Modeling the impact of the components of long work hours on injuries and "accidents"

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2 authors:

Simon Folkard
Swansea University

David A Lombardi
Navitas Life Sciences

Modeling the Impact of the Components of Long Work Hours on Injuries and "Accidents"

Simon Folkard, PhD, DSc (Lond)[1,2,3*] **and David A. Lombardi,** PhD (Mass)[3]

Background *Many of the industrial disasters of the last few decades, including Three Mile island, Chernobyl, Bhopal, Exxon Valdez, and the Estonia ferry, have occurred in the early hours of the morning. Follow-up investigations concluded that they were at least partially attributable to human fatigue and/or error. The potential impact of long work hours on health and safety is a major concern that has resulted in various work hour regulations.*

Methods *The risk of injuries and "accidents" (incidents) associated with features of work schedules from published epidemiological studies are pooled using an additive model to form a "Risk Index." The estimated risks of an incident for various standard work schedules are presented using the proposed model.*

Results *The estimated risk of an injury or accident associated with any given number of weekly work hours varies substantially depending on how work hours are comprised. The risk depends on the length and type of shift, as well as the frequency of rest breaks.*

Conclusions *We conclude that placing a limit on the risk associated with a particular work schedule is likely more effective than setting daily, weekly or monthly work hour regulations in keeping workplace safety within acceptable limits.* Am. J. Ind. Med. 49:953–963, 2006. *© 2006 Wiley-Liss, Inc.*

KEY WORDS: work hours; safety; health; injuries; accidents; mathematical models; risk; regulations; shiftwork

INTRODUCTION

There is considerable worldwide concern over the potential impact of prolonged work hours on workplace health and safety. For example, in the US there are "work hour regulations" for various occupational groups, primarily for those employed in industries and occupations which are safety-critical such as transport operations. However, these regulations typically specify only a maximum permitted number of work hours per day, week, or month. It is hypothesized that such regulations are likely to be of limited value in keeping workplace safety within acceptable safety levels.

The available published literature on shiftwork safety is reviewed. Only those studies that allow for a calculation of the relative risk of "accidents" or injuries associated with specific features of shift systems are utilized. How these relative risk estimates can be pooled in a simple additive model to provide an overall estimate of the relative risk over any given span of shifts, and hence for an entire shift system, is described. Finally, this model is used to estimate the risk associated with different lengths of work week comprised of different types and lengths of shift.

This model is based on the risk of injuries and accidents in view of the various methodological difficulties in attempting to examine the impact of long work hours on health measures. These challenges can be illustrated with reference to a survey conducted of more than 2,000 aircraft maintenance engineers in the United Kingdom (UK), which measured both the "normal" hours worked per week (including overtime) and the

[1]Université Paris Descartes, Faculté de Médecine, Laboratoire d'Anthropolgie Appliquée, Paris, France
[2]Body Rhythms and Shiftwork Centre, University of Wales Swansea, Swansea SA2 8PP, United Kingdom
[3]Liberty Mutual Research Institute for Safety, Hopkinton, Massachusetts
*Correspondence to: Simon Folkard, Université Paris Descartes, Faculté de Médecine, Laboratoire d'Anthropolgie Appliquée, UPRES Ergonomie, 45 rue des Saints Pères, 75006 Paris, France. E-mail: s.folkard@swan.ac.uk

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reported prevalence and incidence of various health problems and illnesses [Folkard, 2003]. As hypothesized, the frequency of minor infections increased with increasing work hours. However, contrary to what was expected, the frequency of cardiovascular symptoms decreased with increasing work hours. It is probable that this finding reflected a self-selection bias of the fittest workers into longer work hours (i.e., an healthy worker effect). Additionally, the data indicated that age was negatively correlated with normal work hours, such that on average, older workers work fewer hours per week. Thus any association between work hours and many chronic (or long term) health outcomes may be confounded by age, and in many cases these chronic health outcomes require long induction and latency times to emerge. Ideally, any examination of the impact of long hours on health needs to control for both age and years of experience, which typically are highly correlated.

There are many health effects and symptoms that are of a more acute nature that could be examined with respect to the impact of various work schedules. These effects include headaches, stomachaches, and others, that may often have a secondary impact on productivity and absenteeism. In some cases, these effects may potentially develop into, or are indicative of, more serious health problems. Unfortunately, it is unusual for records of specific illnesses and symptoms to be kept by employers, and it is thus difficult to relate these outcomes to features of work schedules.

In the light of the challenging issues with studying the impact of work schedules on health measures, this study will focus on acute accident and injury measures (described further as incidents) that have a clear time of onset that can be related to specific features of work schedules. In the vast majority of cases the incidents on which these trends are based were not severe, but it is likely that they represent a relatively direct measure of the occurrence of mistakes and omissions. Workplace safety is often the primary concern of both employers and employees in many shiftworking situations. This is particularly true in situations such as transport or the nuclear power industry where there may be a high "public health" or "environmental" risk. Indeed, a number of authors have noted that many of the "headline hitting" disasters of the last few decades, including Three Mile island, Chernobyl, Bhopal, Exxon Valdez, and the Estonia ferry, have occurred in the early hours of the morning. Follow-up investigations of these disasters concluded that in each case they were at least partially attributable to human fatigue and/or error.

Problems With the a Priori Risk of "Accidents" and Injuries

There are few published studies that allow for an unbiased calculation of relative risk estimates of accidents and/or injuries associated with specific features of shift systems due to non-homogeneous a priori risk. In many organizations the number of individuals at work is not constant over the 24-hr day while the level of supervision, etc., may also vary substantially. Further, in most shiftworking situations the nature of the job and associated tasks being performed may vary considerably across the 24-hr day. For example, longer, and hence safer, production runs are often kept for the night shift. This practice may be official policy within a company, or may simply be condoned or ignored by management. Either way, it means that it is not valid to compare accident rates across work shifts since fewer accidents would be expected on the night shift (or the one with fewer employees at risk).

