Transport: Rhythm and Blues

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This paper is concerned with how our internal body clock may compromise safety in transport operations, and with how we might best try to reduce this risk. In doing so it will draw on examples and data published by a number of authors and drawn from a variety of transport operations in many different countries.

The general problem of fatigue resulting from disturbed sleep and body rhythms is well illustrated by the example of the "Peacock", a Panamanian flagged refrigerated cargo vessel. In July 1966 the "Peacock" ran aground while she was sailing down the inner channel of the Great Barrier Reef under pilotage. The Great Barrier Reef is, of course, renowned as a world heritage site and is recognised as a "particularly sensitive sea area" by the International Maritime Organisation. This incident thus raised considerable concern since the breaking up of the vessel could have caused substantial damage to the coral reef.

Australia's Marine Incident Investigation Unit found that the Peacock had grounded at full speed (about 16 knots) at about 01:55 in the morning and only a hundred metres from a light beacon (Parker et al., 1998). This was despite the fact that navigation lights are actually far more visible at night than they are during the day. The Peacock was grounded for eight days before they managed to re-float her, although they had pumped out all the tanks and the spare fuel that she was carrying by then to try to reduce the environmental hazard. The inquiry concluded that it seemed probable that the pilot had fallen asleep about fifteen minutes before the grounding, and suggested that the formation of competing pilotage services (i.e. privatisation) had resulted in a reduction of income for individual pilots. Indeed, I am led to understand that the pilots' hourly rate of pay had effectively halved with the result that they had doubled their work hours.

Subsequently the Australian Marine Safety Authority (AMSA) financed a study conducted by the Queensland University of Technology, that examined the problems of fatigue in the Great Barrier

Reef marine pilots (Parker & Hubinger, 1998). This found that when a pilot joined a vessel on the inner route they would typically stay on the vessel for about eighty hours in order to take it through the channel. During that time they would frequently go on to the bridge for a work spell and took numerous sleeps, averaging several very short sleeps per day. Clearly this fragmentation of sleep, together with our natural inclination to sleep at night, may have contributed to the Peacock's grounding.

Impaired safety at night

Nor is the Peacock an isolated incident, in recent years both the Exxon Valdez and the Estonia ferry disasters occurred at night, and in both cases they were at least partially attributed to fatigue and/or human error. The same is true for a number of non-transport disasters such as Three Mile Island, Bhopal, Chernobyl, and the Rhine chemical spillage. Indeed, it has been estimated that in the US alone the cost of all sleep-related accidents is between 43 and 56 billion dollars per year, although this includes accidents at work and in the home, not just transport accidents (Leger, 1994).

Some years ago a colleague of mine and I decided to go through all copies of a particular newspaper over a five year period and to work out when all the "headline hitting" accidents had occurred with a view to determining whether accidents really are more likely to occur at night. We very quickly hit on two fundamental problems. The first is that a lot of major headline hitting incidents simply could not have occurred at night. For example the Kings Cross disaster couldn't have occurred at night since although the station could have caught fire at night, it wouldn't have been anything like as serious since very few, if any, people would have been there. Thus the first problem was that in most situations it is virtually impossible to determine the a priori risk of a major disaster occurring. The second problem was that there were simply too few of these "headline hitting" disasters for us to be able to analyse them successfully. Statistical analysis of "relative risk" requires relatively large numbers of accidents.

Both these problems can be overcome by looking at road transport accidents since these are both relatively frequent, and can be corrected for traffic density and/or distance driven. As far as I know the first study to look at road accident frequency as a function of time of day was conducted in Texas by Langlois et al. (1985). They found that in both rural Texas and Saint Antonio there was a distinct peak in the absolute number of accidents at about 03:00, and that this peak was even more pronounced when the frequency data was corrected for the number of vehicles on the road. The magnitude of this early morning peak was such that the frequency of accidents at 03:00 was of the order of ten times as high as that for most of the day.

A comparable increase in road accident frequency in the early hours of the morning in the UK was reported by Horne & Reyner (1995). Once they had corrected for traffic density, they found the relative risk of an accident to be about ten times as high at 02:00-03:00 as it was from 08:00 to 21:00. Indeed, a number of studies have now reported a very similar trend in road traffic risk over the day, and I reviewed these a few years ago (Folkard, 1997). At that time I managed to find a total of six studies that had looked at road traffic accident risk, corrected for exposure, as a function of time of day and that had provided at least two hourly readings, and in most cases one hourly readings, over the entire 24-hour day. In order to produce a composite trend over the day, the data from each study was Z-transformed and then the hourly means and standard errors were calculated. It should be noted that this "macro" analysis places equal weight on each of the studies and hence is not prone to distortion by a large, atypical data set. The results are illustrated in Figure 1, which shows the mean trend over the 24-hour day, from midnight through to midnight. It also shows the standard error bars that provide a measure of the degree to which the trends from the six studies coincided with one another, the smaller these bars are the greater the agreement across the studies.

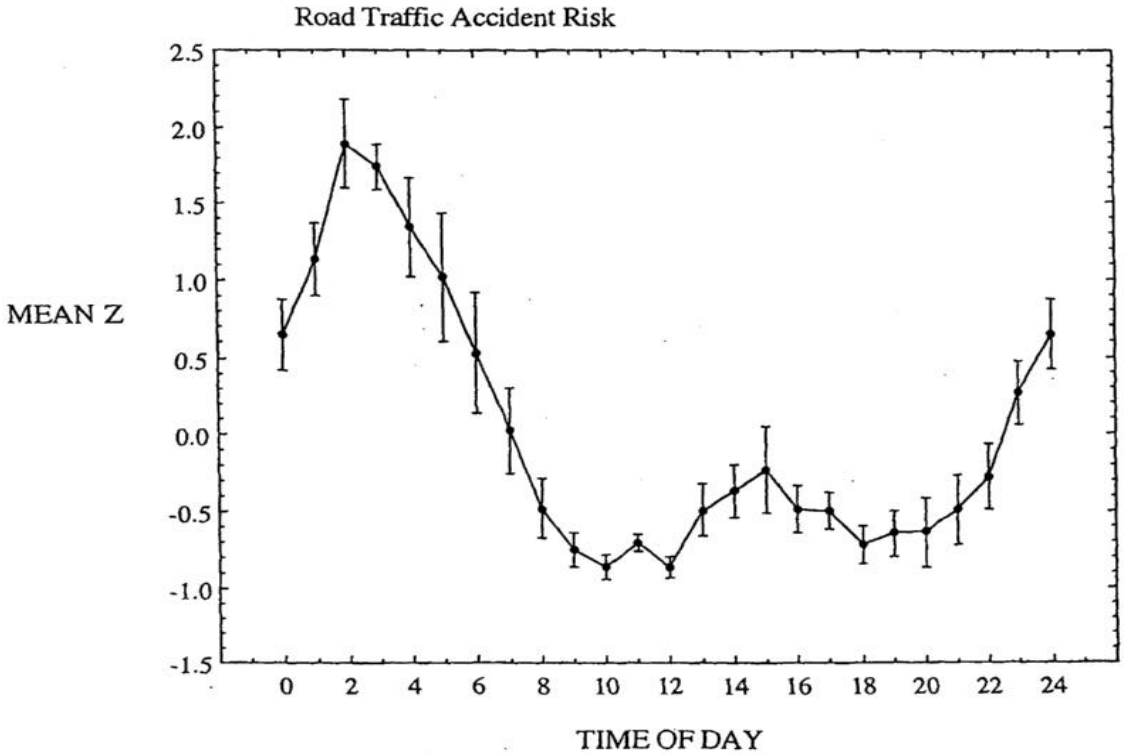

Figure 1

It is clear from Figure 1 that there is a substantially increased risk at about two or three in the morning and a secondary minor increase in risk in the early hours of the afternoon. This latter peak is sometimes referred to as the "post-lunch dip", although there is good evidence that it is not necessarily anything to do lunch (Wever, 1985). There is a natural tendency for us to fall asleep in the afternoon, reflected in the "post-lunch nap" or "siesta", which is nothing to do with food ingestion although it may be exacerbated by the ingestion of a heavy meal or the consumption of alcohol. It is also clear from the small standard error bars shown in Figure 1 that there was a considerable agreement across the six studies over the trend in accident risk over the 24-hour day, and indeed this trend proved to be highly statistically significant.

However, when considering the trend shown in figure 1 it should be borne in mind that although the data has been corrected for exposure, the task of driving at night is actually very different from that of driving during the day. The visual input at night is far less stimulating than it is during the day while there is usually far less traffic on the roads. Indeed, a lot of the early morning accidents are single vehicle accidents where people have essentially run off the road. So there are big differences between driving on a road at night and driving during the day, just as there are for mariners when they're navigating at night rather than during the day. This clearly raises the question as to whether the trend shown in Figure 1 is really due to fatigue, or whether it might simply reflect on the very different nature of the drivers' task at night.

Some light can be thrown on this question by examining the trends in performance in industrial settings where shiftworkers perform an essentially identical task under constant conditions over the 24-hour day. I was able to find three such studies that had provided hourly values and I produced an averaged trend based on the Z-transformation of each data set (Folkard, 1997). This trend is shown in Figure 2, in which high values represent poor performance, and from which it is clear that it is very similar to the trend for road accident risk (Figure 1). Industrial performance was poorest at about 03:00, and indeed there was no evidence that this trend in industrial performance differed from that in road accident risk. This clearly implies that the reason for the increased road accident risk in the early hours of the morning is not because the task of driving is so different then, but rather reflects on the state of the individuals who are doing the driving.

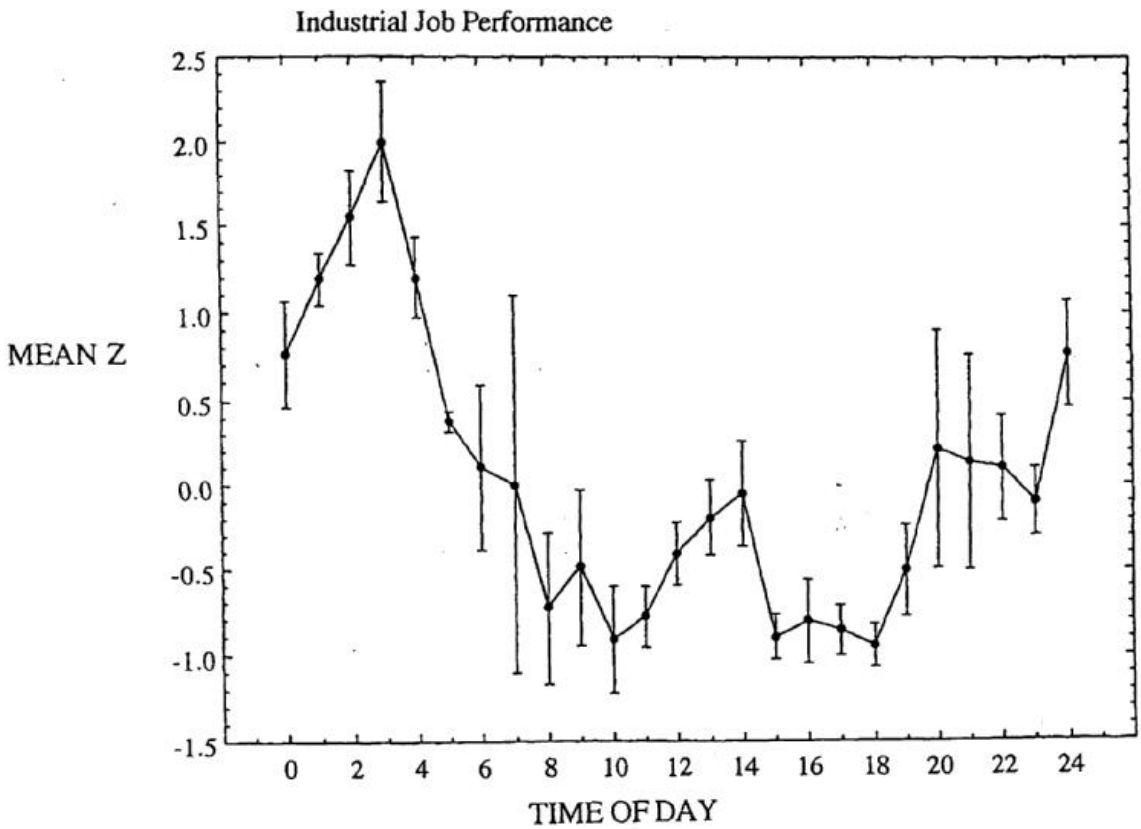

Figure 2

In fact, this trend over the 24-hour day seems to be a fairly general one that has been found to also occur in marine transport operations. Ship collisions show a similar trend but with a rather later peak at about 06:00 (Filor, 1997), perhaps reflecting on an increased density of vessels in congested channels at that time. However, by combining data from the British Marine Accident Investigation Bureau (MAIB) and the Australian Maritime Safety Authority (AMSA) it proved possible to produce a 24-hour trend, albeit at 2-hourly intervals, in ships' groundings which may be less influenced by traffic density. In order to compare this trend with that for road accidents it was first Z-transformed and is shown in Figure 3. Inspection of this figure reveals a pronounced peak at 03:00 and a remarkably similar trend, in terms of both shape and amplitude, to that for road accidents (Figure 1).

