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IN-DEPTH REVIEW: SHIFT WORK

Shift work, safety and productivity

Simon Folkard and Philip Tucker

Abstract The arguments in favour of introducing shift work clearly depend on productivity and safety being maintained at an acceptable level. However, the evidence reviewed in this paper clearly indicates that both productivity and safety may be compromised at night. More specifically, safety declines over successive night shifts, with increasing hours on duty and between successive rest breaks. The only known way to minimize these problems is to improve shift systems with respect to these factors. However, these factors need to be considered in combination with one another since, for example, a long night shift that includes frequent rest breaks might well prove safer than a shorter night shift with less frequent breaks.

Keywords Circadian rhythms; fatigue; performance; productivity; safety; shift work; sleep.

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Introduction

Efficiency and safety on shift systems is a topic of major concern for two main reasons. First, a number of 'headline' incidents, such as Bhopal, Three Mile Island, Chernobyl, the Rhine chemical spillage and the Exxon Valdez, all occurred at night, and have drawn attention to both the risk and cost of impaired safety on shift systems. Secondly, shift work is frequently introduced for purely economic reasons in order to maximize the use of costly equipment. While many shift work researchers would argue that this practice should be discouraged in view of the health and well-being costs to the individual shift workers, the economic arguments in favour of introducing shift work clearly depend on productivity and safety being maintained at an acceptable level. An impairment of individuals' performance efficiency on a shift system may thus seriously undermine any potential economic benefit derived by introducing it.

'Real-job' trends in productivity

Unfortunately, the direct study of productivity and safety on shift systems is fraught with problems. As regards productivity, both the number of people at work and the nature of their work often vary across shifts, with, for example, 'long runs' frequently being saved for the night. Supervision is normally reduced at night, and there may be no maintenance personnel available to ensure that equipment is running efficiently. Despite these complications, three early published studies managed to obtain relatively continuous, 'real-job' measures of speed or accuracy over the 24 h day covered by a variety of continuous shift systems, and these showed similar trends to one another. The precise measures obtained in these three studies varied considerably. They were: (i) the delay in answering calls by switchboard operators [1]; (ii) errors in reading meters [2]; and (iii) the time taken by 'spinners' to tie broken threads in the textile industry [3]. The averaged results from these studies (based on Z scores) are shown in Figure 1 in order to give an 'overall picture' of the effect of time of day.

Two major points emerge from inspection of this figure. First, there was a relatively massive 'dip' in these efficiency measures during the course of the night shift, i.e. from ~22:00 h to 06:00 h, with the trough occurring at 03:00 h. Indeed, these measures had fallen below average levels (i.e. below a mean Z score of zero) by 23:00 h and did not climb back up to average until after 06:00 h. Secondly, there was clear evidence of a secondary 'dip' in the measures shortly after 12:00 h. This secondary dip has commonly been described as the 'post-lunch' dip, although close inspection of Figure 1 suggests that these measures started to decline considerably earlier than normal lunch times, i.e. from ~10:00 h. Indeed, there is

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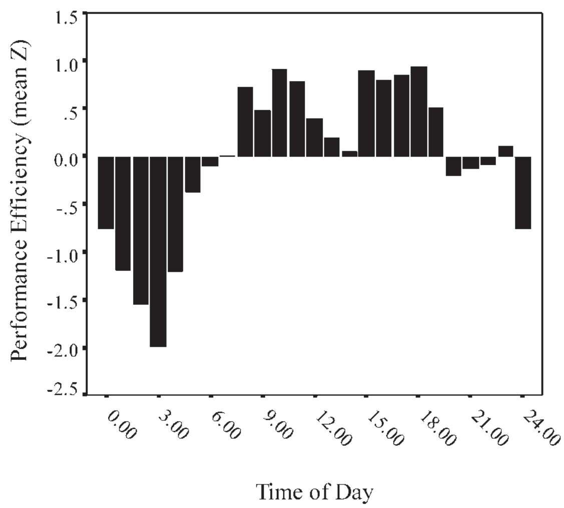

Figure 1. Industrial performance efficiency over the 24 h day.

reasonably good evidence that this 'post-lunch' dip is only partially dependent on the ingestion of food [4]. An alternative way of viewing the results shown in Figure 1 is that these 'real-job' speed and accuracy measures are only above average between 07:00 h and 19:00 h, at all other times efficiency is likely to be relatively impaired, especially so during the early hours of the morning.