One example of this type of bias, and that in drawing valid conclusions, is the study by Adams et al. [1981]. In that study, they report the absolute numbers of accidents on the day, afternoon and night shift but then comment that "precise information about the numbers employed on afternoon and night shift is simply not available" (p 77). However, the authors continue by pointing out that "the personnel department suggests that a fairly good guide to numbers employed on the various shifts would be the ratio evening (night):1; afternoon:2; day:4." These ratios are then used to estimate that injuries on the night shift were about 30% less than expected. This clearly begs two major questions. Firstly the ratio 1:2:4 is insufficient to accurately form the basis for such a calculation. Secondly, it clearly implies that the factory concerned had far fewer people around at night. This may not only reduce the frequency of injuries, but also suggests that the whole work environment may have been totally different at night.

A further problem stems from the fact that many of the studies reporting accident rates on the different shifts refer to what appear to be increasingly uncommon permanent shift systems, at least in Europe. This means that any comparison across shifts not only confounds potential differences in the numbers working on each shift, but also potential differences in worker-related factors for those shifts. For example, in the USA many permanent shift systems operate on a "seniority" basis whereby newly hired employees to a company typically join the night shift (or the least desirable shift) and eventually progress to the afternoon shift or the morning shift, when they have been with the company for a number of years. Thus both the average age and the level of experience of the workers may likely be different across the three shifts. These factors may account for the fact that a number of authors have reported either fewer injuries on the night shift than on the morning or day shift, or similar rates across the three shifts [e.g., Andlauer, 1960; Adams et al., 1981; Ong et al., 1987; Baker et al., 2003; Olowokure et al., 2004].

Problems With the Probability of Reporting "Accidents" and Injuries

Even in the few studies of industrial situations where the a priori risk of incidents appears to be constant across the

24-hr day, the problem remains that the probability of actually reporting an injury or accident may vary by shift. For example, in a recent unpublished study of injury rates in an engineering company, where the a priori risk of injuries appeared to be constant, we discovered that substantially fewer injuries were reported on the night shift than on the day shift. Further investigation revealed that when members of the predominantly male workforce were injured during the day they were treated by a female nurse at the on-site occupational health clinic. However, this clinic was closed at night and first-aid was provided by the male security guards at the entrance gatehouse to the works. It seems highly probable that this dissuaded many members of the workforce from reporting or seeking treatment for less serious injuries on the night shift. Indeed, the nursing sister at the occupational health clinic also commented that the number of injuries reported during the day varied substantially depending on which nurse was on duty!

In this context there are published studies that have reported fewer injuries occurring at night, however, these studies have suggested that night injuries tended to be more serious than those occurring during the day [e.g., Andlauer, 1960; Oginski et al., 2000]. Why more serious incidents occur on the night shift relative to the day is difficult to understand. A reasonable explanation may be that night shift workers are less inclined to report injuries of minor severity, thus resulting in their *reported* injuries at night being, on average, more serious. Some evidence in support of this interpretation can be gleaned from the results of Oginski et al. [2000]. On average, the number of days off work was higher following an injury reported on the night shift than following one reported on the morning shift. These results were not stratified by body part of nature of injury, however, it seems probable that this difference reflected largely on the fact that the number of minor injuries reported that resulted in zero days off work was more than twice as high on the morning shift than it was on the night shift.

METHODS

The current review and proposed ''risk index'' model is based on literature searches using PsycINFO, Web of Science, PubMed, Science Direct and Google Scholar for the search terms: ''work hours,'' ''shift work,'' ''shiftwork,'' ''time of day,'' or ''work schedule'' combined with ''accident,'' ''injury,'' ''safety,'' or ''risk'' conducted in December 2004 and January 2005 and the substantial collection of reprints and papers held by the first author. These queries resulted in over 1,500 ''hits,'' but after examining these results in greater detail, many were general ''review'' or ''advice'' documents, often supplied by commercial consultancies or by governmental organizations.

Two types of analyses were used to examine the trends considered in this review (as appropriate). These analyses were performed using SPSS version 12.0.1 for Windows. First, either a non-parametric Kruskal–Wallis or Friedman test of the relative risks was calculated for each dataset. Non-parametric analyses were chosen since: (i) relative risk values are not likely to be normally distributed and (ii) that the variances are not likely to be equal. This form of analysis gives equal weight to each of the studies, despite differences in the total number of incidents reported, and essentially determines whether the trends reported in the various studies are similar to one another. The main disadvantage with this type of analysis is that it would give undue weight to an atypical trend reported in a study based on only a small number of incidents.

Secondly, for those trends where the frequency values did not have to be corrected for exposure, a chi-square analysis was based on the summed frequency of incidents, giving equal weight to injuries and accidents. These summed frequencies were used to estimate 95% confidence intervals based on a Poisson distribution. These analyses essentially weight the studies according to the number of incidents reported, but suffers from the disadvantages (i) of using chi-square with large data sets and (ii) that undue weight would be given to a study reporting an atypical trend if it was based on a large number of incidents. In the present review both forms of analyses were used in an attempt to overcome the shortcomings associated with each approach individually. If the results of both analyses resulted in similar findings, we would suggest that the conclusions are likely independent of the assumptions underlying each analysis.

RESULTS

Trends in Incidents Associated With Features of Shift Systems

Four consistent trends in incidents associated with features of shift systems were identified and evaluated, based on studies where both the a priori risk and the probability of reporting an injury appeared to be either constant or appropriately controlled for.

