Dit proefschrift is gebaseerd op een deel van de resultaten van dit projekt. Medio 1984 werd hij benoemd tot wetenschappelijk koördinator van de sektor Experimentele psychologie en psychofysiologie.

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