There appear to be few other studies of productivity on shift systems that have successfully overcome the problems of differences in the workforce or work practices. However, an extremely carefully controlled study by Vidacek *et al.* [5] examined the number of capacitors produced by individuals in an electronics component factory over five successive, 8 h, morning, afternoon and night shifts. This particular job demanded a very high level of manual dexterity and was extremely repetitive, with the workers concerned each producing an average of >100 capacitors per hour. As might be expected from Figure 1, overall productivity was highest on the afternoon shift, and was on average ~5% lower at night. However, there was also clear evidence of an interaction between the type of shift and successive shifts. Productivity on the morning and afternoon shifts was relative constant across the five successive shifts, while that on the night shift rose substantially over the first three nights but then declined slightly over the subsequent night shifts. Clearly, there is a need for further studies of productivity in this area to determine whether the trends obtained in this study hold good for other work situations.

'Real-job' trends in safety

Unfortunately, as indicated above, in many industrial situations, the a priori risk is not constant across the day and night. This means that accident or injury rates often cannot be legitimately compared across the shifts since fewer 'incidents' might be expected on the night shift. (Note that the term 'incidents' is used from here on to refer to both accidents and injuries.) Indeed, even in those few industrial situations where the a priori risk of incidents would appear to be constant across the 24 h day, there remains the problem that the probability of actually reporting an injury or accident that occurs may vary. Thus, 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 during the day. Further investigation revealed that when members of the predominantly male workforce reported an injury during the day, they were treated by a female nurse at the on-site occupational health clinic. However, this clinic was closed at night, when first-aid cover was provided by the male security guards at the gatehouse situated at the entrance to the works. It seems highly probable that this dissuaded many members of the workforce from reporting 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!

When these contaminating factors are controlled for, there appear to be a number of reasonably consistent trends in incidents associated with aspects of shift systems.

Risk across the different shifts

The first consistent trend relates to the relative risk of incidents on the morning, afternoon and night shifts on 8 h shift systems. There are five studies of which the authors are aware that are based on relatively large numbers of incidents and that appear to have overcome the potential confounding factors [6–10]. It should be noted that while in some of these studies there were equal numbers of shift workers on each shift, in the others, the authors had to correct the data to take account of any inequalities. In addition, three of the studies report two separate sets of data, for different areas or types of incident, giving a total of eight sets of data across the three shifts. For the purpose of this review, the incidents were summed across the eight data sets and the risk on the afternoon and night shifts was expressed relative to that on the morning shift. Risk was found to increase in an approximately linear fashion across the three shifts, showing an increased risk of 18.3% on the afternoon shift and of 30.4% on the night shift, relative to that on the morning shift, and this is shown in Figure 2. The conclusion to be drawn from this figure would appear to be that in situations where the a priori risk would appear to be constant across the three shifts, there is a consistent tendency for the relative risk of incidents to be higher on the afternoon shift than on the morning shift, and for it to be highest on the night shift.

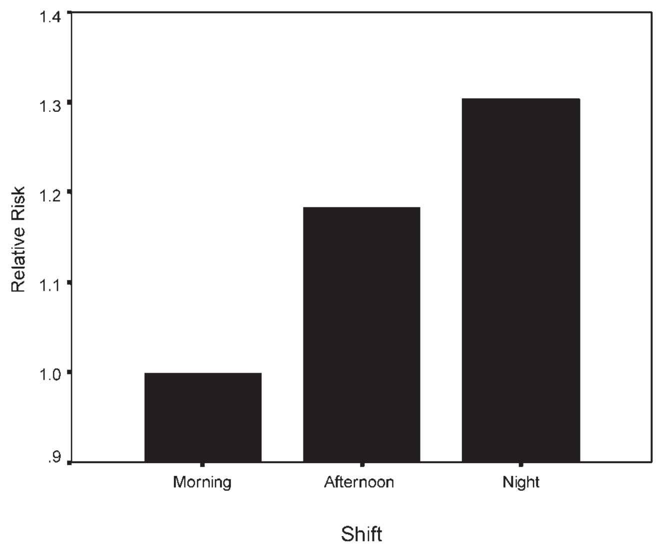

Figure 2. The relative risk across the three shifts.