Trend Across the Three Shifts

The first trend relates to the relative risk of incidents on the morning, afternoon, and night shifts on 8-hr shift systems. There are five studies (Table I) that are based on relatively large numbers of incidents that appear to have overcome these potential confounders and incident rates are reported separately for the morning, afternoon, and night shifts. It should be noted that the studies for this and the subsequent trends considered differed from one another in terms of their location, industry, the numbers of incidents reported, the size of the population in which they occurred, and the time span over which the data were collected. They also likely differed

TABLE I. Summary of Studies Reporting Incidents Across Three Shifts

Author(s)	Industry	Location	Measure	Total number (over three shifts)	Relative risk values Morning	Afternoon	Night
Wanat [1962]	Coal mining	Underground	Injuries	3699	1.00	1.23	1.36
Quaas and Tunsch [1972]	Metallurgic plant	N/A	Injuries	1415	1.00	1.12	1.29
		N/A	Accidents	688	1.00	1.00	1.24
Levin et al. [1985]	Paint manufacturing	N/A	Injuries	119	1.00	1.14	1.26
Smith et al. [1994]	Engineering	Site 1	Injuries	2461	1.00	1.08	1.21
		Site 2	Injuries	2139	1.00	1.23	1.20
Wharf [1995]	Coal mining	"Industrial"	Injuries	1970	1.00	1.10	1.32

in terms of the criteria used in determining whether an incident was recorded. Valid comparisons can be made within each study; however direct comparisons between studies are not meaningful.

It should also be noted that while in some of these studies there were equal numbers of workers on each shift [Quaas and Tunsch, 1972; Smith et al., 1994], the original authors had to correct the data in the others to take account of inequalities in the number of workers by, for example, calculating the frequency per 100 worker-years [Wanat, 1962; Levin et al., 1985; Wharf, 1995]. In addition, two of the studies report two separate sets of data, for different areas or types of incident, giving a total of seven data sets across the three shifts. Further, while some of the studies give no precise details of the shift system in use, many of them involved a total of only 4 or 5 days on each shift before a span of rest days [e.g., Quaas and Tunsch, 1972; Smith et al., 1994].

For each study, the risk values on the afternoon and night shifts were expressed relative to that on the morning shift (see Table I). A Kruskal-Wallis test of these values indicated that there was a significant trend across the three shifts [$\chi^2 = 16.084$, df = 2, $P < 0.001$]. The chi-square test based on the summed frequencies across the seven data sets for the three shifts also yielded a highly significant effect of shift [$\chi^2 = 124.08$, df = 2, $P < 0.001$]. Based on these pooled frequencies, incident risk increased in an approximately linear fashion, with an increased risk of 15.2% on the afternoon shift, and of 27.9% on the night shift, relative to that on the morning shift (see Fig. 1). The increased risk on the night shift may reflect, at least in part, on the shortened day sleeps typically obtained between successive night shifts. However, it should be noted that the night sleeps prior to a morning shift are also typically far shorter than those obtained on the afternoon shift, thus, it is difficult to fully account for the trend shown in Figure 1 in terms of sleep duration [see Folkard et al., 2005, for a fuller discussion on this point].

In a related recent paper, Horwitz and McCall [2004] analyzed 7,717 injuries occurring to hospital employees in Oregon from 1990 to 1997, and corrected for exposure using data from the US's Current Population Survey. They reported that injury rates (per 10,000 employees) were lower on the day shift (176) than on either the evening shift (324) or night shift (279). These values translate into relative risk estimates of day (morning) = 1.00, evening (afternoon) = 1.81, and night 1.59. These values are not only substantially larger than those shown in Figure 1, but also suggest that the risk may be higher on the afternoon shift than on the night shift. However, the authors also point out that the average number of days off following an injury on the night shift was higher (46) than that for the day (38) or evening (39) shifts, which may have reflected on a reporting bias (see above). Finally, they point out that the injury rates they report may reflect on differences in staffing levels, or on the type of jobs undertaken, across the different shifts. Thus it seems unlikely that the a priori risk of injuries was constant across the three shifts.

Trend Across Successive Night Shifts

The second consistent trend in incidents is that over successive night shifts. The authors are aware of a total of

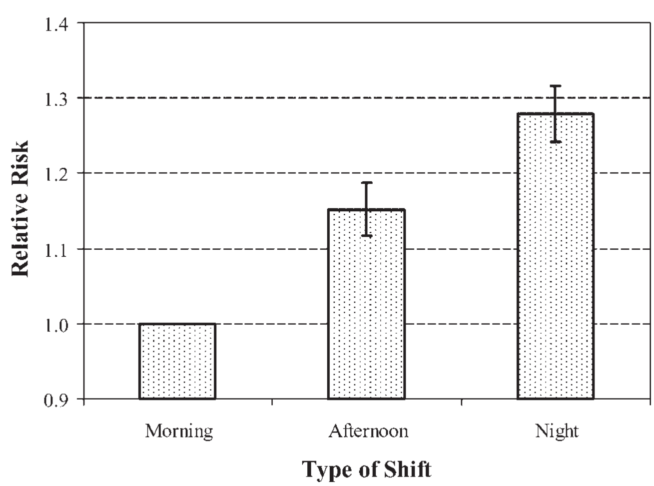

FIGURE 1. The relative risk across the three shifts (error bars are 95% CIs).

TABLE II. Summary of Studies Across Successive Night Shifts

Author(s)	Industry	Measure	Total number (over 1st four nights)	Relative risk values (by successive nights)			
				1st	2nd	3rd	4th
Quaas and Tunsch [1972]	Metallurgic plant	Accidents	261	1.00	1.38	1.79	1.71
Vinogradova et al. [1975]	Dockers	Accidents	272	1.00	1.24	1.11	1.60
Wagner [1988]	Iron mining	Accidents	442	1.00	0.75	0.80	1.26
Smith et al. [1994]	Engineering	Injuries	1686	1.00	1.05	1.12	1.16
Smith et al. [1997]	Engineering	Injuries	842	1.00	1.08	1.27	1.76
Tucker et al. [2001]	Engineering	Injuries	291	1.00	1.30	1.57	1.32
Oginski et al. [2000]	Steel mill	Injuries	63	1.00	1.00	1.21	1.29

seven published studies[1] that have reported accident or injury (i.e., incidents) frequencies separately for each night over a span of at least four successive night shifts, namely those of [Quaas and Tunsch, 1972; Vinogradova et al., 1975; Wagner, 1988; Smith et al., 1994, 1997; Oginski et al., 2000; Tucker et al., 2001] (see Table II). As before, in order to compare across these studies the frequency of incidents on each night was expressed relative to that on the first night shift.