Increased sleepiness at night

In short, there appears to a substantially increased risk of accidents in transport operations in the early hours of the morning. The question of course is why should this occur? The answer seems to be that that people feel sleepy in the early hours of the morning. This was very clearly demonstrated in a study of Swedish train drivers conducted by Torsvall and Åkerstedt (1987) from the Karolinska Institute in Stockholm. They studied train drivers on day and night drives using an

observer who sat beside the drivers and noted any errors that they made and electrodes on the drivers' scalps for the electroencephalographic (EEG) recording of the drivers' sleepiness. The results showed a clear build up in alpha and theta activity, indicating increasing sleepiness, during the course of night drives (see Figure 4) but not during daytime drives. They also found that during the night drives the drivers made errors, such as failing to stop at a light or to reduce speed, despite the observer's presence and that these errors tended to occur when there were relatively high levels of alpha and theta activity. The implication of this is that one of the reasons that transport accident risk is so high at night is simply because people feel sleepy at night.

A similar conclusion can be drawn from the results of a study by Sammel et al. (1999) that obtained self-ratings of fatigue from long-haul airline pilots during day and night flights. They examined the percentage of pilots whose fatigue ratings were sufficiently high to be considered as critical or dangerous at different points within flights lasting up to ten hours. They found that the percentage of pilots with critical fatigue scores increased over the course of both day and night flights, but that the percentages were substantially higher at night such that by the end of a ten-hour night-time flight over 25% of the pilots had critical scores (see Figure 5).

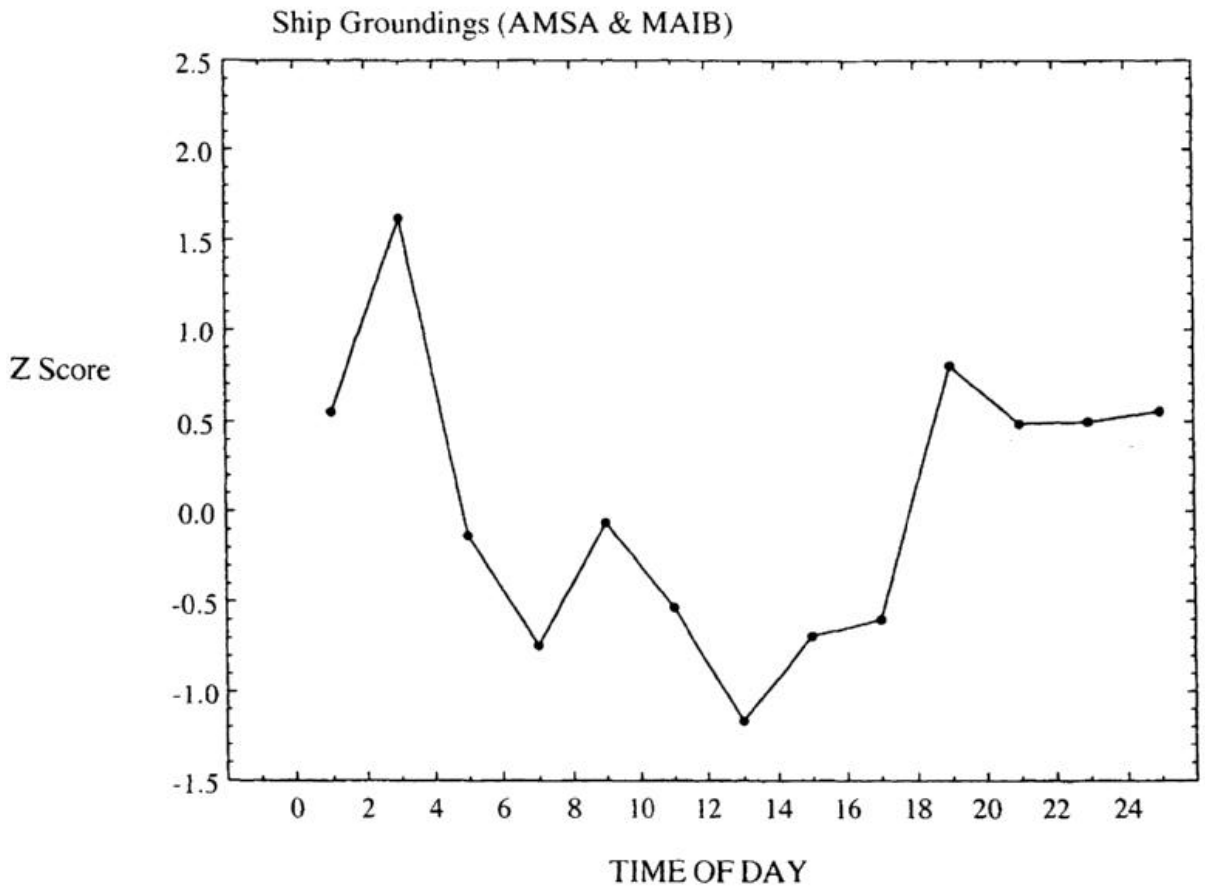

Figure 3

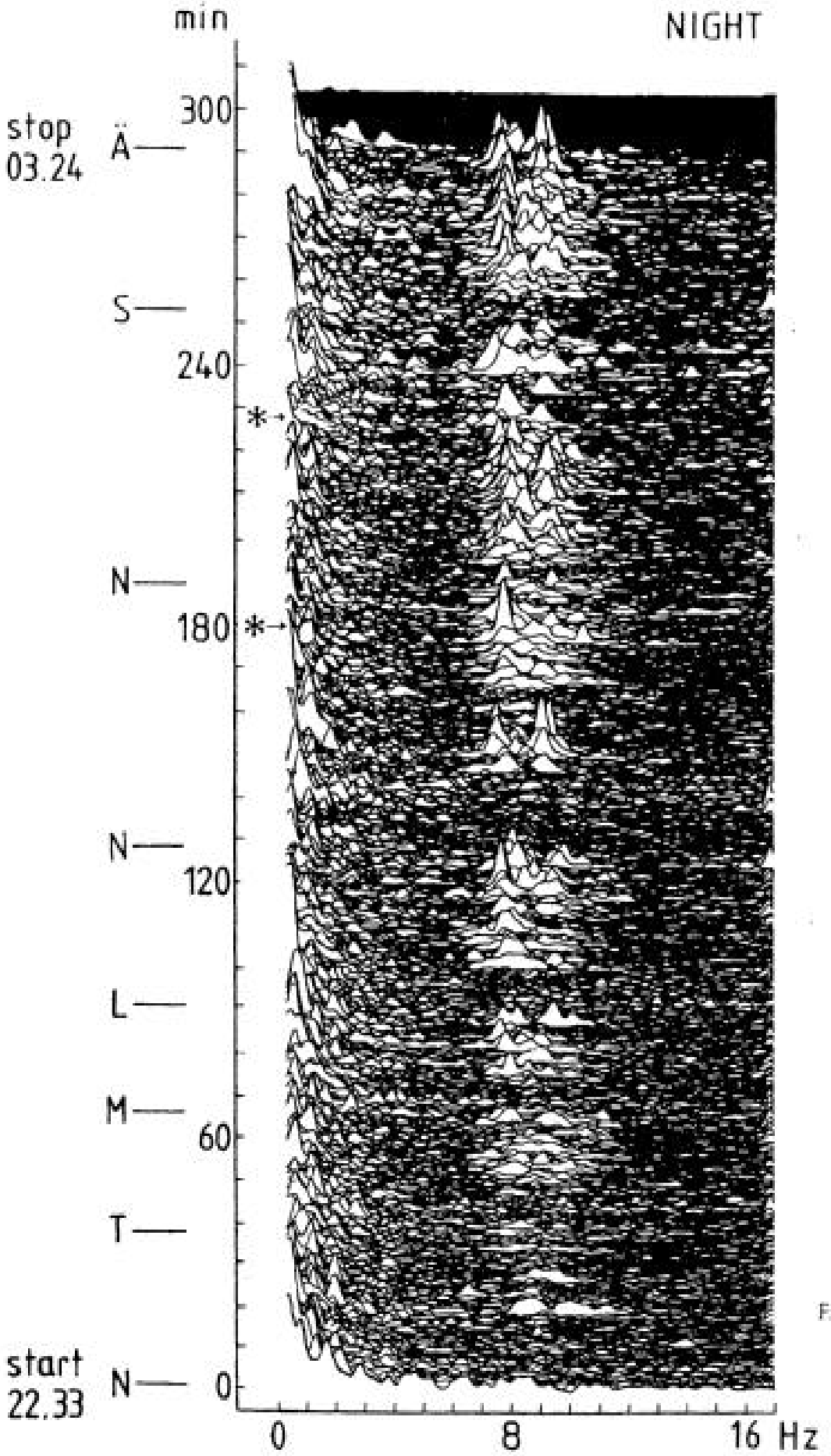
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Figure 4

After Sammel et al (1999)