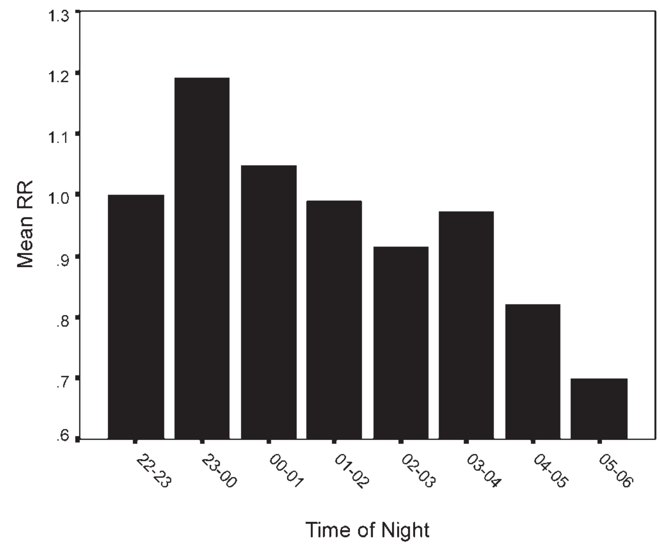

Figure 3. The relative risk over the course of the night shift.

Risk over the course of the night shift

The second reasonably consistent trend in risk is that over the course of the night shift. In 1923, Vernon [11] reported one of the earlier studies in this area. He reported that injury rates declined substantially over the first few hours of the night shift, and that this trend could not readily be explained in terms of changes in productivity levels. A number of more recent studies have also provided hourly incident rates over the course of the night shift [9,10,12–18]. As before, the incidents were summed across all 10 studies and the risk expressed relative to that during the first hour of the night shift. Using these summed values, risk rose by ~20% from the first to second hour, but then fell by a total of ~50%, and in an approximately linear fashion, to reach a minimum at the end of the shift, and this is shown in Figure 3. It is notable that there was a slight increase in risk between 03:00 and 04:00 h, when industrial efficiency is at its lowest ebb (see Figure 1), but this effect was relatively small compared with the substantial decrease in risk over most of the night.

Risk over successive shifts

The third consistent trends in risk are those over successive shifts. The authors are aware of a total of seven studies that have reported incident frequencies separately for each night over a span of at least four successive night shifts [7,9,14,17–20]. Note that the study reported by Monk and Wagner [21] was not included, since the data reported in that paper was a subset of that reported by Wagner [14]. As before, the frequency of incidents on each night was summed across the studies and then expressed relative to that on the first night shift. On average, risk was ~6% higher on the second night, 17% higher on the third night and 36% higher on the fourth night (see Figure 4).

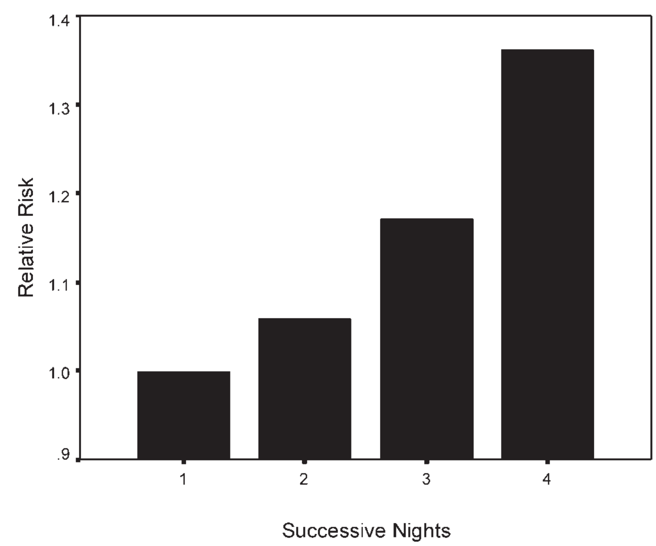

Figure 4. The relative risk over four successive night shifts.

Two important questions arise regarding this substantial increase in risk over four successive night shifts. The first is what happens to risk over longer spans of successive night shifts, but there is a paucity of data relating to this. While the increase in risk over four successive nights is difficult to reconcile with the finding of Vidacek *et al.* [5], that productivity increased over the first three nights, it would nevertheless be of great interest to determine whether risk, like productivity in Vidacek *et al.*'s study, reduced over longer spans of successive night shifts. However, while it is has to be admitted that this might occur, there is as yet no good evidence to indicate that this is the case.

The second 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 that examined risk over successive night shifts, five also reported the risk over successive morning or day shifts [7,9,17,18,20]. As before, the frequency of incidents on each shift was summed across these five studies and then risk expressed relative to that on the first morning/day shift. The results are shown in Figure 5; note that the same scale has been used for this figure as that used in Figure 4 so that direct comparisons can be made. On average, risk was ~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. Clearly, there was some evidence that risk did increase over successive morning/day shifts, but this increase was substantially smaller than that over successive night shifts (compare Figures 4 and 5).