In each of these studies, the same individuals were working on each shift within the span of night shifts. A Friedman analysis of the relative risk values indicated that there was a significant trend across the four successive night shifts ($\chi^2 = 14.304$, df $= 3$, $P < 0.01$). A chi-square test of the summed frequencies across the seven studies for the four successive night shifts also yielded a significant effect of successive shifts ($\chi^2 = 55.584$, df $= 3$, $P < 0.001$). These summed values were used to estimate the risk on the successive night shifts relative to the first such shift and the results are shown in Figure 2. On average, risk was about 6% higher on the second night, 17% higher on the third night, and 36% higher on the fourth night.

Two important questions arise over this substantial increase in risk over four successive night shifts. The first is what happens to risk over longer spans of successive night shifts? There is limited published data relating to this question, and only two of these studies reported incidence rates for a span of more than four night shifts. Additionally, both studies were based on relatively small numbers of incidents. It is noteworthy, however, that each study [Vinogradova et al., 1975; Wagner, 1988] reported a decrease in risk from the fourth to the fifth night shift which was maintained until the seventh, and final, night shift in Wagner's 1988 study.

Two other studies [Quaas and Tunsch, 1972; Tucker et al., 2001] showed a slight decrease in risk from the third to the fourth night shift, but these decreases need to be evaluated in light of the decreases shown by the other smaller studies between the first and second, and second and third, night shifts. Thus, only the two studies with the largest sample size [Smith et al., 1994, 1997] showed a progressive increase in risk over all four successive night shifts, potentially reflecting their precision. Thus while it remains a possibility that over longer spans of night shifts risk may actually start to decrease after the fourth night, there is no current evidence to indicate that this is actually the case.

Trend Across Successive Day Shifts

The other important question is whether the increase in risk over successive shifts is confined to the night shift, or whether it might be general to all shifts and represent an accumulation of fatigue over successive workdays. Of the seven studies listed above, five reported the risk over successive morning or day shifts, namely those of [Quaas and Tunsch, 1972; Smith et al., 1994, 1997; Oginski et al., 2000; Tucker et al., 2001] (see Table III).

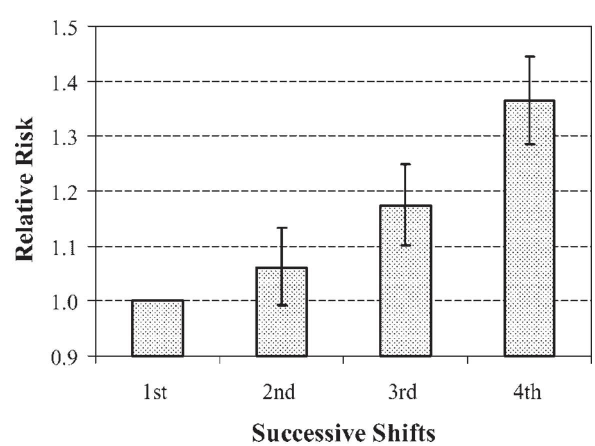

FIGURE 2. The relative risk over four successive night shifts (error bars are 95% CIs).

[1] Note that the study reported by Monk and Wagner [1989], was not included since the data reported in that study were a subset of those reported by Wagner [1988].

TABLE III. Summary of the Studies Reporting Incidents Across Successive Day Shifts

Author(s)	Industry	Measure	Total number (over 1st 4 days)	Relative risk values (by successive days) 1st	2nd	3rd	4th
Quaas and Tunsch [1972]	Metallurgic plant	Accidents	169	1.00	1.21	0.93	0.79
Smith et al. [1994]	Engineering	Injuries	1372	1.00	0.98	1.05	1.11
Smith et al. [1997]	Engineering	Injuries	761	1.00	1.09	1.04	1.45
Tucker et al. [2001]	Engineering	Injuries	297	1.00	0.88	1.22	0.97
Oginski et al. [2000]	Steel mill	Injuries	85	1.00	1.12	1.59	1.29

A Friedman test of the relative risk values suggested a non-significant trend across the four successive day shifts ($\chi^2 = 2.040$, df = 3, $P > 0.25$), which can be interpreted as indicating that the trend was relatively inconsistent across the studies. This finding may also reflect a statistical power issue given the relatively small number of incidents in some of these studies (see Table III). A chi-square test of the summed frequencies for the four successive shifts across the five studies yielded a significant effect of successive shifts ($\chi^2 = 10.092$, df = 3, $P = 0.018$). These summed values were then used to estimate the risk on the successive morning/day shifts relative to the first such shift and the results are shown in Figure 3. Note that the same scale has been used for this Figure as that were used in Figure 2 for direct comparisons. On average, risk was about 2% higher on the second morning/day, 7% higher on the third morning/day, and 17% higher on the fourth morning/day shift than on the first shift.

Although the trend across successive day shifts was relatively inconsistent compared to the other trends reported in this review, it is clear that incident risk increased over successive morning/day shifts. It is important to note, however, that this increase was substantially smaller than that over successive night shifts (compare Figs. 2 and 3).