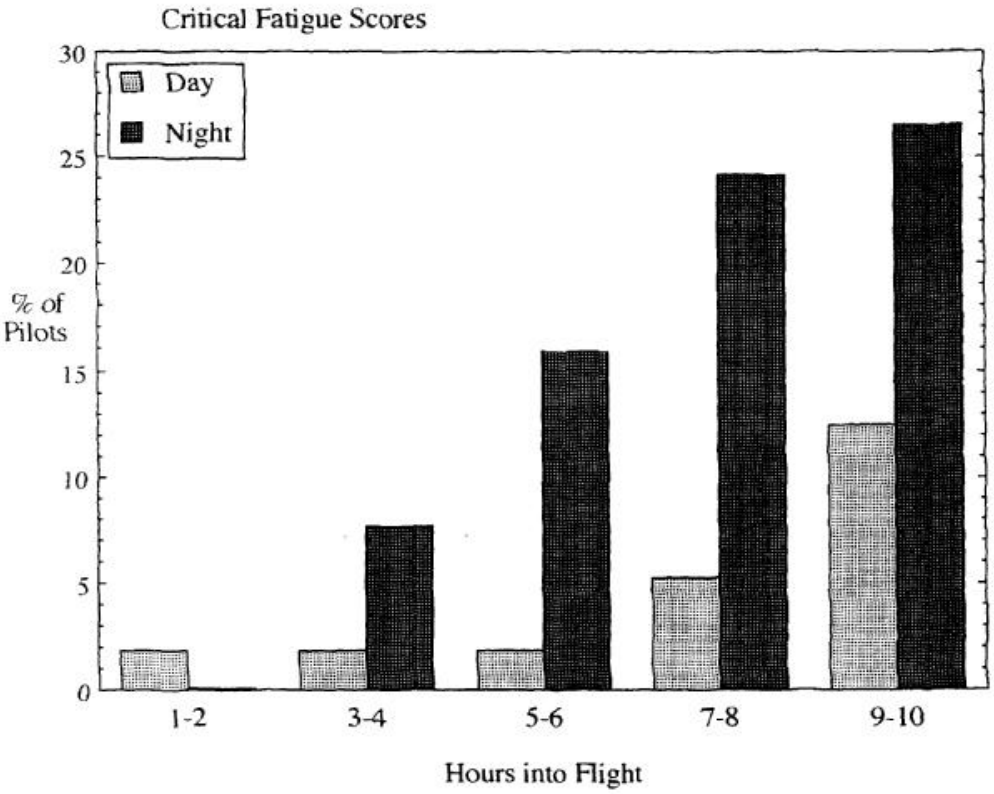

Figure 5

Evolution in a rhythmic world

It thus seems that not only is the risk of accidents in transport operations increased at night, but also that the transport operators are more likely to be sleepy at night. The reason for this appears to be very simple. Namely that, like all other species, we have evolved in a world subject to pronounced 24-hour changes in light, temperature, etc., due to the movements of the earth relative to the sun. Early life forms probably simple responded to these changes, but at some point during the course of evolution it transpired that there was an advantage to actually be able to anticipate these changes rather than merely respond to them. Thus, for example, "the early bird catches the worm" and to do so it clearly needs to be able to anticipate dawn. Almost all species have evolved an internal "body clock" that allows them to anticipate the pronounced 24-hour environmental changes and we now know that this clock is situated in the suprachiasmatic nuclei (SCN). If the SCN is removed from animals they lose their normal sleep/wake cycle and other "circadian" (around a day) rhythms, while if the SCN cells that have been removed are kept alive they continue to show a pronounced rhythm. Thus there is no doubt that like most other species we posses an internal "body clock", and that the SCN plays an important role in its time keeping abilities.

Sleep propensity

The most obvious manifestation of this clock is our marked propensity to sleep at night rather than during the day. This is very clearly illustrated by the results of a series of studies conducted by Peretz Lavie and his colleagues at the Technion University in Israel (see Lavie, 1986). He asked volunteers to take part in a rather strange study that lasted over twenty-four hours. Some of them were sleep deprived on the night prior to the study while others were not. For the entire duration of the study he put the volunteers to bed for seven minutes every twenty minutes, and then got them out of bed for thirteen minutes. He referred to this procedure as an ultra short (i.e. 20 minute) sleep/wake cycle. The volunteers had electrodes on their scalps for the entire study so that the experimenters could determine precisely when they were asleep. If they had been sleep deprived the night before they were asked to try to stay awake during the periods in bed, whereas is they had slept normally the night before they were asked to try to fall asleep when in bed.

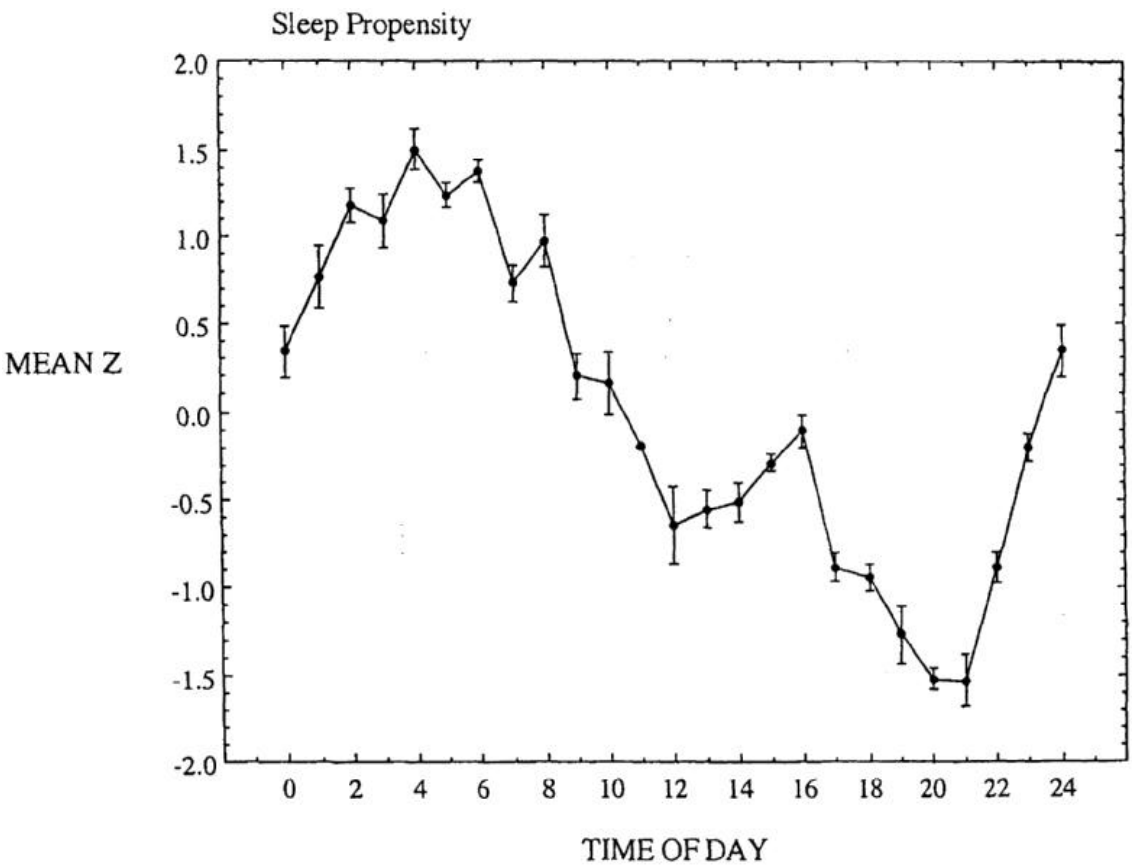

Figure 6

It transpired that it made very little difference whether or not the volunteers were sleep deprived, or whether they were asked to resist sleep or to attempt to sleep. In all cases when they were put to bed in the early hours of the morning they spent a substantial proportion of the seven minutes asleep, whereas if they were put to bed at eight or nine in the evening they spent very little

time asleep. Nor can these results be simply attributed to how long the volunteers had been in the study for since the start time of the study was varied for different groups of volunteers. The overall trend in sleep propensity is shown in Figure 6. To derive this figure from Lavie's results the data from each condition was first Z-transformed and then the mean hourly values and their standard errors were calculated in order to allow a direct comparison with the road transport accident risk shown in Figure 1. The small standard errors in this figure confirm that the various conditions produced very similar results to one another. However, while the overall trend looks not dissimilar to that in road accident risk, with both being high in the early morning hours, these two trends actually differ significantly from one another (see Folkard 1997).

Our diurnal nature

Nevertheless, it is clear that there is very powerful circadian in sleep propensity, i.e. in the probability of falling asleep. Nor is this rhythm in sleep propensity the only circadian rhythm we have. We now know that almost all living species exhibit rhythmicity, although in some species this is tidal rather than circadian, and that in humans all physiological and biochemical processes exhibit circadian rhythmicity. Indeed, it seems that rhythmicity is a fundamental facet if of life and it is clearly the case that human beings have evolved such that they have a high sleep propensity at night and a low one during the day. Thus, at some point during our evolutionary history our ancestors took the path towards being a day-oriented or "diurnal" species.

The fact that we are a diurnal species is reflected in many characteristics of humans that we take for granted. Thus, for example, it is clear that our most highly attuned sensory system is our vision and that as a species we rely more on vision than we do on hearing, touch, smell, or taste. Yet compared to many species our night vision is extremely poor. This reflects on the fact that we have evolved to asleep during the night and hence we do not need good night vision. Indeed, our diurnal nature is as fundamental to us as the fact that we are a terrestrial rather than an aquatic species. Asking people to work at night is a bit like throwing them into the sea and saying, right from now on you're aquatic. We're not designed to be aquatic, we haven't evolved with webbed hands or fins. Nor are we designed to drive or pilot a vessel at night, we don't have good night vision and our body clock winds down all our physiological processes in the evening in anticipation of sleep. It is clear that we can resist this pressure to fall asleep, but equally clear that there may be costs associated with doing so.

The endogenous body clock

One of the best ways to demonstrate the influence of the internal body clock in humans comes from what have become known as “constant routine” studies. These essentially involve keeping all external, or “exogenous”, influences at a constant low level and then measuring people's various physiological processes to determine whether they demonstrate a circadian rhythmicity. One of the first and most extensive of this type of study was conducted at the Karolinska Institute in Stockholm by Jan Fröberg and his colleagues (Fröberg 1977). He took a group of fifteen military personnel and put them into a laboratory that was shielded from natural daylight and had no clocks in it. He kept them there for seventy-two hours and they spent the entire time awake and sitting at desks completing various tasks. He fed them frequent, three-hourly, small snacks rather than normal meals in order to minimise the effects of food ingestion. Various physiological and psychological measures were taken at regular intervals throughout the study to determine whether they exhibited circadian rhythmicity under these unusual conditions in which exogenous influences had been minimised.

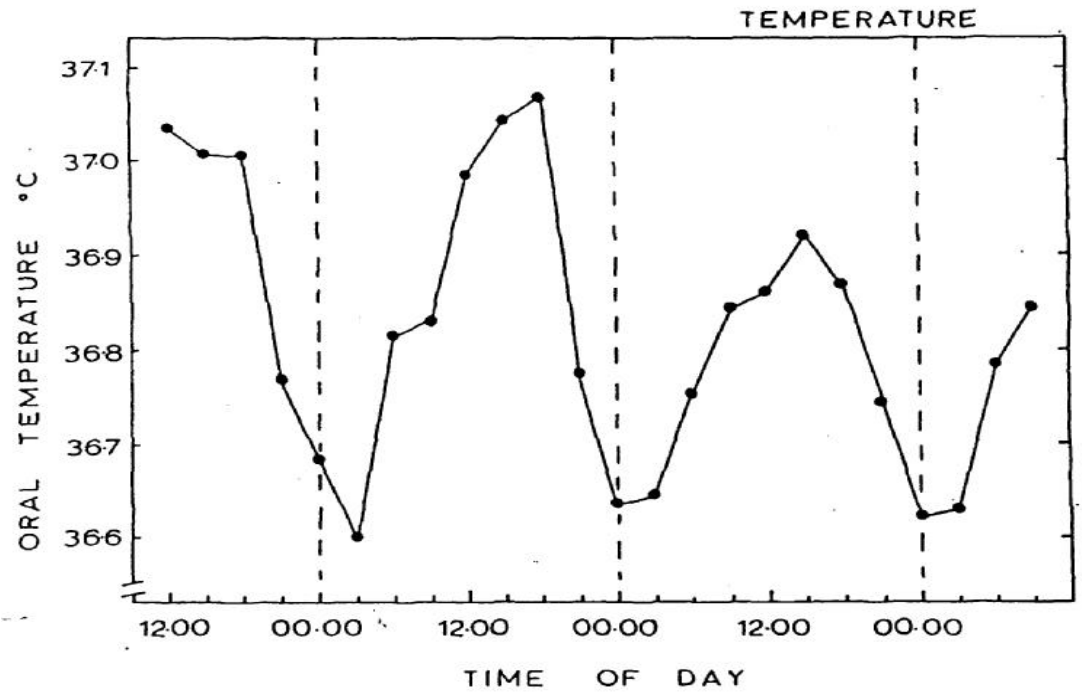

Figure 7

Some of the measures, such as heart rate and urinary noradrenalin showed no evidence of rhythmicity under these conditions, suggesting that the rhythm in them found under normal conditions is very largely due to exogenous influences. However, other measures such as body temperature, urinary adrenalin and self-rated fatigue showed pronounced rhythms that persisted throughout the course of the study. This implies that the rhythms in these variables are at least

partially due to the influence of our internal, or "endogenous", body clock. Thus changing the timing of exogenous influences will have relatively little impact on these rhythms.