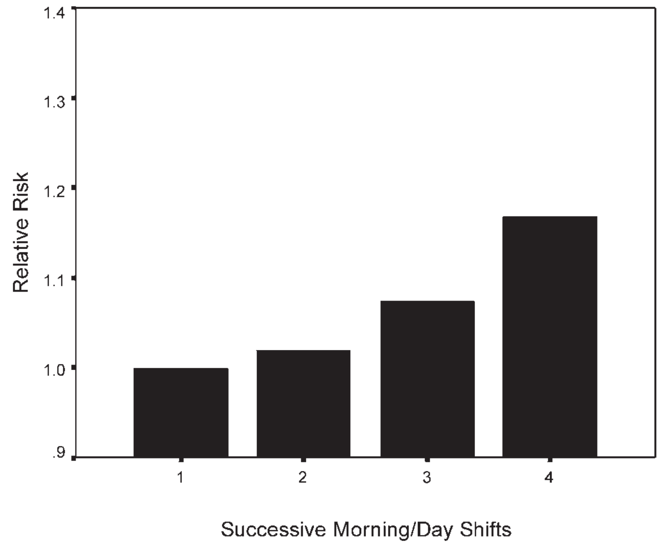

Figure 5. The relative risk over four successive morning/day shifts.

Risk over hours on duty

There appear to be four studies that have reported the trend in risk over successive hours on duty and that have managed to correct for exposure in some manner [15,22–24] (see also the review by Nachreiner [25]). However, the study by Folkard [22] was based on a statistical combining of several relatively small studies, and made various assumptions in deriving an overall trend. Since the remaining three studies were all based on substantial numbers of injuries/accidents and report fairly similar trends to that derived by Folkard [22], the latter was omitted from consideration in deriving an averaged trend. The three studies considered all examined trends in national accident statistics and corrected for 'exposure' in some manner. By setting the mean risk in each study for the first 8 h at one, it was possible to calculate hourly relative risk values for each study. The values were then averaged to derive an averaged trend, and this is shown in Figure 6. It is clear from this figure that, apart from a slightly heightened risk from the second to the fifth hour, risk increased in an approximately exponential fashion with time on shift such that in the twelfth hour it was more than double that during the first 8 h. The increased risk from the second to the fifth hour is considered in more detail by Folkard [22] and Tucker *et al.* [26].

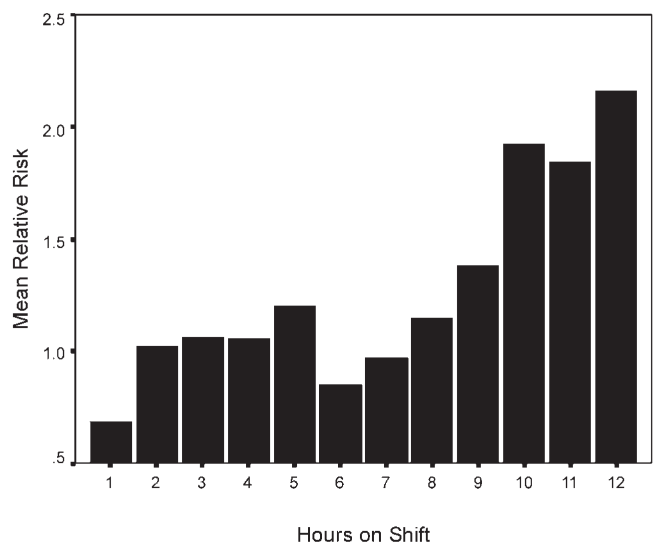

Figure 6. The mean relative risk over hours on duty.

Risk as a function of breaks

The trend for hours on duty shown in Figure 6 does not control for the influence of breaks during a duty period, and indeed one possible explanation for the decrease in risk after the fifth hour may be that it reflects the influence of rest breaks. Although a number of studies on the effects of breaks have been conducted [27–29], there appears to be only a single, very recent study that has examined their impact on the risk of incidents [30]. This study examined industrial injuries in an engineering plant in which a 15 min break was given after each period of 2 h 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 results are shown in Figure 7, from which it is clear that 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 noteworthy that there was no evidence that this trend differed for the day and night shifts, or for the three successive periods of 2 h of continuous work within a shift.