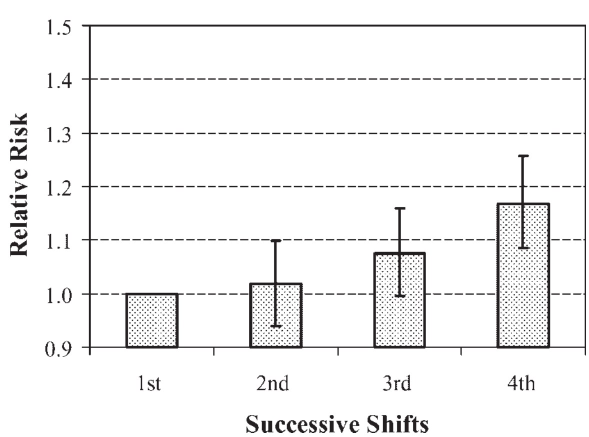

FIGURE 3. The relative risk over four successive morning/day shifts (error bars are 95% CIs).

Thus, there is evidence for an increase in risk over successive workdays, irrespective of the type of shift, but also evidence that this increase is substantially larger on the night shift than on the morning/day shift.

Trend Across Hours on Duty and the Length of Shifts

The fourth trend considers the impact of different lengths of shift on risk. Previous studies that have examined this trend have faced the problems previously described earlier in this study. However, those studies that have interpolated performance measures have typically found a deterioration in performance and alertness on 12-hr shifts compared to that on 8-hr ones [e.g., Rosa, 1991]. In contrast, Laundry and Lees [1991] found a slight reduction in the occurrence of industrial accidents in a company that changed from an 8-hr system to a 12-hr one, but the authors did not provide any details of the shift systems involved, such as the number of successive work-days. Nevertheless, they report a significant reduction in minor, but not more serious, injuries on the 12-hr system. The obvious question arises, as to whether this effect may reflect a differential reporting bias of accidents across shifts.

Four studies, have reported the trend in risk over successive hours on duty and have managed to correct for exposure in some manner (see Table IV). These studies were reviewed in detail by Nachreiner [2000], and are those of Åkerstedt [1995], Olkard [1997], Aenecke et al. [1998], Nachreiner et al. [2000]. Folkard [1997] statistically combined several relatively small studies and made various assumptions in deriving an overall trend. However, the other three studies were based on substantial numbers of injuries/accidents and report fairly similar trends to that derived by Folkard [1997]. These three studies examined trends in national accident statistics and corrected for "exposure" in some way.

A Friedman test based on the relative risk values for the four data sets indicated a highly significant trend over time on shift ($\chi^2 = 34.380$, df = 11, $P < 0.001$). Note that it was not

TABLE IV. Summary of the Studies Across Hours on Duty

Author(s)	Data	Measure	Total number
Åkerstedt [1995]	Sweden (1990/1991)	Lost time injuries (1+days)	160,000
Folkard [1997]	Various transport operations	Accidents or SPADs	N/A
Haenecke et al. [1998]	Germany (1994)	Lost time injuries (>3 days)	1,200,000+
Nachreiner et al. [2000]	Germany (1994–1997)	Fatal injuries	2,000+

possible to base a chi-square test on the summed frequencies (and hence to estimate the confidence intervals), since each of the published trends had to correct for exposure in some way and thus combining raw frequency scores would be biased. By setting the mean risk in each study for the first 8 hr at one, comparable hourly relative risk value could be calculated for each study and then averaged to give an averaged trend across the four studies. This is shown in Figure 4 from which it is clear that, apart from a slightly heightened risk from the second to fifth hour, risk increased in an approximately exponential fashion with time on shift.

The increased risk during the second to fifth hour has been reported in a number of studies. One suggestion to explain the decreased risk after the fifth hour it is that it represents a beneficial effect of a break (see below). However, this explanation has difficulty in accounting for the fact that a similar trend to that shown in Figure 4 has been found in situations where individuals are given frequent (e.g., 2-hr) breaks. An alternative suggestion is that increased risk during the second to fifth hour reflects on a decrease in controlled, effortful, processing that has been insufficiently compensated for by automated processing. This latter explanation is considered in more detail by Folkard [1997] and the results of a laboratory study that lend some support to it are described by Tucker et al. [2000].

It is possible to estimate the relative risk of shifts of different lengths by calculating, and comparing, the average risk associated with each given length of shift (see Fig. 5). Note that the risk of an 8-hr shift has been set at one based on the procedure described above. From Figure 5 it is clear that variations in shift length from about 4–9 hr will have relatively little impact on overall safety because of (i) the exponential nature of the time on shift trend and (ii) the increased risk from the second to fifth hours. However, the most important point is that we can now estimate the change in risk associated with shorter or longer shifts. Thus, for example, we can estimate that relative to 8 hr shifts, 10 hr shifts are associated with a 13.0% increased risk and 12 hr shifts with a 27.5% increased risk.

The risk values shown in Figure 5 are estimates of the effect of shift length based on studies of the trend in the frequency of injuries over hours on duty. Dembe et al. [2005] report on a longitudinal study of over 12,000 males who between them reported a total of over 5,000 work-related injuries or illnesses (about 50% of which were acute injuries). They found a clear ''dose response'' curve for the impact of the number of hours worked per day on the frequency of these incidents. As a check on the accuracy of the estimates shown in Figure 5, the values reported by Dembe et al. were compared with those derived from Figure 5. First, the relative risk of injuries for shift durations between 8.0 and 9.9 hr was set at 1.0 in both data sets. Their data indicates that relative risks for duties periods of 10.0–11.9 and 12.0–13.9 hr per day were 1.12 and 1.29, respectively. These relative risk

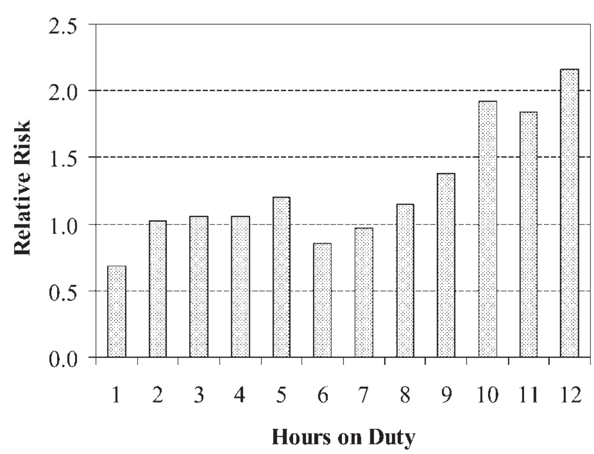

FIGURE 4. The mean relative risk over hours on duty.