Other researchers have used what have become known as "temporal isolation studies", to examine peoples circadian rhythms in the absence of any known time cues. These studies were pioneered by Rütger Wever in the early 1960s (see Wever 1985). Professor Wever recruited volunteers to live in an underground laboratory for periods of a month or more. The laboratory essentially comprised of a "bed-sit" that was shielded from the natural light dark cycle, outside noise, and even the earth's magnetic field! The volunteers were allowed to sleep and wake whenever they wanted and were provided with fresh food and drink through a soundproofed "airlock". They were not allowed access to radio and televisions broadcasts, but were able to play cassette tapes, etc. During their entire stay in the laboratory their body temperature was monitored continuously and samples were taken of all their urines for the analysis of various constituents. In most studies they also performed some simple performance tests several times each "day".

The results of these studies showed very clearly that even in the total absence of any time cues people continued to sleep and wake on a fairly regular basis. They also showed that the circadian rhythm in body temperature persisted with the maximum usually occurring during the equivalent of mid-afternoon, and the minimum occurring during sleep. In most of his volunteers the period adopted by the sleep/wake cycle was a little longer than 24 hours and was the same as the period of the temperature rhythm. It has subsequently been suggested that it may actually be adaptive for a species to have an imprecise biological clock that is regularly reset by exposure to daylight since this will allow it to adjust to the seasonal changes in the timing of dawn and dusk. A perfect timekeeper that was uninfluenced by exposure to natural time cues clearly could not keep pace with seasonal changes.

The body clock and sleep duration

However, in about a third of his participants Wever observed that although the circadian rhythm in temperature ran with a period just a little longer than 24 hours, the sleep/wake cycle adopted a period that was either much shorter, or much longer, than this. Thus, for example, many of his participants had a 24.5-hour rhythm in their temperature, but would only go to sleep and wake up once every 33 hours. This "spontaneous internal desynchronisation" of the temperature rhythm and sleep/wake cycle proved to be extremely important. It allowed Wever's colleagues, notably Jurgen Zulley, to examine the influence of the internal body clock, as reflected in the temperature rhythm, on the probability of falling asleep and, having done so, on sleep duration (Zulley et al. 1981). Their findings are illustrated in Figure 8. The middle panel shows a schematic representation of the body

temperature rhythm. The probability of falling asleep is shown in the upper panel and is high when temperature is falling or low, but low when temperature is rising or high. This is essentially the same pattern of results as that illustrated in Figure 6 above.

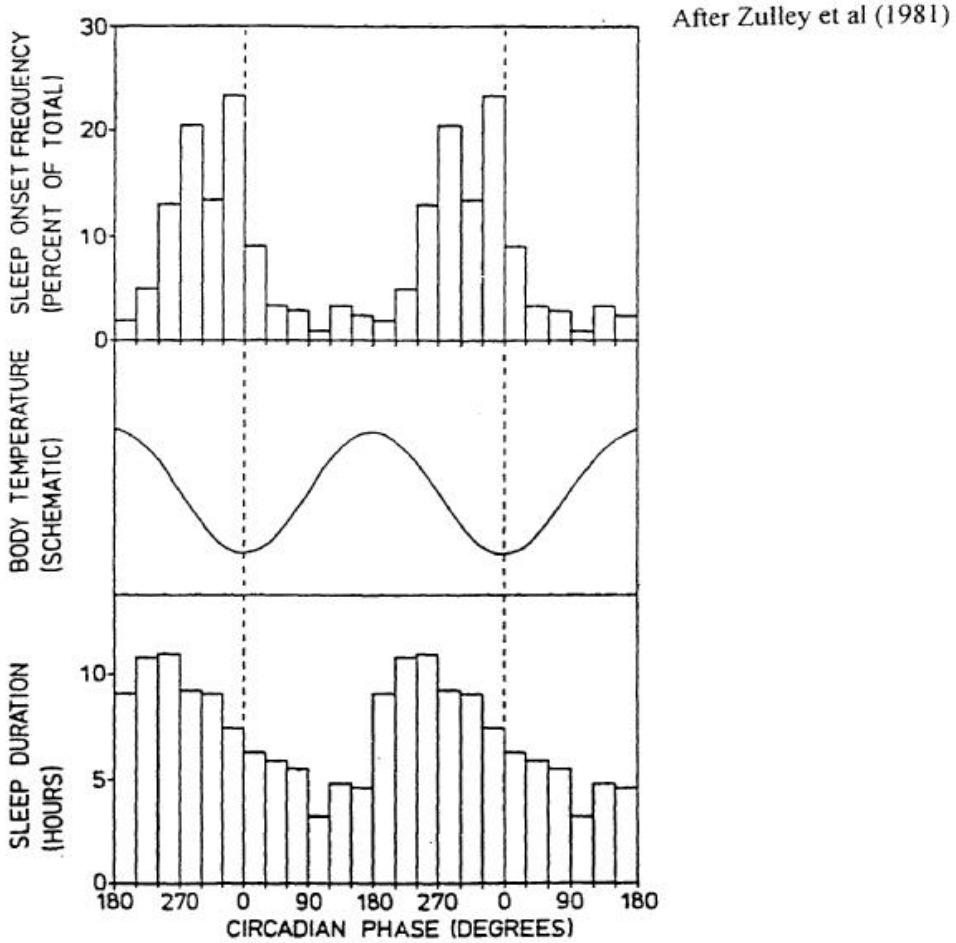

Figure 8

When a transport operator such a train driver comes off a night duty and tries to go to sleep their temperature will typically be rising rapidly and so they will have problems falling asleep. Further, if they do manage to fall asleep it is clear from the bottom panel of Figure 8 that they are unlikely to sleep for very long. Thus if people fall asleep when their temperature is rising or high they only sleep for a short duration, while if they fall asleep when their temperature is falling they will sleep for a far longer duration. It is important to bear in mind that these findings come from volunteers who were sleeping in a sound proofed laboratory and were completely removed from the outside world. Clearly these results were not due to social pressures to stay up or to go to bed at a particular time, rather they reflected on the control of sleep by the endogenous body clock.

Despite the fact that this trend in sleep duration must be due to the influence of the endogenous body clock, it is extremely similar to that for the sleep duration of shiftworkers as a function of the time of day at which they go to sleep. Large-scale surveys of shiftworkers sleep durations have been conducted in both Germany and Japan (see Kogi 1985). If we simply assume a normal timing of the temperature rhythm of Zulley et al's participants we can directly compare the two trends, and this is shown in Figure 9. Note that the trends have been "double plotted" to emphasise their rhythmic nature. It is clear from inspection of Figure 9 that the trends paralleled one another very closely, and indeed the cross correlation between them accounted for 82% of the variability (Folkard, 1988). The only obvious difference between these trends is that Zulley et al's participants slept for rather longer than shiftworkers, but this is, perhaps, hardly surprising when one considers that the former typically only went to sleep once every 33 hours! The obvious conclusion to be drawn from the close parallelism shown in Figure 9 is that the sleep duration of shiftworkers is very largely determined by their endogenous body clocks, rather than by exogenous factors such as the demands of their families, meal timings, or social pressures.

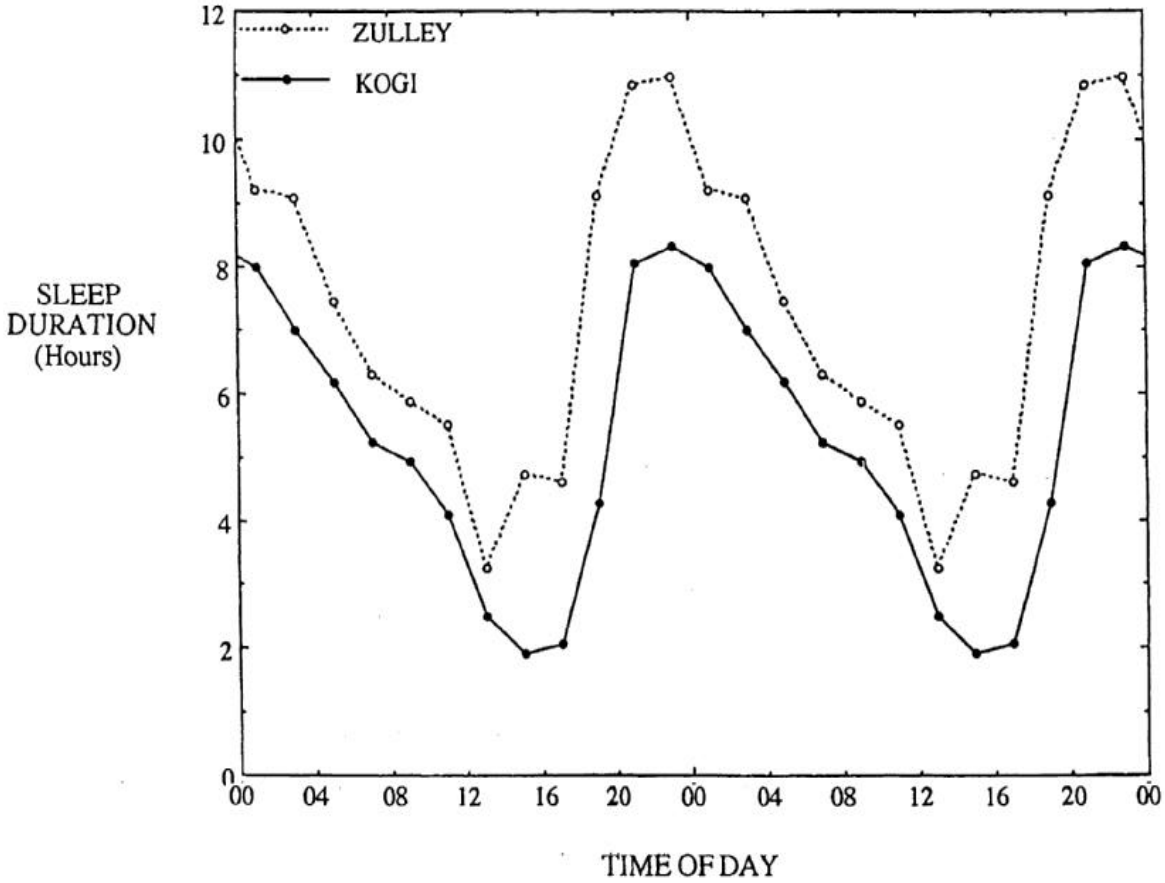

Figure 9

Successive Nights

The implication of this is that if a shiftworker goes to sleep between night shifts at seven or eight o'clock in the morning they are going to have a very short sleep duration. This means that we may not only have a problem that accident risk is increased at night, but also that this increased risk might actually get worse over successive nights because of a cumulative sleep debt. Indeed, the available evidence supports this suggestion. Thus, for example, a German study of long-haul pilots found the incidence of "micro-sleeps" during night flights to increase substantially from the first to the second successive night flight (Sammel et al 1997). This is shown in Figure 10 from which it is clear that the increase was especially marked after the pilots had been flying for six hours. Unfortunately, there seems to be a paucity of studies on the effects of successive nights on fatigue or risk in transport operations. However, a number of studies have reported industrial accident risk over at least four successive night shifts (Folkard et al., 2000). By expressing the risk on each night relative to that on the first night for each study, it was possible to produce an averaged trend in relative risk over successive night shifts. This is illustrated in Figure 11, which also shows the standard errors of the means across the five available studies.