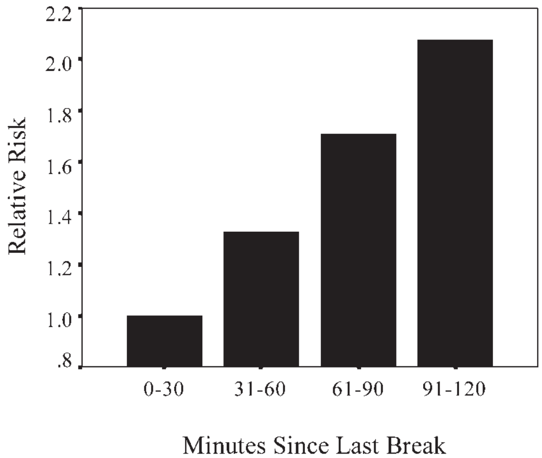

Figure 7. The trend in relative risk between breaks (from [30]).

Underlying factors affecting productivity and safety

Impaired safety and productivity on shift systems will almost certainly reflect the combined influence of a large number of factors; the psychosocial factors and physical health effects typically associated with abnormal work hours are discussed in other reviews in this issue [31–33]. It has long been recognized that people's efficiency at performing various tasks is not constant, but varies over the course of the normal waking day. Early theorists attributed this to either a build-up of 'mental fatigue' over a period of wakefulness [34] or an underlying rhythm in 'sleepiness' that was independent of whether people had actually slept [35]. More recent studies have confirmed that both these factors contribute to circadian variations in performance [36]. Indeed, a number of authors have developed mathematical models based primarily on these two factors [37–40], and these have proved relatively successful in predicting variations in alertness and performance on various laboratory tasks on both normal and abnormal sleep/wake schedules [41,42]. These models essentially assume that productivity and safety are low at night because (i) the circadian rhythms in performance are at a low ebb at this time and (ii) they remain relatively unadjusted over normal spans of successive night duties.

Unfortunately, while these mathematical models might be able to account for the trends in productivity described above, they have great difficulty in accounting for the trends in risk. Thus, while the models would predict that safety should be lowest at night, they would also predict that it should be highest on the afternoon shift, which it is clearly not (see Figure 2). Likewise, these models would predict that risk would be highest at ~04:00 h in the morning, while in fact risk is substantially lower then than at ~00:00 h (see Figure 3). Finally, the models would predict that risk should stay constant or reduce slightly over successive night shifts rather than show the substantial increase illustrated in Figure 4. The reasons for these large disparities between the predictions made by current models and the objectively determined trends in risk are as yet unclear, but may reflect on additional, as yet unidentified, factors that need to be incorporated into the models, and/or the possibility that risk is not linearly related to alertness and performance on laboratory tasks.

Other, mainly laboratory, studies have shown that the trend in performance over the day varies according to the nature of the task under consideration. In general, it would appear that the speed (and in some cases the accuracy) with which simple perceptual–motor tasks are performed tends to increase over much of the day and, with the possible exception of a 'post-lunch dip', parallels changes in body temperature [43,44]. In stark contrast, short-term memory, and in particular that for the information presented in prose, has been found to be at its maximum in the morning (between ~08:00 and 11:00 h) and to decrease over most of the day [43,45]. In this context, it is noteworthy that Monk and Embrey [46] found that process controllers made fewer errors at night in entering codes into a computer, presumably reflecting on the fact that their task was essentially one of short-term memory for alphanumeric codes. However, it seems unlikely that the failure of the mathematical models to account for the trends in risk reflects on the memory load involved since most of the studies of risk were based on highly repetitive perceptual–motor tasks.

Conclusions

The main conclusion to be drawn from the studies reviewed in this paper is that both safety and productivity are reduced at night. This reduction probably reflects on a number of underlying factors, including impaired health, a disturbed social life, shortened and disturbed sleep, and disrupted circadian rhythms. Despite the fact that current mathematical models of alertness and performance have difficulty in accounting for the precise trends in risk associated with various features of shift systems, it is clear that these trends could be used to try to reduce the risks associated with working at night. More specifically, it would seem that in order to minimize the overall risk on a shift system we need to consider the number of successive night shifts, the length of the night shifts and the provision of breaks within them. Finally, however, it is clear that these factors need to be considered in combination with one another since, for example, a 12 h night shift that included frequent rest breaks might well prove safer than a shorter 8 h night shift with only a single, mid-shift break. Likewise, the length of the night shifts and the number of successive night shifts involved in a shift system will act in combination to determine the overall risk on that system.

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