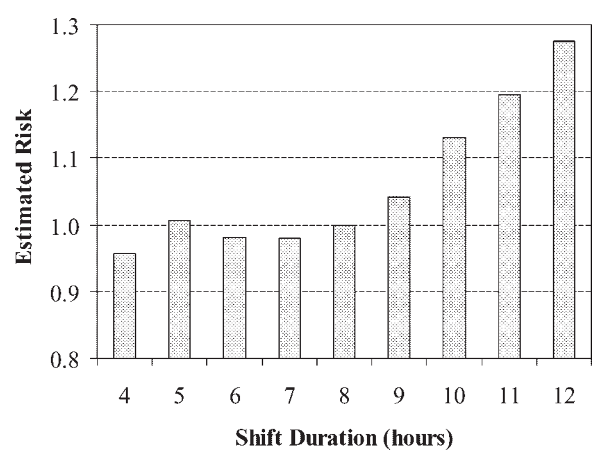

FIGURE 5. The estimated relative risk on different lengths of shift.

values were extremely close to the estimates derived from Figure 5, namely 1.13 and 1.28 respectively. Clearly there was very close agreement between the estimates derived from Figure 5 and the values reported by Dembe et al. [2005] for longer lengths of work day.

In a recent study, Barger et al. [2005] demonstrated that the risks associated with longer shifts are not confined to industrial accidents. They conducted a case-control study of medical interns using a prospective nationwide, web-based survey in their first postgraduate year (interns). Two-thousand seven-hundred and thirty-seven interns completed 17,003 monthly reports that provided detailed information about work hours, work shifts of an extended duration and also documented vehicle crashes and near-miss incidents. They reported that, compared to non-extended shifts, extended shifts (greater than 24 hr) were significantly associated with an increased risk of vehicle crashes (odds ratio of 2.3) and near-misses (odds ratio of 5.9) following their work shift. While industrial shifts are seldom of this duration, a number of authors have warned of the dangers of driving home after a night shift, and the results of Barger et al. [2005] add considerable evidence to this argument.

What is unclear from the results of this study by Barger et al. [2005] is why the odds ratio for a near miss should be increased so much more than the odds ratio for an actual crash following an extended shift. One possibility is potential reporting bias, namely that a tired individual may perceive a given situation as rather more dangerous than an alert one, simply because they feel less able to cope with it. However, the fact that the increase in actual crashes was rather less than that in near-misses also suggests that tired individuals may actually underestimate their ability to cope with potentially dangerous situations.

Effects of Rest Breaks

The trend for hours on duty, shown in Figure 4, does not control for the influence of breaks during a duty period and one possible explanation for the decrease in risk after the fifth hour may be that it reflects the influence of rest breaks. A number of laboratory studies and experimental interventions in the work place have been conducted to evaluate the effects of breaks [see, the review by Tucker, 2003, and, for example, Kopadekar and Mital, 1994; Galinsky et al., 2000; Dababneh et al., 2001]. However, there appears to be only a single, recent study that has examined the impact of rest breaks on the risk of injuries [Tucker et al., 2003].

The study of Tucker et al. [2003] examined industrial injuries in an engineering plant in which breaks of 15, 45, and 10 min, respectively, were given after each period of 2 hr of continuous work. The number of injuries within each of the four 30-min periods between breaks was calculated, and the risk in each 30-min period was expressed relative to that in the first 30-min period immediately following the break. The

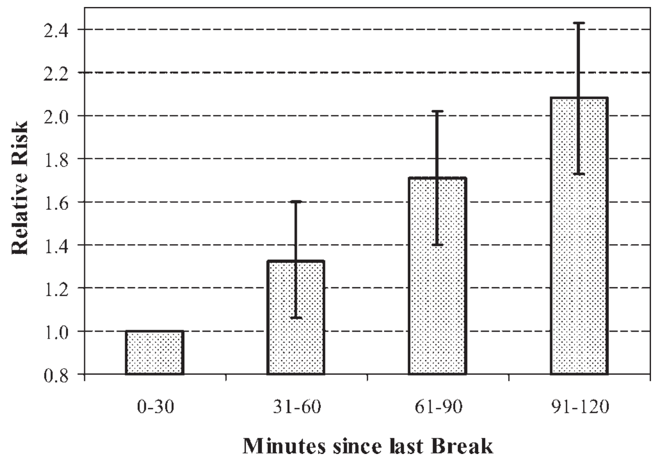

FIGURE 6. The trend in relative risk between 2-hr breaks (error bars are 95% CIs).

results are shown in Figure 6 and it is clear that injury risk rose substantially, and approximately linearly, between successive breaks such that risk had doubled by the last 30-min period before the next break. It is also important to note that there was no evidence that this trend differed for the day and night shifts, or for the three successive periods of 2 hr of continuous work within a shift.

"RISK INDEX" MODEL

Given that the various trends discussed above are based upon estimates of the relative risk of incidents, the combined effects of the type of shift, shift length, the number of successive shifts, and the interval between breaks can be estimated in a relatively straightforward manner. For simplicity, this is illustrated using a model in which the single effects are assumed to combine in a simple additive manner. However, the use of a multiplicative model would likely result in an essentially similar pattern of results for normal ranges of shifts. The additive model can be expressed simply as:[formula 1]

$$RR_S = RR_T + CR_N + CR_L + CR_B$$

where RR_S, the relative risk for a span of shifts; RR_T = the relative risk for the first shift of this type in the span; CR_N = the change in risk for the number of successive shifts of that type in the span; CR_L = the change in risk for the length of the shifts in the span; and CR_B = the change in risk for the interval between breaks.