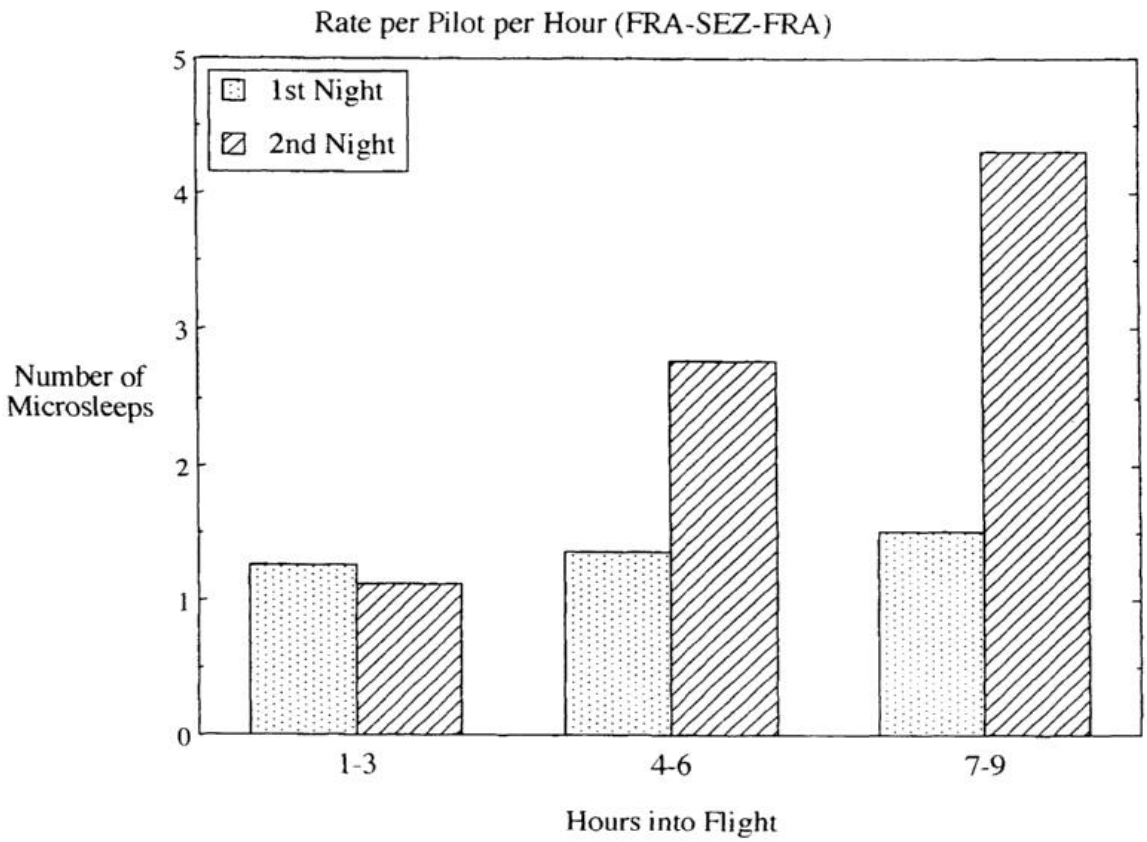

Figure 10

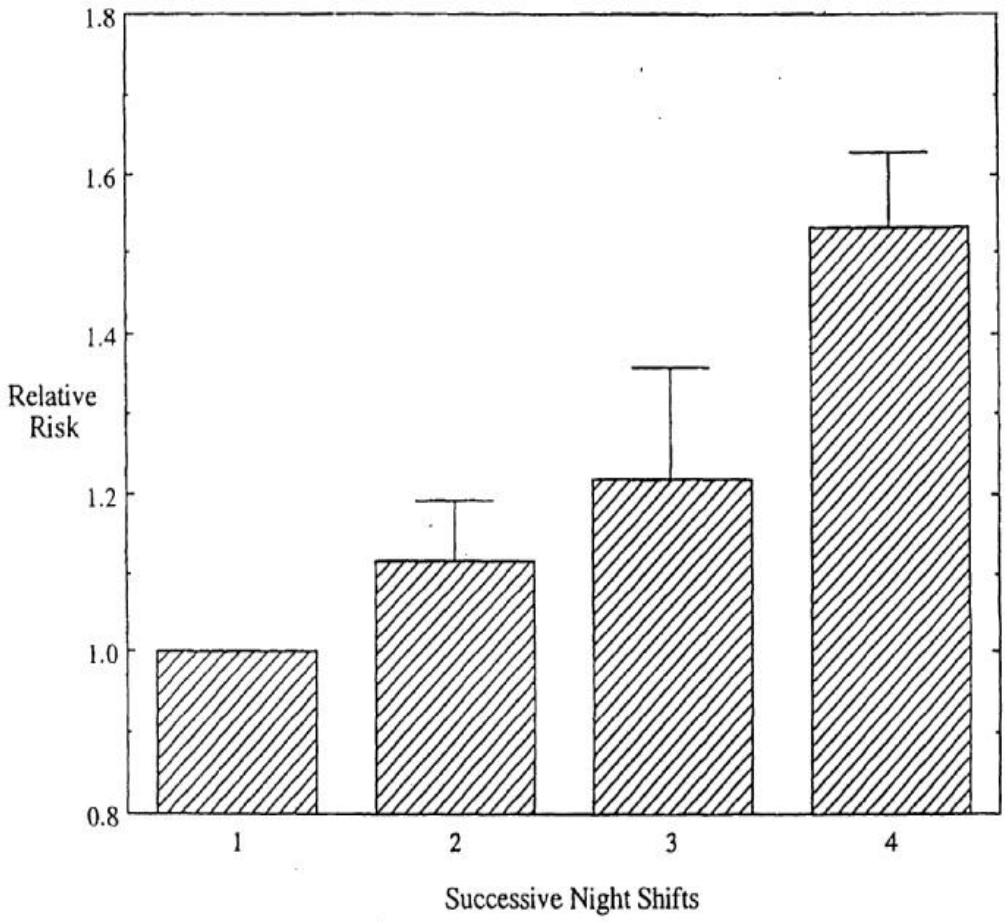

Figure 11

It is clear from figure 11 that industrial accident risk increases in a substantial, and approximately exponential, manner over successive night shifts. Relative to the first night shift, the risk is increased by about 10% on the second night shift, by about 20% on the third night shift, and by over 50% on the fourth night shift. Although few studies have examined more than four successive nights if we fit a linear or exponential line to the data shown in Figure 11 and extrapolate it to a greater number of nights the predicted risk on an eighth successive night shift is between twice and four times that on the first night shift (Figure 12). Further, in one of the studies summarised in Figure 11 the authors managed to obtain comparable data from successive day shifts and were able to show that this increased risk over successive shifts was confined to the night shift (Smith, Folkard & Poole, 1997). In short, there is good reason to suppose that there are substantial effects of successive night shifts on accident risk in transport operations, although there is a very real need for further research in this area.

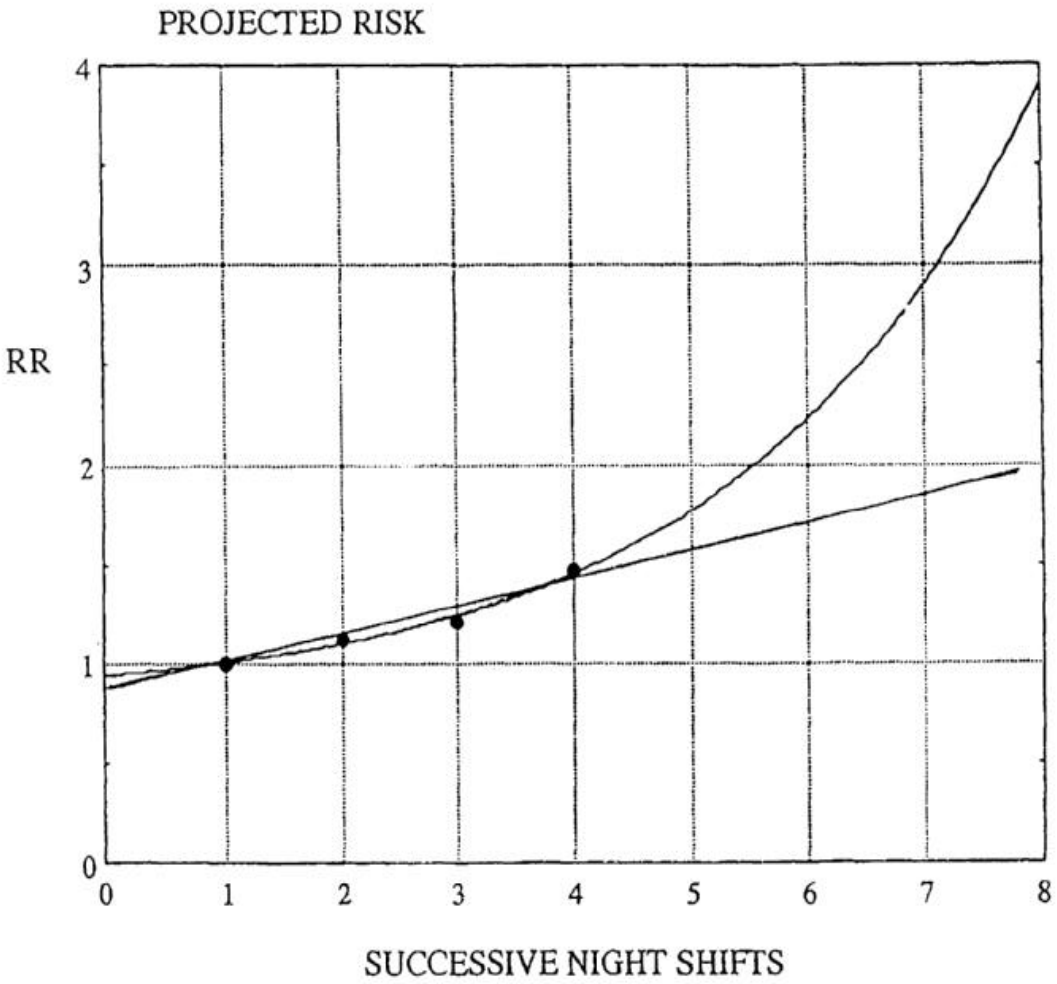

Figure 12

The implication of these findings is that the number of successive night shifts should be kept to a minimum, and that they should be followed by rest days to allow the individuals to completely recover from any accumulated fatigue. This raises the question as to how many rest days are required, and some insight into the answer to this question is provided by Totterdell et al (1995) who examined the subjectively rated alertness of shiftworking nurses over a 28-day period. They found that alertness increased in a substantial, and approximately linear, manner over three successive rest days, and that this increase was most marked when the rest days followed a span of night shifts. These authors were also able to show that alertness during the first three days back at work was rather higher following two rest days than following a single rest day (see Figure 13). Thus it would appear that a single rest day may be insufficient to completely dissipate the fatigue that builds up over a span of shifts, and especially so in the case of night shifts, and that residual fatigue effects may impact on at least the first three of the subsequent span of shifts.