The relative risk of the first shift in a span of a given type must be estimated before this model can be applied. This value differs from the estimates given above since those values were typically based on spans of four shifts and we know that the trend over successive shifts differs depending on whether they are morning/day or night shifts. However, given that we know the mean risk over a span of four successive day or night shifts, and increase in risk over successive day or night shifts, we can calculate the risk on the first of a span of day or night shifts. If we set the risk on the first day shift as 1.00 then we can calculate the relative risk on the first night shift as being 1.06.

Further, rather than express the relative risk on different shifts, spans of shifts, and durations of shifts relative to a single 8-hr day shift it would seem appropriate to use a reference of a span of five successive 8-hr day shifts, that is, the ''normal working week.'' Thus, the relative risk on a span of five successive 8-hr day shifts with a single, mid-shift break was set at 1.00, and the relative risks for all other combinations were expressed relative to this. Finally, a linear extrapolation of the trends over successive shifts and the interval between breaks was made in order to estimate the relative risk associated with longer spans of shifts or intervals between breaks. In an earlier study it was demonstrated how this model can be used to estimate the risk associated with a particular shift system, and we have also shown that the output from this model agrees fairly well with that from the UK's Health and safety Executive's ''Fatigue Index'' [Folkard and Lombardi, 2004].

ESTIMATING THE RISK OF LONG WORK HOURS

This simplistic model can also be used to estimate the risk associated with long work hours. Thus for any given number of hours per week (or per month) we can estimate the risk associated with different work schedules that involve that particular number of hours. For example, the European Union's ''Working Time Directive'' limits the hours of work per week to an average of 48 hr. If the 48 hr are comprised of six successive 8-hr day shifts, we estimate the associated risk to be only 3% higher than that on the ''standard'' 40-hr week involving five successive 8-hr days. However, if the 48 hr are worked as four successive 12-hr day shifts, we then estimate that the risk increases by 25% over the ''standard.'' For night shifts, the estimated risk is increased by 41% for six successive 8-hr night shifts, but by 55% for four successive 12-hr night shifts, relative to the ''standard'' 40-hr week. These estimates are illustrated in Figure 7.

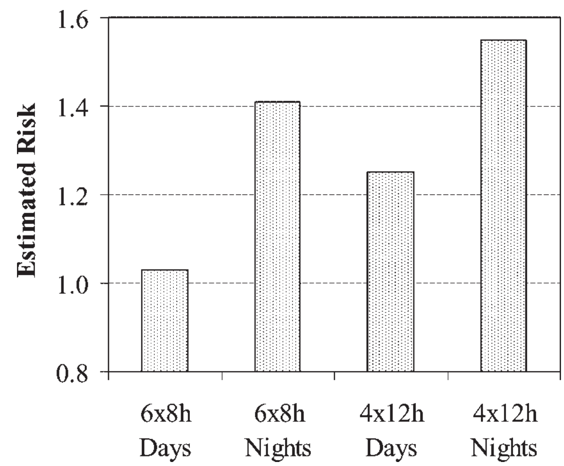

FIGURE 7. The estimated risk associated with different forms of a 48 hr week.

Another way of expressing this is to say that the safest way of working a 48 hr week would appear to be to work six successive 8-hr day shifts. This is about 20% safer than working four successive 12-hr day shifts, nearly 40% safer than working six successive 8-hr night shifts, and over 50% safer than working four successive 12-hr night shifts. Clearly safety may vary widely on a 48 hr week depending on the type and length of the shifts involved.

Similarly, if we consider a 60-hr week, we can model this as six 10-hr day or night shifts, or five 12-hr day or night shifts. In this case the increased risk on six 10-hr shifts, relative to our ''standard'' 40-hr week involving five successive 8-hr days, is estimated to be 16% for day shifts and 54% for night shifts. In contrast, the increased risk for five 12-hr day shifts is estimated to be 28%, while that for five 12-hr night shifts is 62% (see Fig. 8). Again, an alternative way of expressing this would be to say that the safest way of working a 60 hr week would appear to be to work six successive 10-hr day shifts. This is about 10% safer than working five successive 12-hr day shifts, nearly 40% safer than working 6 successive 10-hr night shifts, and about 45% safer than working work 5 successive 12-hr night shifts. Again, worker safety may vary widely for a 60 hr work week depending on the type and length of the shifts involved.

As a general principle it would appear that for any given length of work week, a long span of short shifts (e.g., 6 × 8 hr shifts) is likely to be safer than a short span of long shifts (e.g., 4 × 12 hr shifts). Likewise, day shifts will normally be safer than night shifts. However, these generalizations ignore the potential influence of rest breaks. Although there is a paucity of studies that have examined the impact of rest breaks, the

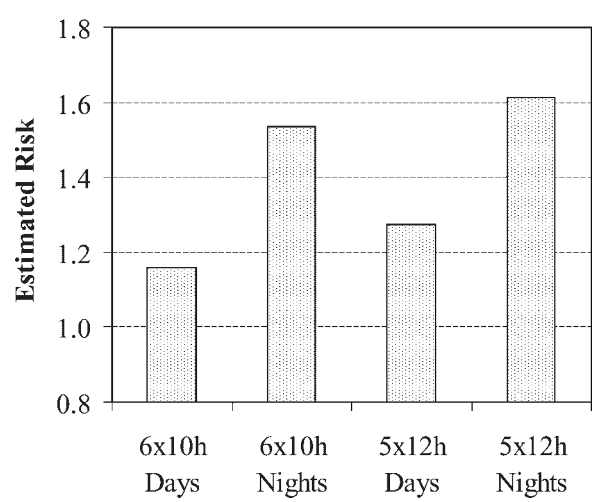

FIGURE 8. The estimated risk associated with different forms of a 60 hr week.