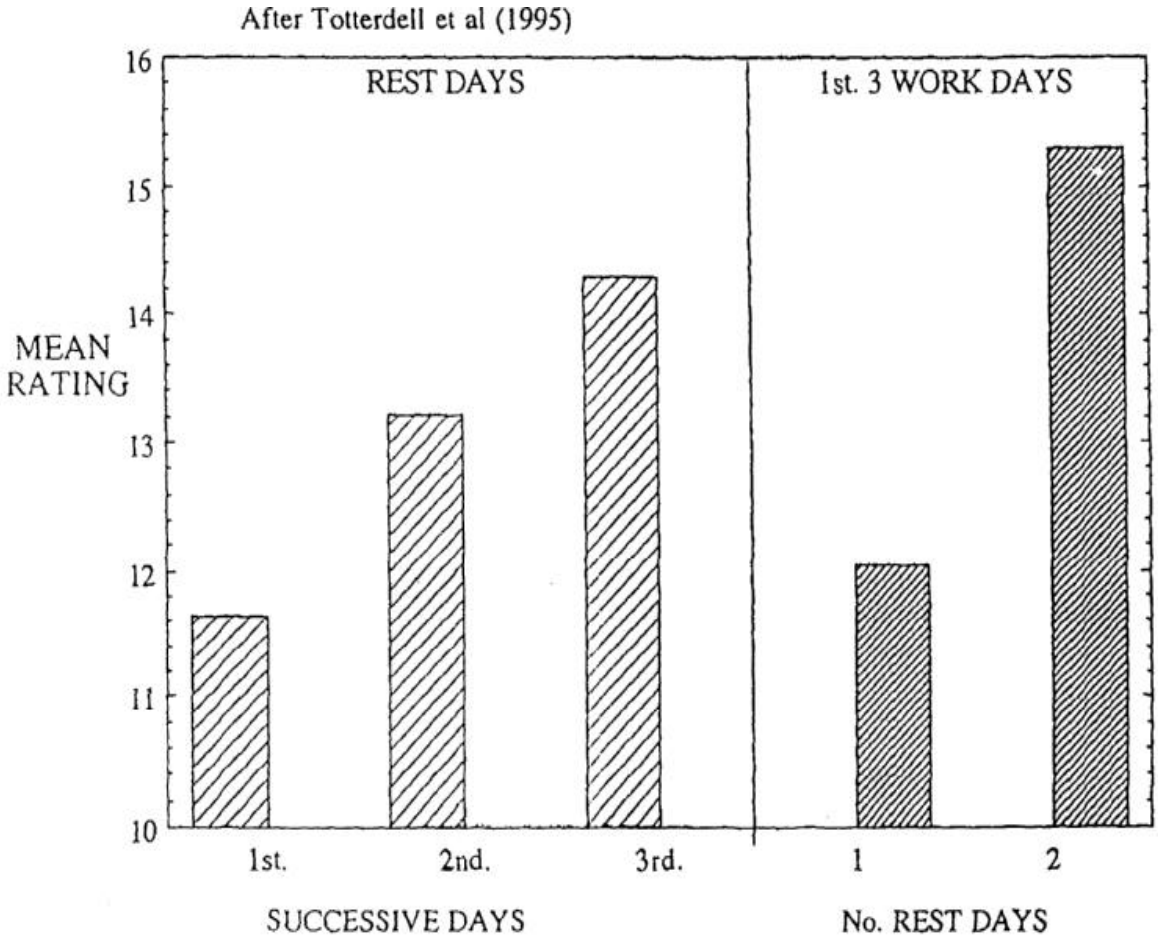

Figure 13

Early Duties

However, it is not only the night shift that may cause problems. Inspection of figure 6 indicates that sleep propensity is very low at about 21:00, and then increases rapidly until about 02:00. Indeed, it transpires that this low point and subsequent rapid increase is even more marked when the results from individual subjects are considered separately rather than averaged. Thus there is a time shortly before an individual's habitual bedtime when they are very unlikely to fall asleep, and this has been termed the "forbidden zone" for sleep onset which is followed by the "sleep gate" during which sleep propensity rapidly increases (Lavie 1986). This "forbidden zone" for sleep onset has important implications for morning or "early" shifts since even if the individuals concerned go to bed earlier than normal the night before, they are unlikely to fall asleep much before their habitual sleep time. This means that the earlier people have to get up to start work, the shorter their sleeps are likely to have been.

This point is well illustrated by the sleep duration of short-haul pilots prior to morning and afternoon flights (Cabon et al 2000). Figure 14 shows that whereas these pilots obtained about 7.5 hours sleep prior afternoon flights their sleep prior to morning flights was truncated to less than six hours. It is perhaps not surprising that the pilots' subsequent ratings of both fatigue and sleepiness during the flight were clearly higher during the morning flights than during the afternoon flights (Figure 15). There thus seems little doubt that sleep may be truncated prior to an early duty or shift, and that this may have serious consequences for safety. Further, there is reasonably good evidence that this is due to the "forbidden zone" for sleep onset rather than to social pressures on the individuals concerned to say up until a "normal" bed time (Folkard & Barton 1993).

After Cabon et al (2000)

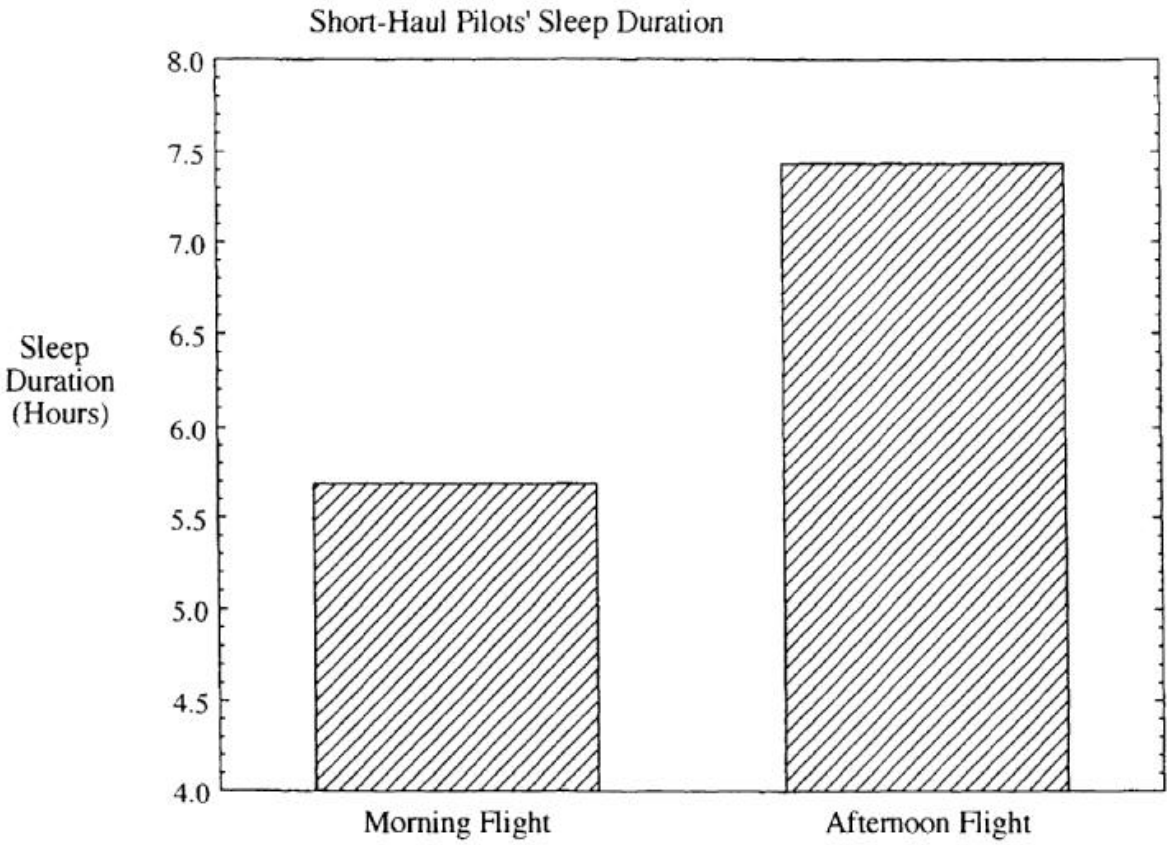

Figure 14

After Cabon et al (2000)

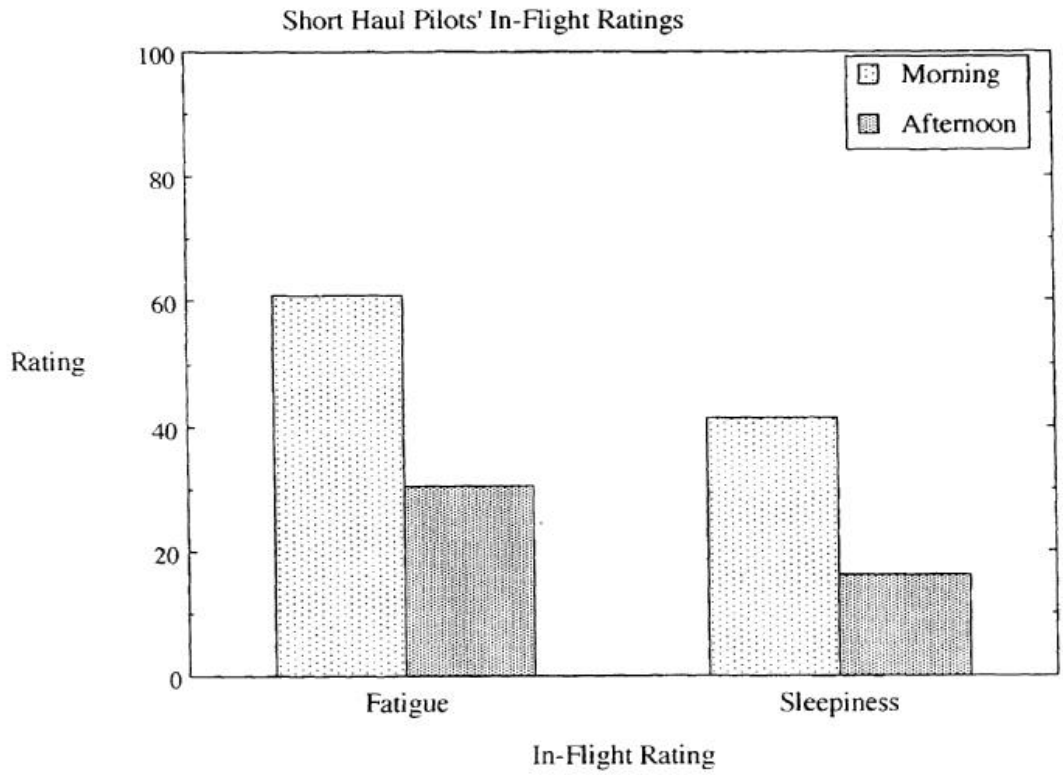

Figure 15

Length of Duties

So far we have considered the fatigue associated with disturbed or truncated sleep, but it would be wrong to ignore the effects of "time on task" or "duty duration". A number of studies have examined duty duration effects in accident risk within transport operations and found a very interesting, but somewhat unexpected, trend. The earliest such study that I am aware of is that of Patrick Hamelin (1987) who examined the accident involvement of French lorry drivers as a function of how long it was since their last break of six hours or more. Hamelin, found that the relative risk of accidents was substantially increased after 12 or more hours, but also that the relative risk was rather higher in the first four hours that it was from the fourth to the tenth hour (see Figure 16).

Interestingly, a fairly similar trend was reported by Wharf (1993) for the "Signals Passed At Danger" (SPADs) by British Rail train drivers. Wharf found a substantial increase in risk, i.e. SPADs per million driver hours, from the first hour to the 2nd to 4th hour, followed by a decrease to later hours. Wharf failed to find an increased risk at later hours although this might well reflect on the restrictions placed on train drivers' duty hours and driving times. It is also clear from Figure 17 that this trend was fairly consistent across train divers from rather different types of depot,

suggesting that it is a genuine effect that is relatively unaffected by the precise demands placed on the driver. Furthermore, a rough calculation suggests that if we could get rid of this 2 to 4-hour peak in SPADs we would approximately halve the total number of SPADs that occurred.

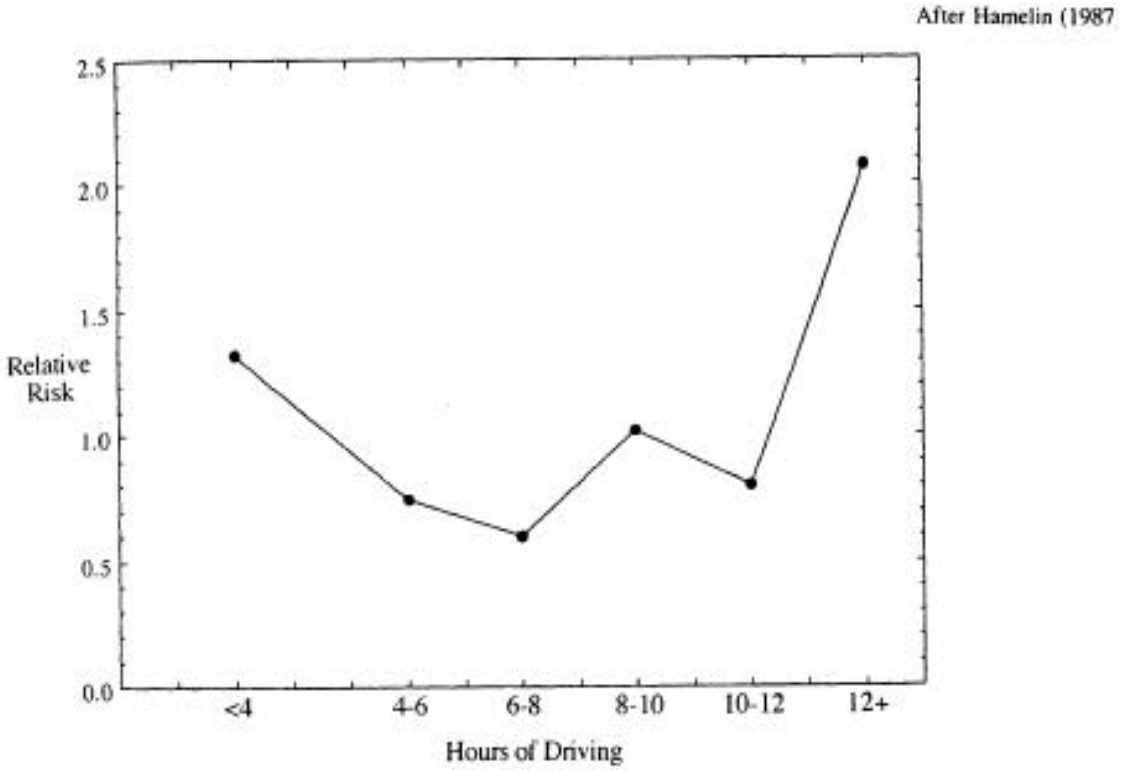

Figure 16

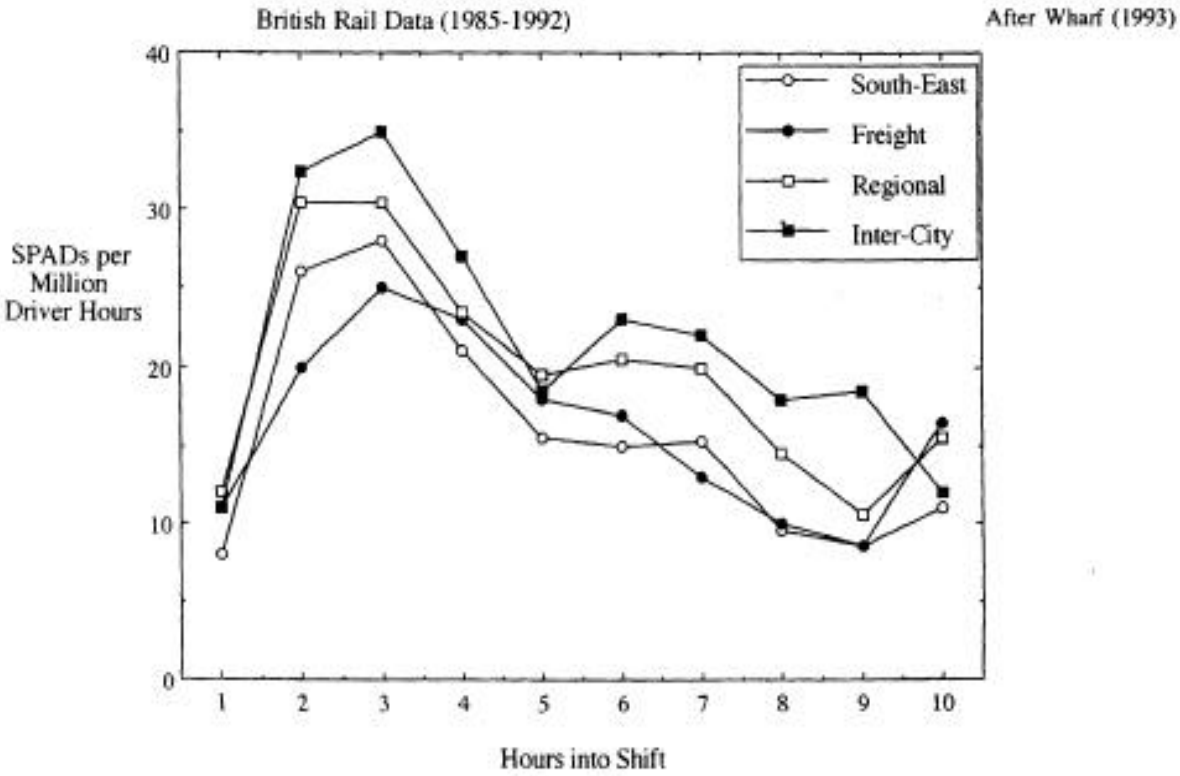

Figure 17

In order to produce a composite curve of the data from different transport operations, including lorry drivers (Hamelin 1987), train drivers (Wharf 1993), and bus drivers (Pokorny et al 1981), the values from each study were expressed relative to the average risk for the first eight hours in that study. This had the effect of equating the scale across studies, and allowed the data to be represented in a single graph (Figure 18). This figure shows the averaged hourly values from the studies of train and bus drivers together with the available points from lorry drivers. The curved line represents an exponential curve that provided a statistically reliable fit to the data points when those from the 2nd to the 5th hour were excluded. Thus it would appear that there is an underlying exponential increase in accident risk over time on duty, but with a transient, 2-4 hour increase in risk superimposed on top of this underlying trend. Current theories simply cannot account for this transient 2-4 hour increase in risk, and thus there is clearly a very strong need for research aimed at an understanding of its underlying cause(s).

Despite our lack of understanding as to why this transient 2-4 hour increase in risk occurs it would appear to have very important implications for the optimal length of duties since it results in short duties being relatively unsafe. This is illustrated in Figure 19 which shows the risk associated with duties of various lengths and is based on a smooth curve fitted to the data points shown in Figure 18 (see Folkard 1997 for details). In this figure the risk is expressed relative to that on an eight-hour duty period. Thus, apart from duties of less than about two hours, the safest duty lengths are between eight and ten hours long, with the risk being increased on both shorter and longer duties. Indeed four-hour duties have over a 20% increase in risk relative to an eight-hour one, while a twelve-hour duty has only a 7% increased risk. Indeed the duty length would have to be increased to fourteen hours before the risk matched that on a four-hour duty. While there is a clear need for further research to substantiate these figures, the current evidence suggest that duties of up to twelve hours long are likely to prove less of a risk than those between three and six hours long. Thus they clearly question both the need to limit duty length to less than twelve hours and the desirability of short duties in transport operations.

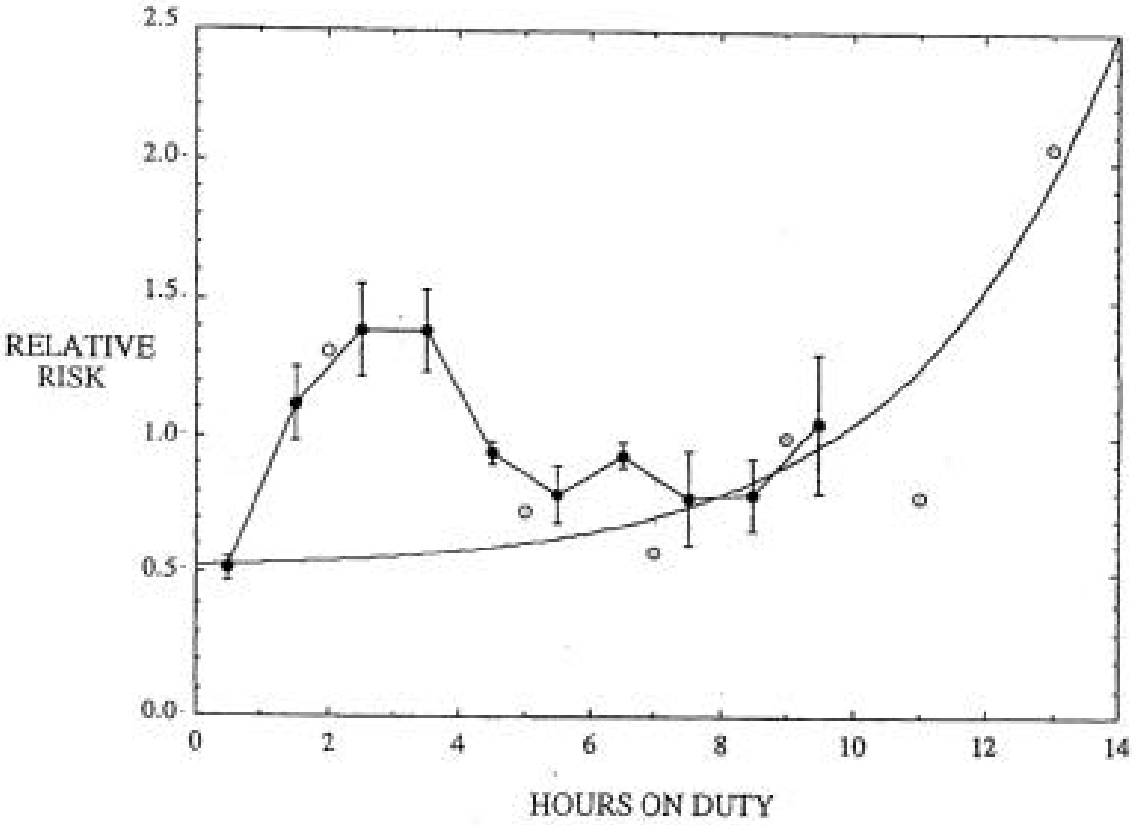

Figure 18

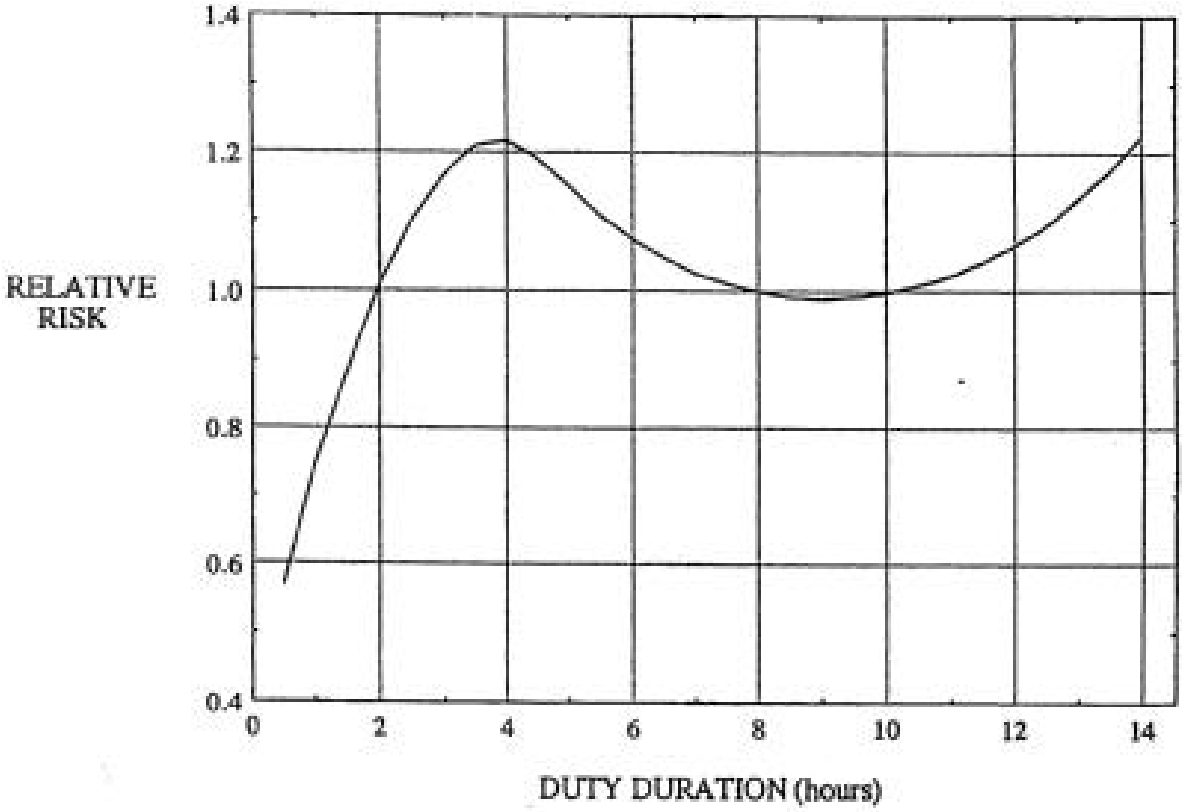

Figure 19

Possible Interventions

Most experts agree that the available evidence clearly indicates that any work schedule that involves the displacement of sleep from its normal time may compromise the safety of transport operations, and a number of possible interventions have been identified with a view to keeping safety within acceptable levels.