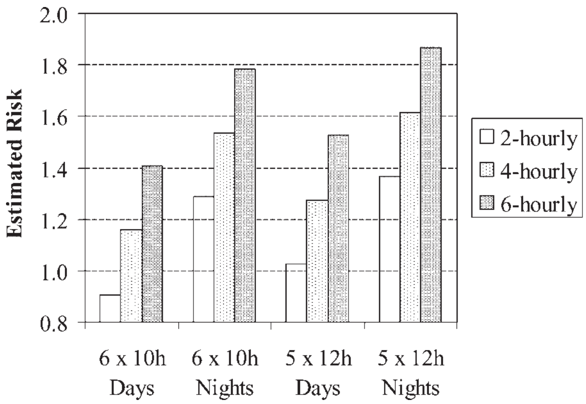

FIGURE 9. As Figure 8 but for various intervals between breaks.

single study reviewed above [Tucker et al., 2003] suggests that there may be a major impact of the frequency of rest breaks on the risk of incidents. This is illustrated in Figure 9 in which rest breaks at intervals of 2, 4, and 6 hr were assumed to be given on the various spans of shifts shown in Figure 8.

It is clear from an inspection of Figure 9 that frequent breaks can negate the general principles outlined above. Thus, for example, five successive 12-hr shifts with 2-hr breaks are actually estimated to be safer than six successive 10-hr shifts with 4-hr breaks. Likewise, five successive 12-hr night shifts with 2-hr breaks are estimated to be safer than five successive 12-hr day shifts with 6-hr breaks. Clearly breaks play an important role in the estimated risk associated with a given work schedule. However, the most important point to emerge from this modeling of different work schedules is that it is necessary to consider the various features of the schedule in combination with one another, rather than in isolation from one another. Thus, weekly or monthly work hour regulations may be of limited value in ensuring an acceptable level of safety.

The motivation behind work hour regulations is essentially to keep the health and safety risks associated with a work schedule within acceptable limits. Determining what those limits should be is, of course, a matter for debate. However, if we take an arbitrary limit of a risk of incidents of 1.5 (or a 50% increase in risk), relative to that on the ‘‘standard 40 hr week,’’ then we can see from the modeling described above that this would ‘‘outlaw’’ some 48 hr work weeks (namely four successive 12-hr night shifts–see Fig. 7) while allowing some 60 hr work weeks (namely six successive 10-hr day shifts or five successive 12-hr day shifts–see Fig. 8). Further, if more frequent rest breaks are provide than our assumed standard of 4-hr breaks this may bring even longer weekly work hours below an estimated relative risk of 1.5.

DISCUSSION

Undoubtedly, work hour regulations will reduce the risk of injury and accidents as compared to if no regulations are in place. Further, lesser weekly or monthly work hour limits will, on average, result in a lower risk of an incident than higher ones. In order to guarantee that risk is maintained below a predetermined threshold, work hour limits would have to be far more restrictive than necessary for most of the work schedules that it permitted. Thus it would have to insure that the risk on the ‘‘worst case’’ work schedule permitted by the limit did not exceed the predetermined threshold, while the vast majority of the work schedules permitted by the work hour limit would be associated with a lower estimated risk. This is, perhaps, one explanation of why work hour limits have been so difficult to agree on and implement.

A more reasonable approach would be to produce a complex set of limitations, not only on the weekly or monthly work hours, but also on the maximum length of a shift, the maximum number of successive night shifts, and the minimum interval between breaks. Sets of limits such as these are not unusual for safety-critical work groups in the UK, and indeed throughout Europe. For example, the EU’s ‘‘Working Time Directive’’ not only limits the average hours per week, but also places restrictions on the length of a night shift, the minimum number of hours rest between two successive shifts, and maximum number of hours of work before a rest break.

Likewise, UK Air Traffic Control Officers have limits on the maximum length of shift and the maximum number of hours work before a rest period, and they are also limited to a maximum of two successive night shifts before having a minimum of 54 hr off-duty. The challenge with this more general approach is that it becomes very complex since it is difficult to produce limits that take account of more than two factors at a time. Thus, for example, it has been recommended that spans of night shifts for UK Aircraft Maintenance Engineers should be limited to six 8-hr night shifts, four 10-hr ones, or two 12-hr ones [Folkard, 2003], but this fails to take account of the frequency of breaks.

CONCLUSION

Based on this study it is proposed that the best approach to work hour limitations is to place limits on the acceptable level of fatigue or risk, rather than on any specific feature or features of the work schedule. In theory, this approach clearly has much to recommend it. It places the limit directly on what most would agree is the critical factor, namely worker safety, rather than on a factor that is only loosely related to this such as weekly work hours. It also allows maximum flexibility and is not unduly restrictive in that it enables work groups to work any schedule they want provided that it does not exceed the predetermined level of risk. It is clear that the ‘‘Risk Index’’ needs further validation and additional empirical data from epidemiologic and experimental studies to produce more accurate estimates and that at this time it could not be recommended for general use.

This final approach is essentially that of the UK Health and Safety Executive's ''Fatigue Index.'' This index is provided as a tool by the regulating authority to allow organizations to assess whether their work schedules are likely to be associated with undue levels of fatigue. While there are weaknesses in the ''Fatigue Index'' it is currently being revised to take account, amongst other things, of the trends in the risk of incidents described in this paper. Thus in the future we would advocate the abandoning of what are often over-restrictive work hour regulations in favor of an auditing system where work schedules are assessed with respect to their likely impact on the risk of incidents.

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