Selecting tolerant individuals. The first stems from the fact that one only has to talk to a handful of shiftworkers to realise that some individuals cope far better with night work than others. Historically, researchers have distinguished between "Morning-" and "Evening-types" (M- and E-types) who differ in their preferred timing of various activities, including sleep (Kleitman, 1939). There is reasonably good evidence that, compared to M-types, E-types prefer working at night and that their internal body clocks show rather greater adjustment to night work. However on the most commonly used rotating shift systems, where individuals rotate through the different shifts, there is no evidence that E-types fare any better than M-types. Further, in a recent study we found evidence that E-types on a permanent night shift actually reported greater physical health complaints than M-types, but fewer complaints on a permanent day shift (Folkard & Hunt 2000)! These findings not only indicate that individuals may actually choose to work on the type of shift which is most damaging to them, but also that partial adjustment of the body clock to a particular shift, and its readjustment on rest days, may actually underlie the health problems of shiftworkers.

Rather more success in predicting individuals' tolerance to shiftwork has been obtained using measures of the flexibility, or rigidity, of their sleeping habits, and of their ability to overcome drowsiness (Folkard et al, 1979). These measures were used in one of the few longitudinal studies in this area. Various measures of individual differences were obtained some 18 months before those concerned first became shiftworkers, and then various measures of tolerance to shiftwork, including sleep and health problems, were taken at two yearly intervals after they had become shiftworkers (Vidacek et al., 1987). However, although sleep flexibility and the ability to overcome drowsiness reliably predicted some of the tolerance measures in this study, the most they accounted for was about 10% of the variance. Thus while in the future we may be able to successfully select tolerant individuals, the measures currently available are clearly insufficient to enable us to do so with any accuracy.

Education and Counselling. The second approach is to educate or counsel individuals as to how best to cope with their work routine, and indeed many organisations provide some sort of service in this respect. Thus, for example, Dr David Flower, a consultant occupational health physician with British Airways, has produced detailed advice for their pilots as to when to sleep, etc., before and after eastward and westward flights through different numbers of time zones and starting at different times of day. The pilots simply select the appropriate card from a file on the basis of this information, and this card provides them with advice as to when to sleep or nap, when and what to eat, etc. However, although schemes such as this are clearly laudable and to be encouraged, the available evidence on their efficacy is remarkably disappointing. Thus, for example, in one study the beneficial effects associated with intensive advice given in individual counselling sessions had completely disappeared within six months (Taylor, 1994). Indeed a recent review of such intervention studies concluded that none had found any long-term beneficial effects (Rankin & Wedderburn, 1999). This is not to say that we should abandon such attempts, but simply that we appear to be a long way from designing effective interventions of this type and that further research is needed in this area.

Resetting the body clock. The third possible intervention is one that has enjoyed widespread media coverage over the past few years and aims at resetting individuals' body clocks by the judicious timing of their exposure to bright light, or feeding them a naturally occurring hormone called melatonin. There is good scientific evidence that the use of either bright light or melatonin can shift the timing of the body clock either forwards or backwards depending on the precise time at which they are administered. There is also evidence that taking melatonin can reduce the subjectively rated severity of jet lag symptoms (Arendt et al., 1986) and improve the rated quality of the day sleeps taken be shiftworkers between their night shifts (Folkard et al., 1993). However, although these short-term effects are clearly beneficial, there have, as yet, been no studies of the long-term effects of such interventions. Indeed if the short-term beneficial effects reflect an increased adjustment of the individuals' body clocks, then there is good reason to suppose that the long-term effects may be detrimental to the continually repeated adjustment and readjustment of these body clocks (Folkard & Hunt 2000).

Technological detection of fatigue. The fourth approach has been to try to develop technological devices that can detect fatigue levels with a view to warning people that they should not continue to work or drive. Systems are being researched based on electroencephalographic recordings, eye movements and blinks, and, in the case of road vehicles, the precise use of the steering wheel. The development of these various devices, that might collectively be termed "fatiguealysers", has

attracted a lot of research funding but as yet none have been proved. Indeed in most cases fatigue has to have risen to a totally unacceptable level before the device can detect it! This not only questions the devices' usefulness, but also whether it might not prove better to simply ask the individuals concerned to rate how fatigued or alert they feel. People can make such ratings with remarkable ease and accuracy, and indeed it has long been known that such ratings are more highly related to physiological measures of alertness than the physiological measures are to one another (Clements et al., 1976). In short, a technological device seems a distant, costly, and over complex manner in which to answer a simple question.

However, although people are fully aware of how fatigued they are, they often persist in working or driving. Indeed it would seem that the more fatigued people are, the less able they are to judge either the extent to which their performance capabilities are impaired or the risk associated with continuing to drive. Research on how to make people more aware of the impairments and risks associated with fatigue might yield a far higher return on investment than the development of fatiguealysers.

Improving work schedules. The fifth and final form of intervention is to improve work schedules by placing limitations on them through self-regulation or legislation. There is considerable evidence to support such limitations and there is no doubt that this is currently the most cost-effective approach to keeping safety within acceptable limits. Essentially what is required is a set of limitations that aim to minimise the build up of fatigue and maximise its dissipation in any given period of time. This requires limits to be set on the maximum amount of time that people are allowed to work, and the minimum period of time that they must have off, per day, per week, per month, per year, etc. However, in addition to this limits are also needed to minimise the disruption of the body clock and/or sleep, and to take account of the marked circadian rhythm in sleep propensity. Further, there is no universally applicable set of limits that will ensure acceptable levels of safety in all situations since factors such as the public or environmental risk associated with an error, the age of the workforce, or the commuting times of those involved need to be taken into account.

The use of limitations

Examples of schemes based on limitations are widespread and range from the minimalist limits contained in the EU's working time directive (CEC, 1993) that are intended to apply in a very wide range of situations through to very specific schemes aimed at particular occupational groups. Thus, for example, the British CAA's "Scheme for the Regulation of Air Traffic Controllers' Hours" (SRATCOH) includes maximum limits of 2 hours' work before a break, 10 hours' work per duty, and 50 hours' work (or six duty periods) before a rest day. It also requires minimum breaks of 30 minutes after 2 hours' work, 12 hours rest between duties, three breaks of not less than 60 hours per 30 days, and 10 days holiday per year taken in blocks of not less than 5 days. In addition to these basic maxima and minima limits it also limits the number of successive night duties to two, and requires that they are immediately followed by a minimum of 54 hours of off-duty. These latter limits are intended to minimise any accumulation of fatigue that may occur over a span of night duties, and to ensure that any fatigue that does accumulate can be completely dissipated during two, normally timed, night sleeps before the individual is allowed to return to work.

A rather different limitation was required when the crews on the cross-channel ferries were changed to a "live on board" scheme in order to get rid of the very long duty periods of 24, or even 48, hours that they had previously worked. Here the problem was that although duty periods were restricted to a total of 12 hours per 24 hours and every crew member was given a minimum uninterrupted rest period of 8 hours per day, for some individuals this 8 hour off-duty period occurred at a time of day when they were likely to sleep for substantially less that 7-8 hours. In this case the solution was to put in a requirement for an additional uninterrupted rest period of 2 hours if the 8-hour off duty period started between 04:00 and 10:00, or of 4 hours if it started between 10:00 and 20:00. This effectively ensured that although some crewmembers had to "split" their sleeps, a practice that is very common on deep-sea vessels, they all that the opportunity to obtain a total of 7-8 hours sleep per 24 hours.

Beyond limitations

The main problem with limitations is that they may prove too inflexible. Thus, for example, with respect to airline pilots the limitations needed to ensure safe short-haul flight operations may be too strict in some ways, and too lenient in others, when applied to long-haul operations. Jim Lyons of the British CAA's safety regulation group has devised an ingenious scheme to overcome this problem. What he has proposed is a set of basic limitations that can never be broken under any circumstances, the "outer limits", and a second, stricter set of "standard limits". Any tour of duty that

falls entirely within the standard limits is automatically permitted. However, one or more of the standard limits can be broken provided they still fall within the outer limits and that the breaking of the standard limit(s) is compensated for in an acceptable manner by a tightening of one or more of the other standard limit(s). This scheme thus allows considerably more flexibility than a rigid set of limitations, and Jim Lyons envisages that a set of recognised "variations" from the standard limits would be established to take account of, for example, long-haul flights or early starts. As I see it, the main problem with this scheme is that some system needs to be developed to determine whether the breaking of one of the standard limits can be adequately compensated for by the tightening of another, and if so the extent to which the latter needs to be tightened.

This problem is essentially the same as that faced by Air New Zealand some years ago when they persuaded their CAA to essentially allow them to fly any tour of duty that they wanted to provided that they could demonstrate that it was not unduly fatiguing. In order to achieve this Air New Zealand set up a "Flight Crew Fatigue Study Group" which comprises representatives from management and the unions as well as the airline's chief medical and nursing officers and a scientific adviser from the University of Auckland. This group monitors fatigue through fairly standard "fatigue reports", but more importantly through intensive studies of volunteer pilots on particular tours of duty using a range of subjective and objective measures of fatigue (see Powell et al 1998 for further details). Importantly, these studies are externally validated by a group of internationally recognised experts in the area of fatigue and performance. To date this system has worked very well and has, for example, resulted in one tour of duty that had been in operation for some time being stopped because it proved too fatiguing. In short, the required flexibility has been achieved through a combination of intensive studies and an expert advisory panel.

Conclusions

It seems reasonable to conclude that there are distinct and predictable temporal trends in transport operation accident risk. Where the data is available, these trends appear to be remarkably consistent across different types of transport operation. It also seems that they are, at least partially, due to fatigue and/or impaired performance although there is a very strong need for further basic research in some of the areas, particularly in the case of the transient 2-to 4-hour peak in accident risk. Further, the magnitude of some of these trends is quite substantial. They include a tenfold increase in the risk of single vehicle accidents at three o'clock in the morning, and a 50% increase in risk over four successive night shifts. As such, it would seem foolish to ignore these trends, especially in those transport situations where there may be a high public or environmental risk. The most effective way of keeping safety within acceptable limits that has been identified to date is to

place limitations on the individuals' work and rest hours. However, in some cases such limitations may prove too rigid in which case a system involving an expert panel that oversees objective studies of the fatigue associated with particular tours of duty is probably the most flexible and cost effective way forward.

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